The Influence of Climatic Anomalies on Hot Spots Occurrence in the Brazilian Amazon Region

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Abstract: In this paper, we describe the generation of climatic anomaly surfaces for the Brazilian Amazon region and the correlation between these surfaces and hot spot incidence detected by NOAA 12 satellite. Quarterly anomaly surfaces of temperature and precipitation for the period of January 1992 to December 2000 were produced by fitting a partial thin plate smoothing spline to data from meteorological stations located in 9 states in the Brazilian Amazon area. Summary statistics and graphical representation of the surfaces are used to check for data errors and to compare with hot spots. During the period of investigation, the quarterly surfaces show that the Brazilian Amazon climate has been experiencing some changes. The research shows that there is not a good correlation between hot spots and climatic anomalies since hot spots are mainly produced by human activity in that region. A better understanding of the influences of climatic anomalies on the hot spots occurrence in that region requires the use of fire scar data in the analysis.

Keywords: *Precipitation and temperature data; Amazon Forest; Thin plate smoothing splines; Hot spots.*

1. INTRODUCTION

Fires constitute one of the most serious environmental problems affecting the Brazilian Amazon area, with large areas being destroyed each year. In the Amazon, fire has been used to convert closed-canopy forests to cattle pasture and agricultural fields. According to official data from the Brazilian Environmental Protection Authority - IBAMA, 160,329 hot spots were detected in the Brazilian Amazon area in 2002. Hot spots can become wildfires depending on vegetation type and climatic conditions. In 1998, nearly 11,730 square kilometres of forest area in the Brazilian state of Roraima was devastated by a wildfire (Ciencia Hoje, 2000). The Roraima wildfire started with small fires ignited by farmers to clear the land for agriculture. These fires, in conjunction with the 97/98 El Nino phenomenon that caused a longer dry season with a negative precipitation anomaly and high temperature, spread through the forested area.

This paper reports the first results from research that focuses on the Brazilian Amazon Forest, which aims to develop methodologies that can quantify the relationship between climatic anomalies, landuse change and fire occurrence. The broader research will develop techniques to predict fire occurrence over time using geographic information system and spatial modelling.

2. STUDY AREA

Geographically the Amazon Forest is spread across the countries of Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Suriname, Guiana and French Guiana and covers an estimated area of 6.3 million square kilometres representing about 7 per cent of the earth's surface and constitutes approximately 40 per cent of the world's remaining rain forest. Figure 1 shows the location of the study area.

Figure 1. Location of the study area

According to the Brazilian Institute of Geography and Statistics – (IBGE), the Brazilian Amazon Forest covers approximately 5 million square kilometres and extends across 9 Brazilian states. The climate of the Amazon Forest is a combination of several factors. The most important of them is the solar energy available. According to Molion (1993), who studied the circulation and dynamic processes that act in the Amazon Forest, the precipitation in that region is caused by diurnal convection; instability lines originating in the N-NE Atlantic coast and large-scale convective agglomerations. The average precipitation in the Amazon basin is approximately 2300 $mm.year^{-1}$ and the average temperature varies between 24 and 26 degrees Celsius.

3. DATA

The climatic analyses presented in this paper were based on historical monthly data of precipitation and maximum temperatures for 64 meteorological stations located in the Brazilian Amazon Forest. The period analysed was between 1992 and 2000 and the dataset was obtained from The Brazilian Institute of Meteorology (INMET).

Images from the National Oceanic and Atmospheric Administration's advanced very high-resolution radiometer - AVHRR (1.1 Km resolution) were used to detect hot spots in the Brazilian Amazon area. These images, acquired by the NOAA 12 satellite, were recorded by the NOAA/AVHRR receiver installed at Cachoeira Paulista – SP and Cuiaba - MT for 1998 and 1999. The analyses were based on AVHRR channel 3 representing thermal emission.

A digital elevation model (GTOPO30) was used to construct the climatic surfaces. The model was acquired from the EROS Data Center.

4. METHODOLOGY AND RESULTS

4.1. Climatic surface construction

The climatic series of precipitation and maximum temperatures for each meteorological station were summarized for the period of 8 years. A quarterly climate database was constructed from The Brazilian Institute of Meteorology records for all stations for the period 1992 to 2000. Each year was divided into four quarters; January, February and March representing the first quarter. A quarterly mean value for each station was then calculated and quarterly surfaces constructed for precipitation and maximum temperature with dependence on elevation using GTOPO30 and two independent position variables (longitude and latitude).

ANUSPLIN software version 4.1 (2000), a suite of programs for fitting surfaces developed by Hutchinson (2000), was used to construct climatic surfaces. ANUSPLIN allows for the incorporation of a linear parametric sub-model, which permits a known physical control of the variable to be incorporated as a dependent variable. This allows for more accurate interpolation than by other methods and is an advantage when dealing with data, which are limited, either in terms of accuracy or spatial density (Hutchinson, 2000).

The first step in the construction of maximum temperature climatic surfaces was to generate spline coefficients from the database for each quarter. Summary statistics, a list of 15 largest residuals, a list of the data and fitted values, files containing the coefficients of the fitted surfaces, files with estimated standard errors and the parameters used to calculate the optimum smoothing parameter were provided by this program. The surface coefficients and their error covariance matrices were used to calculate values and standard errors of the fitted surfaces using LAPGRAD.

The SPLINA program was also used to calculate spline coefficients for the precipitation dataset. The data was transformed by the square root transformation. According to Hutchinson (1998b) the square root transformation reduces overall error when interpolating daily precipitation data. The square root transformation applies more smoothing to large precipitation data values and less smoothing to small precipitation data values. The LAPGRD program was then used to develop the grid files of quarterly mean precipitation.

The statistics outputs in the diagnostics file generated by ANUSPLIN were used to check for data homogeneity. The output log file contains the generalized cross validation (GCV), mean square residual (MSR), the data error variance estimate (VAR) and the mean square error (MSE) with their square roots (RTGCV, RTMSR, RTVAR, RTMSE).

Detecting data errors

To access the station homogeneity, the root mean square residuals - RTGCV was compared for all station in the database. The RTGVC is a good measure of the predictive power of the fitted surface, especially when comparing the values from the same climate variable over time (Kesteven and Hutchinson, 1996). The time series of maximum temperature root mean square residuals for all stations are given in Figure 2. The Figure 2 suggests that there is one possible outlier at point A (first quarter of 1992). The inspection of the data files reveals that two stations in the dataset had some problems. For example, the station 83361 does not have values for the month of January and April and station 83267 had values of minimum temperature instead of maximum temperature. Problems like this can happen when automatic meteorological stations are not used. Table 1 shows the 5 stations with the highest root mean square residuals in the diagnostics file for the point A that represents the first quarter of 1992. The stations with problems were removed from the database and new coefficients were then generated. Figure 3 shows the same time series of the RTGCV for maximum temperature with two stations with problems removed.

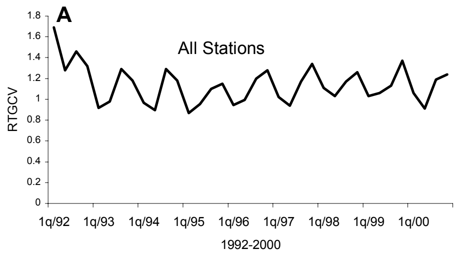

Figure 2. Time series of the RTGCV for maximum temperature 1992-2000, all stations.

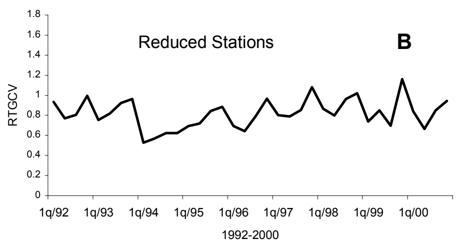

Figure 3. Time series of the RTGCV for maximum temperature 1992-2000, reduced number of stations

Table 1. Ranked root mean square residuals for the first quarter of 1992 representing point A in the Figure 2 for all stations.

First quarter 1992		
Rank	Station	RTMSR
1	83267	4.20
2	83361	3.98
3	82460	2.33
4	82280	1.69
5	82141	1.49

The removal of the two suspect stations reduces the RTGCV observed in point A in Figure 2 from 1.69 to 0.93 in Figure 3. Figure 3 suggests that there is still one possible outlier at point B. Table 2 shows 5 stations with the highest root mean square residuals in the diagnostic file for the quarter represented by point B (forth quarter of 1999). When the worst stations are removed the RTGCV and the root mean squared error reduce significantly. The removing of stations with larger error should be repeated many times to reduce overall surface error. When the coefficients did not result in large changes with the removal of additional stations, they were used to create the quarterly climatic surfaces using the LAPGRAD program. The software ArcGIS version 8.1.2 was used to convert ASCII files generated by ANUSPLIN to grids. These grids were used for statistical analysis and modelling. The same methodology explained above was used for checking precipitation data for errors and to construct quarterly climatic surfaces of precipitation.

Table 2. Ranked root mean square residuals for the forth quarter 1999

Fourth quarter 1999		
Rank	Station	RTMSR
1	82460	2.35
2	82280	1.49
3	82246	1.17
4	82024	1.05
5	83410	0.986

4.2. Climatic anomaly surface construction

Quarterly mean climatic surfaces were constructed for the entire period (1992-2000) using ANUSPLIN. The same methodology to check data error and data homogeneity was used. Quarterly surfaces for each year were then subtracted from quarterly mean climatic surfaces. The research analysis that every value below or above the mean was a negative or a positive climatic anomaly respectively.

4.3. Hot spots

Spatial distribution of hot spots in the Brazilian Amazon area

The spatial distribution of hot spot incidence between July and December for the years of 1998 and 1999 in the Brazilian Amazon area is given in Figure 4 and 5. The higher concentration of hot spots is observed in the east of Acre, Rondonia, south of Amazonas, centre and Northern Mato Grosso, Southeast and east of Para, center and Northern Tocantins and west of Maranhão in both years. This area is called the deforestation arc because many changes have occurred due to agricultural expansion using fire as a management tool.

As Figures 4 and 5 show, the spatial distribution of hot spots does not have significant changes between the years due to its anthropogenic origin. The human activity is the main driver of hot spot occurrence in the Brazilian Amazon. The agricultural expansion in this area can be observed when Figures 4 and 5 are compared. Figure 5 shows an increase in hot spot activity in the Northern Para.

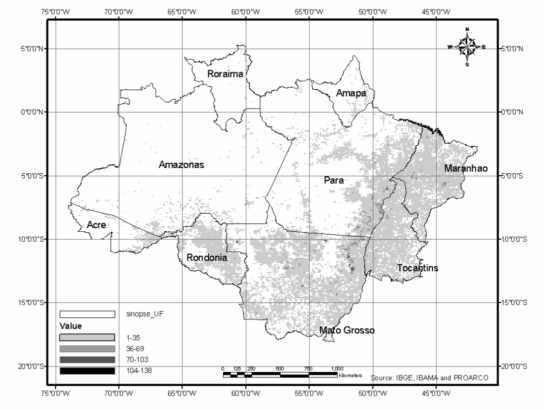

Figure 4. The spatial distribution of hot spots between July and December for 1998

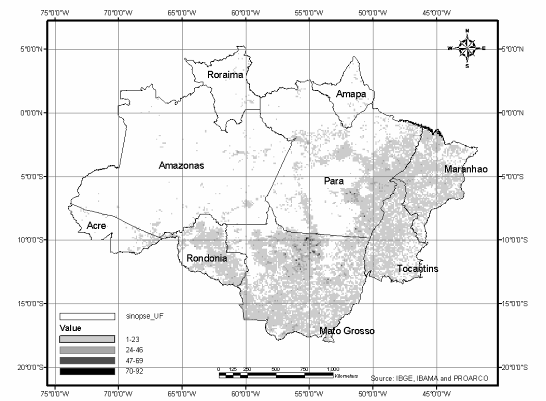

Figure 5. The spatial distribution of hot spots between July and December for 1999

4.4. Comparison between anomaly climatic surfaces and hot spots

The comparison between hot spots and climatic anomaly surfaces was performed using the third and fourth quarter of 1998 and 1999. The greatest incidence of hot spots in the Brazilian Amazon area is observed between June and October each year. Also, the lowest values of precipitation occur in the same period in the central Amazon area. These favourable climatic conditions favour the use of fire as management tool increasing the incidence of hot spots. A different climate regime occurs in the north Amazon where the minimum precipitation occurs between November and March. These areas will not be analysed in this paper, because the maximum concentration of hot spots is where the deforestation arc is located.

As Figure 6 shows (third quarter of 1998), a higher concentration of hot spots occurred in the north and northeast of Mato Grosso, southeast and east of Para and central north of Tocantins. This region represents part of the deforestation arc. Analysing the climatic anomaly surface of precipitation for the same period, it is evident that areas with higher hot spots incidence had negative precipitation anomalies of up to 13mm. The higher incidence of hot spots in this region was from vegetation dryness as a result of a long period of drought that occurred in the third quarter of 1998. The same areas also presented a positive temperature anomaly of up to 2°C.

On the other hand, the same areas in Mato Grosso experienced precipitation close to the climatic mean in the third quarter of 1999. This did not reduce significantly the number of hot spots in that area (Figure 7). It confirms the close relationship between agricultural practice and hot spot incidence.

A high concentration of hot spots was observed in the north and central of Mato Grosso and centre-east and southeast of Para in the third quarter of 1999 (Figure 7). North and central of Mato Grosso had precipitation around the climatic mean. The centre, mid-north and east of Para had negative precipitation anomalies as large as 25mm. Temperature was up to +2.4°C in the centre east of Para and centre and north of Mato Grosso. Temperatures around the climatic mean were observed in the east of Para.

The comparison between climatic anomalies of precipitation and hot spot concentration for the fourth quarter of 1998 is presented in Figure 8. It was observed that the central Amazon area had negative precipitation anomalies of up to 70mm but the concentration of hot spots was in the north and northeast of the Amazon area, covering north and northeast of Para and west and northwest of Maranhão. It can be explained by the sowing time, which is different for each part of that region.

A similar spatial distribution of hot spot concentration can be seen in Figure 9 (fourth quarter of 1999) where they are located in the north and northeast of the Amazon. It was observed positive precipitation anomalies in that region up to 23mm combined with mild temperatures.

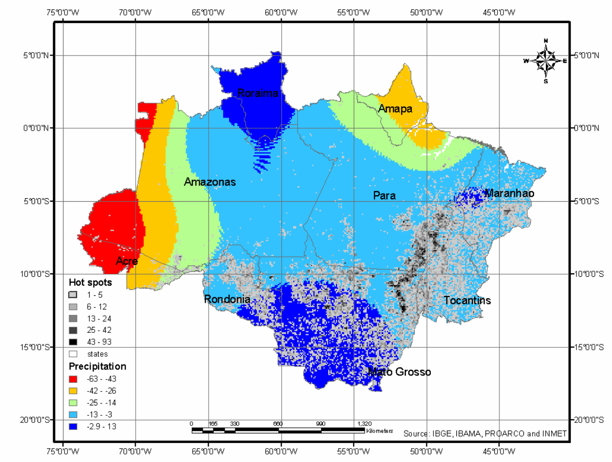

Figure 6. The spatial distribution of hot spots and climatic anomalies of precipitation for the third quarter of 1998

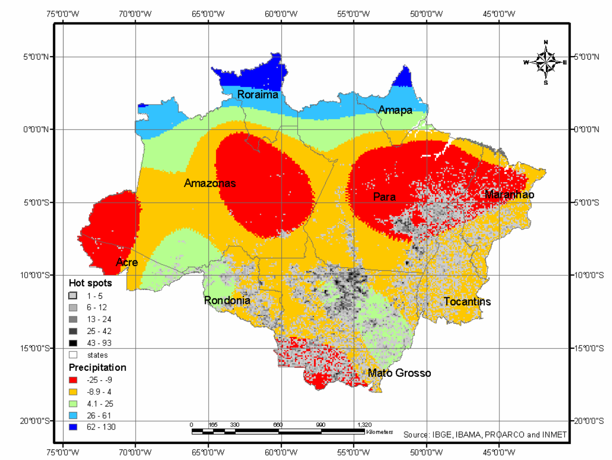

Figure 7. The spatial distribution of hot spots and climatic anomalies of precipitation for the third quarter of 1999

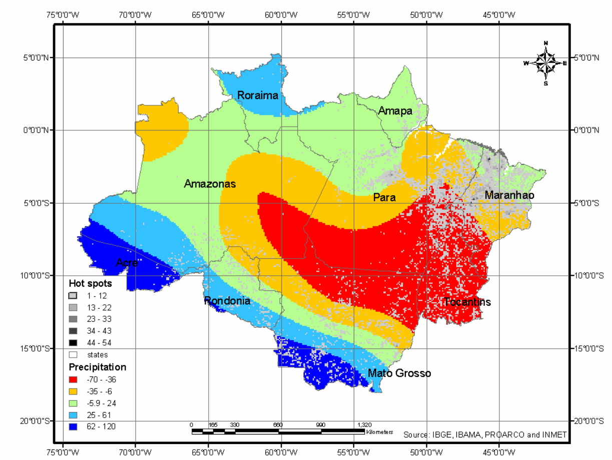

Figure 8. The spatial distribution of hot spots and climatic anomalies of precipitation for the fourth quarter of 1998

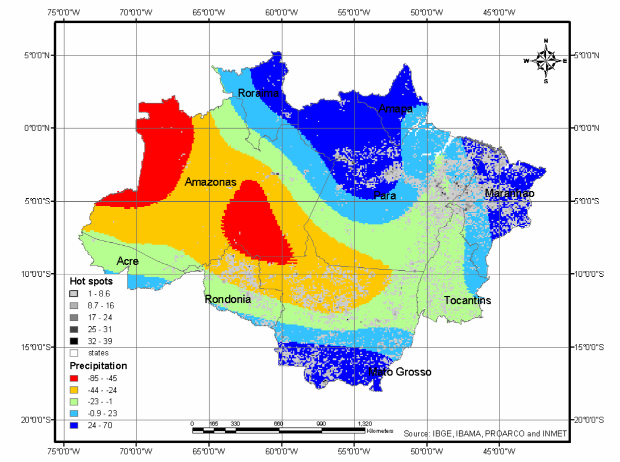

Figure 9. The spatial distribution of hot spots and climatic anomalies of precipitation for the fourth quarter of 1999

Figure 10 represents the frequency of hot spots versus climatic anomalies of precipitation for the third quarter of 1998. Negative anomalies of precipitation up to 63mm were observed in the centre and north of Acre and west of Amazonas (Figure 6), but the higher frequency of hot spot incidence was located where there are anomalies of precipitation between –13 and –3mm (Figure 10).

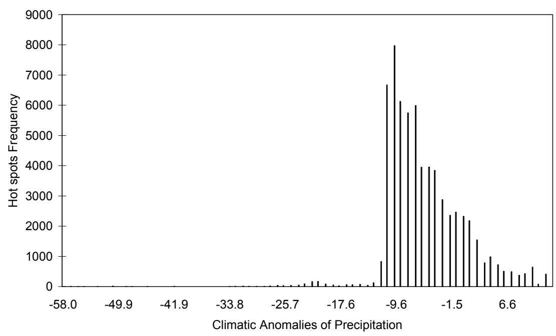

Figure 10. The frequency of hot spots versus climatic anomalies of precipitation for the third quarter of 1998

A similar scenario is evident in the third quarter of 1999. The centre and west of Amazonas had climatic anomalies of precipitation up to –25mm, but the higher incidence of hot spots was between –18 and 9mm (Figure 11).

The areas with expressive climatic anomalies of precipitation and temperature did not have a significantly high number of hot spots. Thus climatic variables are apparently not the most important factor in determining hot spot occurrence in the Brazilian Amazon Forest.

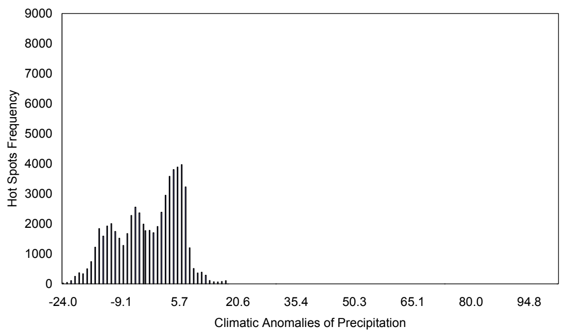

Figure 11. The frequency of hot spots versus climatic anomalies of precipitation for the third quarter of 1999

5. CONCLUSIONS

The ANUSPLIN software allowed analysis of small data sets of climatic variables with topographic dependencies. The methodology used and diagnostic files generate provide an excellent tool to assess the integrity of the dataset. In the maximum temperature surfaces there was a significant reduction in surface errors after removal of 3 stations.

This paper has also been concerned with the relationship between climatic anomalies and hot spot incidence in the Brazilian Amazon area. The results showed that the climatic variables play an important role in the incidence of hot spots in the Brazilian Amazon area, but they are not the main factor of hot spots occurrence. The principal factors are human activities and sowing time.

It is anticipated that climatic variables have more effect in fire propagation than hot spot incidence. The next step in this research will be to compare burnt areas detected by NDVI with climatic anomalies to quantify the importance of climatic anomalies in wildfire occurrence and spread.

6. REFERENCES

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