Combining satellite-derived products and geo-spatial health information for assessing the impacts of drought conditions on children's respiratory diseases in the Brazilian Amazon

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Abstract: It is generally acknowledged that climate change will have an impact on human health, however within a region as vast as the Amazon; research on the topic is scarce. This study analyses the impacts of the 2005 drought on respiratory diseases in children under five years of age. Satellite observations of rainfall, active fires and aerosol were used to assess the extent of the drought, and hospitalisation data was used to establish general trends and changes during the drought. We identified critical areas of the 2005 drought, and established the peak period of respiratory diseases over a ten year period (2001-2010).Throughout the basin respiratory diseases for children under five years of age peaked at the end of the wet season. The 2005 drought affected south-west Amazonia; during this period increases in active fires were recorded. In Acre in 2005 the peak of respiratory diseases shifted to later in the year corresponding with the peak of the drought. Critical areas of drought were explored in more detail at a micro-region and municipality level. Aerosol is the main driver influencing respiratory disease hospitalisations during July, August, September period of 2005. During this period hospitalisations for respiratory diseases in children under five years of age increased 54% in Acre, 99% in Rio Branco, & 195% in Porto Acre in relation to the ten year mean.

Keywords: MODIS, TRMM, FIRE, Drought, Health, Amazonia

1. Introduction

Health problems have a spatial dimension, influenced by both the environment and socio-economic conditions (Cromley and McLafferty 2002). Effects of the environment can be direct or indirect. For example, increases or decreases in rainfall have the potential to alter the distribution vector borne diseases, cause malnutrition, and create dust storms, temperature changes can cause urban heat islands which increase the risk of respiratory and cardiovascular diseases, or affect the start of the pollen season, and increases in fires produce higher levels of air pollution which increases respiratory problems. The Amazon is a vast area with varying land use, climate, population structure, and development. Understanding how these factors might affect the health of the population would be impossible without the use of remote sensing monitoring of environmental and climatic conditions. Incorporating health data and remote sensing information into Geographic Information Systems (GIS) provides a tool for exploring connections between people, health and the environment in which they live.

Drought events cause both environmental and social devastation; water stress, tree mortality, lack of food and medical supplies, isolation of communities and health problems to name a few. During drought events, dust storms can occur through wind erosion that can cause respiratory health problems in deforested areas. This occurs because soil particles and microbes are blown into the air causing irritation of the respiratory tract and exacerbating allergies (Pimentel et al. 2007). Moreover, increases in forest fires due to drought can have negative impacts on human health, particularly respiratory diseases. Smoke from fires tend to emit finer particulate matter at 2.5 micrometers (μm) particles ($PM_{2.5}$), these particles are more hazardous since, when inhaled, they may reach deep in the lungs (Ignotti et al. 2010b). Moreno (2006) shows that smoke from fires is associated with irritation of the throat, lungs and eyes, and Boman, Forsberg and Jarvholm (2003) suggest that particles from wood smoke are more injurious to human health than particles from other sources known to cause ill health. One of the most drastic effects of drought in Amazonia is an increase in fires. Drought conditions further the vulnerability of forest to fires due to water stress, leaf litter and drying (Cochrane and Schulze 1999, Laurance and Williamson 2001). Furthermore, Aragão et al. (2007) show that forest flammability increases in drought conditions even when deforestation rates are declining within the Amazon.

Respiratory diseases are one of the most common causes of diseases globally, with pneumonia accounting for more under-five's mortality than malaria, aids and meningitis combined. Respiratory diseases are defined by the World Health Organization (WHO) as 'diseases that affect the air passages, including the nasal passages, the bronchi and the lungs' (WHO. 2011). Within the Amazon region, excluding pregnancy, respiratory diseases are the most common cause of hospitalisations. Yet, little research exists on respiratory diseases and no research examines the impacts in droughts or floods on these particular health conditions.

The aim of this study is to assess the impacts of the 2005 Amazonian drought on respiratory health. Specifically, rainfall, fire, and aerosol data from satellite observations were used to identify anomalous areas within the basin. Subsequently, spatially explicit heath data were incorporated to the analysis to detect relationships at different spatial scales within the basin, focusing on the drought affected area.

2. Methodology

2.1 Datasets

For estimating rainfall anomalies, we used a time-series (2001 –2010) of Tropical Rainfall Measuring Mission (TRMM) (3B43-v6) data at spatial resolution of 0.25^{o}. The data is provided as mm/hr for each month (NASA. 2011), so monthly cumulative precipitation for each pixel was calculated. Aragão et al (2007) validated the TRMM dataset showing a good agreement between satellite-derived rainfall and rain gauges data in Amazonia.

Active fire data are indicators of fires, which although may be underestimated do allow for patterns over time to be seen (Aragão et al. 2007). For this, we used monthly active fire data for the period between 2001 – 2010 produced by the University of Maryland (UMA) from the Brazilian Institute of Space Research, Queimadas project database (INPE 2011).

In addition, we used Aerosol Optical Depth/Thickness, (AOD/AOT, Optical Depth Land and Ocean at 0.55 microns, MOD08_M3 collection 051) for the same ten years period. Values vary between -1 and 5 (adimentional), the higher the value the more concentration of particles in the air (NASA 2011).

Databases of the S*istema de Informações Hospitalares*, SIH/SUS (Hospital Information System) of the Brazilian Ministry of Health were utilised to obtain information regarding hospitalisation data for respiratory diseases (DATASUS 2011). Chapter X, diseases of the respiratory system, of the International Classification of Diseases revision 10 was used for all disease codes in the chapter (coded from J00 to J99), for people living in the Brazilian Amazon between 2000–2010. Hospitalisations were selected by the following variables; paid *Autorizações de Internações Hospitalares*, AIH (Authorisations for Hospital Admissions), micro-region of residence and municipality of residence, year of admission, month of admission, all those for children under 5 years of age. Cases by micro-regions and municipalities were selected based on residence rather than hospital attendance, this ensures a better representation of the spatial distribution of the exposed population to the environmental factors.

Population data for each municipality in the Amazon was obtained from the *Instituto Brasileiro de Geografia e Estatística*, IBGE (Brazilian Institute of Geography and Statistics) (IGBE 2011). Municipality data was aggregated to micro-region for the analysis at this level.

2.2. Analysis

To quantify the spatial and temporal extent of the drought, rainfall surfaces were grouped at 3-monthly intervals to show seasonal differences. Anomalies for 2005 were calculated based on the departure from the 2001–2010 mean (TRMM 2001 – 2010) and normalised by the standard deviation (σ 2001-2010). This was done for each year(*y*), each quarter (*q*) and at a pixel by pixel (*i, j*) level (equation A).

$$TRMM\ anomaly, q(i,j) = \frac{TRMMy,q(i,j) - TRMM\ 2001-2010\ (i,j)}{\sigma\ 2001-2010\ (i,j)} \qquad \text{(Equation 1)}$$

Anomalies for active fires were calculated using hot pixel density based on the accumulation of hot pixel counts for each quarter. These anomalies were calculated following a similar method as the TRMM data (Equation 1). In addition, environmental data were aggregated to micro-regions to allow for comparison with the number of hospitalisations.

Cumulative monthly age standardised rates (ASR) of hospitalisations were estimated to create a baseline of the seasonal and spatial distribution across the basin (Equation 2). Moreover, the number of hospitalisations per micro-region and per quarter within the year was used to calculate anomalies to identify localised trends. Critical areas of drought conditions within the basin were identified using the anomalies from the environmental datasets. Micro-regions and municipalities exhibiting less than 100 mm monthly rainfall, once data had been aggregated, were analysed to identify relationships between those experiencing drought conditions and hospitalisations for respiratory diseases.

$$ASR = \left(\frac{\sum elat}{\sum sat}\right) \times 100{,}000 \qquad \text{(Equation 2)}$$

Where *e* is the expected rate of hospitalisations for a given location, age group, and time (*l, a, t*), over the WHO standard population (*s*) for *a* and *t*.

3. Results and Discussion

In 2005 large negative rainfall anomalies affected the south-west part of the Amazon, resulting in a drought (Figure 1). The negative rainfall anomalies intensified during the wet-to-dry season transition of April, May and June (AMJ) and peaked in the dry season months of July, August and September (JAS). The south-west of the basin was mainly affected, with a large extent of this region presenting negative rainfall anomalies (≤ -1 σ). Positive anomalies, on the other hand, were observed in the north mainly during October, November and December (OND). Active fires in 2005 increased in frequency in the south-west of the basin in JAS, corresponding to the areas intensely affected by drought (Figure 1). There are also notable positive anomalies in fires around the east and south of the basin, corresponding to the spatial pattern of deforestation, known as the 'arc of deforestation'. Cumulative numbers of active fires in the Brazilian Amazon were 39% higher in 2005 compared to the 2001-2010 mean. Within Acre a 338% increase in active fires were observed from 2004 to 2005, and within Rio Branco, the micro-region of most intense fires, a 214% increase in active fires was observed from 2004 to 2005.

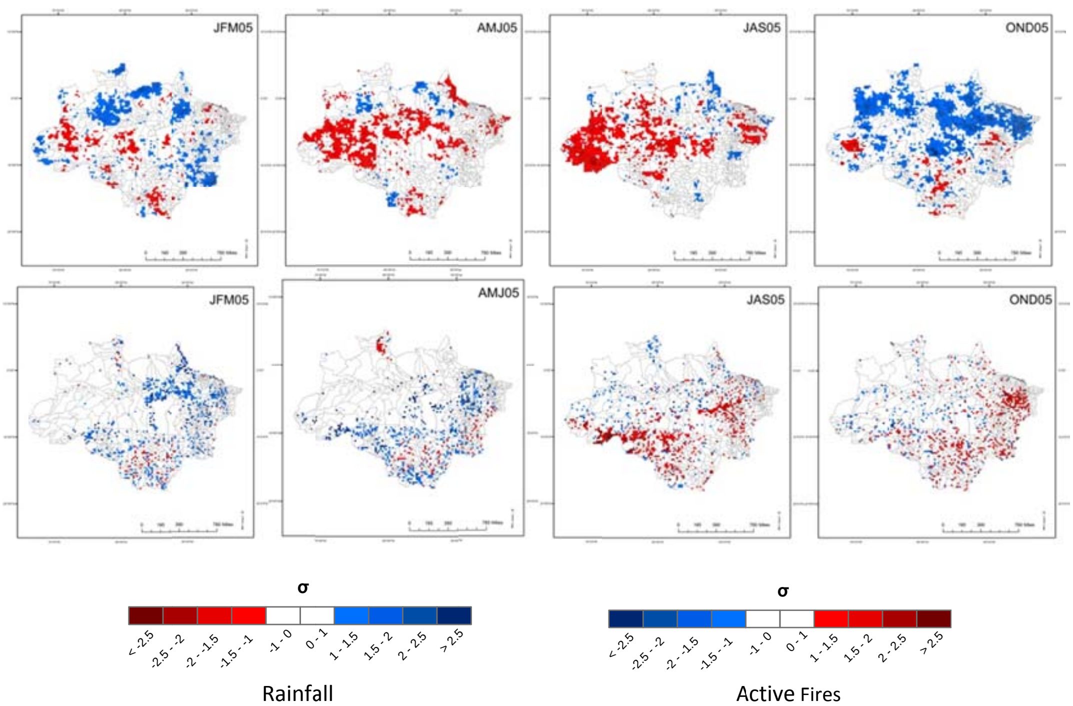

Figure 1 –Top: Rainfall anomalies as a departure from the 2001-2010 mean. Bottom: Active Fire anomalies as a departure from the 2001-2010 mean. The panels from left to right corresponds to each trimesters.

The analysis of the monthly distribution of hospitalisations during the study period for the Brazilian Amazon showed that hospitalisation rates were higher at the end of the wet season and interim period between the seasons (Figure 2). The highest rate for respiratory diseases was experienced in March in Tocantins, showing 546 cases per 100,000 under-five's inhabitants for the 10 year period. March was also the peak month for respiratory diseases in states dominated by savannah type vegetation in the east of the region. Other states presented a peak in hospitalisations in May, apart from Roraima, which peaked in July. Small peaks are also observed during the dry season, these are not as pronounced as in March however. Basin wide and local studies in the Brazilian Amazon have observed this same pattern for respiratory diseases (Rosa et al. 2008a, Rosa et al. 2008b). It is suggested that peaks may occur in March because it is the start of the school term, higher number of allergens due to increases in humidity after the wet season and operational factors such as hiring physicians during this time (Rosa et al. 2008b).

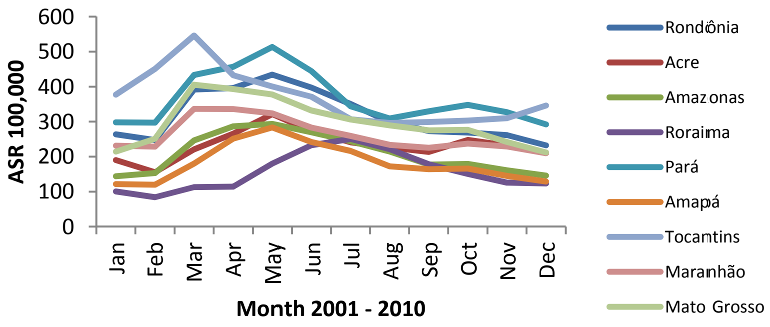

Figure 2: Mean monthly age standardised rate for under 5 respiratory disease hospitalisations for the period 2001-2010.

Although Figure 2 shows respiratory diseases peaking at the end of the wet season for the basin, as can be seen in Figure 1 there were extremely high numbers of fires in some areas of the basin, particularly Acre, the epicentre of the drought. Findings in other countries regarding forest fires and health have shown increases in emergency room visits and hospitalisations during the periods of fire. For example, increases in asthma, chronic obstructive pulmonary disease, and upper respiratory tract infections were noted during the periods of large forest fires in California in the 1980s and 1990s (Mott et al. 2002). In Acre during JAS of 2005, there was a 88% increase in the total number of hospitalisations for respiratory diseases compared to the same period in 2004, and in relation to the ten year mean, a 54% increases was observed (Figure 3). Throughout 2005, this period also accounted for the greatest number of hospitalisations in Acre, disagreeing with the general trend of peak hospitalisations occurring at the end of the wet season.

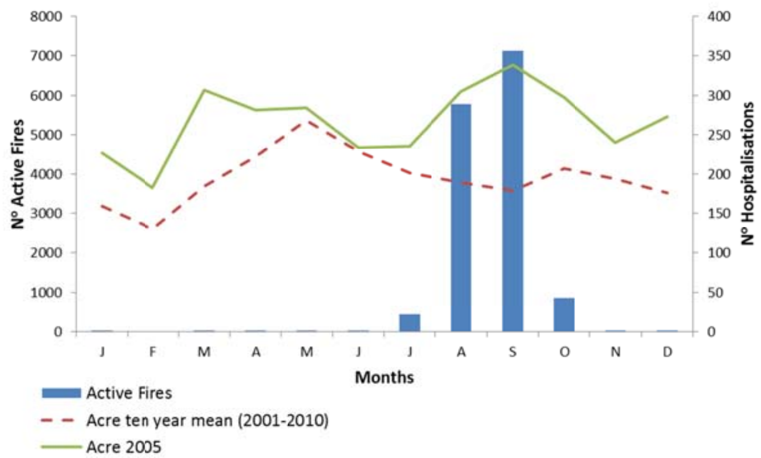

Figure 3: Temporal trend of fire and hospitalisations for respiratory disease in Acre 2005, with reference to the ten year mean. Bars indicate the number of monthly active fires detected in Acre in 2005 and lines represent the number of hospitalizations for Acre state during 2005.

The eastern part of Acre was subject to intense fires during the drought. Examining the total number of hospitalisations in micro-regions of this area we observed a greater increase in the number of hospitalisations. In Rio Branco for example, we observed a 99% and 157% increase in the total number of hospitalisations during JAS of 2005 compared to the ten year mean and the same period in 2004, respectively. Moreover, total number of hospitalisations during the drought event accounted for a large positive anomaly in hospitalisations (≥1.5 σ). It was the only location in the basin during that period that had high percentage increases and a large positive anomaly.

Rainfall anomalies have been discussed thus far, working with actual rainfall values, drought conditions in Amazonia are referred to as months with 100 mm or less of rainfall because the forest enters into water deficit (Shuttleworth et al. 1989, da Rocha et al. 2004). Based on the five micro-regions adjacent to the epicentre of the drought with less than 100mm of rainfall a month (300mm cumulative) relationships were identified. The relationship between rainfall, fires and aerosol with hospitalisations were not significant at micro-region level (Table 1).

Table1: Linear regression results between the environmental variables and age standardised rates of respiratory diseases for Tarauacá, SenaMadureira, Rio Rranco, Brasiléia, and Boca do Acre.

Variable	**R^2**	**P-value**
Rainfall	0.12	0.50
Active Fires	0.52	0.10
Aerosol	0.72	0.07

To understand local changes, which could be more valuable to policy makers, the analysis was also carried out at the municipality level in Acre. The greatest increases in total number of hospitalisations compared to the same period in 2004 were observed in Brasiléia and Senador Guiomard, in Acre (400%), and Boca do Acre, Amazonas (850%). In relation to the ten year mean the largest increase observed was 196% in Porto Acre. A higher number of municipalities in the epicentre of the drought had large positive anomalies (≥1.5 σ). Of the five in Acre, three are part of the Rio Branco micro-region. High concentrations of smoke in Rio Branco during September 2005 were recorded by the Federal University of Acre (Mascarenhas et al. 2008) which could explain the high number of hospitalisations recorded during the JAS 2005 period.

Eighteen municipalities around the epicentre of drought had less than 300mm of rain during JAS of 2005. During this period, significant relationships between drought conditions and age standardised rates of respiratory diseases were identified (Table 2). The same pattern occurs as observed for the micro regions, with rainfall not showing a significant relationship, while active fires and aerosol present positive relationships ($p < 0.01$). The largest coefficient of determination was found between aerosol and age standardised rates of hospitalisations (r^2 0.36, $p<0.01$). Although active fires and aerosol explain a smaller percentage at municipalities, the local level statistics have statistical significance. The relationship with rainfall is not significant for either spatial scale.

Table 2 - : Linear regression results between the environmental variables and age standardised rates of respiratory diseases for Jordão, Tarauacá, Feijó, Santa Rosa do Purus, ManoelUrbano, SenaMadureira, Assis Brasil, Brasiléia, Rio Branco, Boca do Acre, Xapuri, Epitaciolândia, Bujari, Porto Acre, Capixaba, Senador Guiomard, Plácido de Castro, and Acrelândia (n = 18).

Variable	**R^2**	**P-value**
Rainfall	0.12	0.16
Active Fires	0.23	0.01
Aerosol	0.36	0.008

For both micro-region and municipality level aerosol presents the strongest relationship with respiratory diseases during the drought period. Our findings suggests that active fires alone are not sufficient for identifying the co-variation between respiratory diseases and drought related impacts, which could be explained by the movement of smoke. Within Amazonia, smoke tends to be carried by easterly winds (Mascarenhas et al. 2008). Similar conditions were seen in 1997 in Southeast Asia where intense forest fires were recorded in Indonesia. Haze from the fires remained in air for several months and the effects were wide spread, affecting as far as Thailand and Vietnam. Increases in respiratory diseases and cardiovascular diseases compared to previous years were seen in the affected regions, demonstrating long distance dispersion of smoke particles (Mott et al. 2002).

4. Conclusions

This analysis for the Brazilian Amazon shows that at the basin scale respiratory diseases tend to peak at the end of the wet season, however, during drought conditions local impacts show contrasting results. We have identified significant associations between fires and aerosols in JAS and respiratory diseases in children under five years of age during the 2005 drought. Hospitalisation rates were at least 99% higher during the most intense period of the drought compared to other years and the ten year mean. The rates as well as the anomalies for total number of hospitalisations were also higher in micro-regions and municipalities close to the epicentre of the drought. Respiratory diseases are complex. Numerous factors influence their development, including both environmental and social aspects. However by selecting children under the age of five, we reduce the risk of external confounding factors such as smoking. Therefore, we suggest that the increase in respiratory diseases during the 2005 drought was associated with the drought and associated conditions. The results found here are consistent with other findings regarding exposure to smoke from biomass burning (Mott et al. 2005, WHO 2005, Ignotti et al. 2010a, Silva et al. 2010, Carmo et al. 2010).

Understanding the impacts of droughts on respiratory diseases will enable health departments to plan for greater demand on services during drought periods. Moreover, if climate models predicted greater frequency in drought events, policies can be in place to mitigate the impacts on health. Further work on this is being carried out.

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