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Extreme Events of Droughts and Floods in Amazonia: 2005 and 2009

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Abstract The southern border of the Brazilian Amazon is one of the most sensitive areas to deforestation in Brazil. Pondering problems related to changes in land use, new issues are emerging, such as, climate change and its negative effects on the regional hydrological cycle. The higher frequency of El Niño and La Niña seems to have strong influence on rainfall in Amazonia. They are becoming more lasting and intense in the course of the last 20 to 30 years compared to the past 100 years. This paper may confront the scientific knowledge of the relations of climate and water resources in Amazon with the points of vulnerability that anthropic societies present in the region. The impact of climate change is not uniformly borne by different regions and populations. Actually, individuals, sectors and systems are affected to varying degrees and, besides, they may be prejudiced to a greater or lesser extent. These impacts vary in magnitude and intensity in accordance with certain aspects, for instance, geographical location, time, the prevalent social, economic and environmental conditions and the infra-structure of a given location. A comprehensive description of these extreme climate events is one of the first steps to a regional vulnerability approach.

Keywords Amazon · Climate change · Vulnerability · Seasonal climate · Hydric resources

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1 Introduction

The Amazon Basin has an outstanding role in the climate dynamics and the hydrological cycle of the planet, representing approximately 16% of the stock of fresh surface water. Regional and global changes have caused alterations in climate and hydrology of the region. Such changes mainly occur through changes in land use with the conversion of more than 600,000 km^2 of tropical forests into pastures**.** Moreover, the phenomenon of global warming, which has recorded increases in average temperature from 0.6° to 0.9°C in the past 100 years**,** may contribute to this scenario.

The change in temperature can lead to several modifications of the environment, amongst them, alteration in the global hydrologic cycle. This circumstance provokes impacts on water resources at regional level. In fact, distinct changes in temperature of the atmosphere, continents and oceans may lead to changes in atmospheric pressure patterns and winds. Therefore, modifications in precipitation patterns could be expected, such as**,** the mathematical models to predict global climate of Hadley Center to 2050 that show average reductions 150–250 mm.yr-1 of rain in the region.

In addition to alterations in temperature, the worldwide average sea level did record an average increase of 1–2 mm/year during the twentieth century, which may modify the areas of flooding and the influence of marine water. The higher frequency of El Niño and La Niña produces a deep effect on rainfall in Amazonia (mentioned by: Kousky and Cavalcanti 1984; Aceituno 1988; Rao and Hada 1990; Marengo 1992; Roucou 1997; Liebmann and Marengo 2001; Molinier et al. 2002; Ronchail et al. 2002). They are becoming more lasting and intense in the course of the last 20 to 30 years compared to the past 100 years (WMO 2004). This essay may confront the scientific knowledge of the relations of climate and water resources in Amazon with the points of vulnerability that anthropic societies present in the region.

Highlighting climate changes and global warming, it should be mentioned that there is a growing concern of nations. The creation of IPCC (Intergovernmental Panel of Climate Change), originated from a worldwide effort to understand the previously presented issues, was a remarkable action for the collection and the publication of studies that focus on them. Although the IPCC (Parry et al. 2007) cites the causes of climate changes, they are probably accelerated due to human actions.

More recently, several papers were published based on the subject of Extreme Events, especially about Droughts and Floods in general and/or specific way. Moreover, they were applied in different areas and different scales of analysis. Some of them may be mentioned: Nadarajah and Shiau (2005); Mosquera-Machado and Ahmad (2007); Guimarães and Magrini (2008); Filizola (2009); Kundzewicz et al. (2010); Hussain (2011); Santos et al. (2011); Tiwari and Joshi (2011).

2 Characterization of the Amazon Basin

The Amazon River Basin (Fig. 1) is the largest river basin around the world, covering an area of 6.1 million km^2. It is also one of the wettest regions on Earth, with rainfall ranging from 2,300–2,460 mm/year (Fisch et al. 2006 and Molinier et al. 2002). The Basin has widely varying climatic and topographic characteristics, with elevations ranging from sea level at the River's mouth, to an altitude of 6,500 m in the Andes (OAS 2005). There are several studies about the rainfall variability in the Brazilian Amazon and Andes in the tropical zone (Aceituno 1988; Kayano et al. 1988; Rao and Hada 1990; Marengo and Hastenrath 1993; Roucou 1997; Ronchail 1998).

Fig. 1 Amazon Basin

The Amazon River Basin is also an important source of natural resources for human economic development. It contains some of the world's largest known reserves of bauxite (nearly 15% of the world total), and industries within the Basin are some of the largest suppliers of iron and steel to world markets. Wood and wood byproducts, gold, and tin are other products from the Basin that are increasingly in demand for export. The population of the Amazon River Basin is estimated at approximately 10 million, mostly concentrated in urban areas along the river and its main tributaries. Population growth rates range from 5.2% to 7.2%, well above the national averages for the Amazon countries. These factors, combined with the high levels of poverty, place constant pressure on the region's natural resources, and in particular on residual native forests (OAS 2005).

Thus, the flow regime of this river system is relatively pressed by human action, being subject to interannual variability and long-term tropical rainfall, which results in large variations in the superficial runoff (Marengo and Nobre 2001). The recycle of local evaporation and precipitation, which seems to be influenced by the forest, accounts for a considerable portion of the regional water availability. Large areas of the basin are subject to intense changes in land use, as dense rainforests are lost to pasture or soybean crops. To a certain extent, there is a major concern about how changes of land use and biomass can affect the hydrological cycle in the Amazon Basin (Marengo and Nobre 2001 and Freitas 2005).

Some authors, such as Duarte (2005), argue that the effects of these mechanisms on rainfall may be responsible for half of the volume of moved water in the hydrological cycle in Amazonia. The other half would come from the contribution of the Atlantic and Pacific Oceans. The influence of sea surface temperature in the Pacific (El Nino and La Nina) as well as in the Atlantic also determines the conduct of the precipitation.

Considering the possible effects of changing land use in the Amazonian region, one must pay attention to the correlation between these effects in relation to rainfall anomalies and trends related to the temperature of the oceans. According to Duarte (op.cit.), both influences feed themselves, implying that human intervention results in more and more noticeable signs of climate changes.

A symbolic case about extreme precipitation event in Amazonian Basin is a drought occurred in 2005. The social and economic impacts will be discussed in the following topic.

2.1 Episode of Drought in 2005

The 2005 drought in western Amazonia may not have been the outcome of global climate processes. However, it seemed to be the consequence of changes of pattern of land use in Brazil and neighboring countries. Deforestation presents a dual role in this scenario. First, it causes a decreased ability to retain rainwater and, secondly, it provokes a proportionate increase in the runoff water of these rivers. In other words, it increases the variability of the flow of rivers. This change of regime of rivers could be felt by the occurrence of floods in the same region of Amazon, a few months after the drought period.

It is important to point out that with the growth of population in Amazonia in the last 40 years, the impact of drought has become more significant. According to National Secretariat of Civil Defense, only in the state of Amazonas (Brazil), the 2005 drought affected more than 914 communities. This statistic is compared to approximately over 167 thousand inhabitants or 32 thousand families (Fig. 2).

The rivers most affected by the drought of 2005 were the snippets of the central Amazon Basin, Jurua, Solimões, Negro, Uatumã, Purus, Tefé, and Madeira. However, once the rain restarted in the headwaters and in Tabatinga, the waters began to rise in 5 days.

Despite the great water availability, the effects of an extreme event of drought in the Amazon Basin are considered severe in many areas. Consequently, they can be perceived in various aspects of Amazon population's life. Among these aspects, there are the following ones listed below:

- Increased isolation of communities that is affected by navigation, because the rivers are the main route of transportation of cargo and people in Amazon. Then, when the rivers are low, hindering the transportation of diesel oil from power generation, food is not produced in the same locations and, also, the access to medicines and other vital goods is prejudiced.
- The lack of water that affects fish production, the main source of animal nutrient for these communities. In recent years, the fishing has also been affected by two different actions: human predatory activities and uncontrolled expansion of alligators, which has reduced the fish availability in normal times.
- Lack of water also hinders the access to drinking water supplies for both human beings and animals in some areas of ranching. The river water within the most part of Amazonia is of poor quality to drink. Drinking water can be obtained in the underground by precipitation and when collected before reaching the ground. It is also used in water treatment plants that turn river water into drinking water through the use of some dissolved substance, for example, mercury in some cases.

The problem is that these isolated communities have few water treatment plants. Besides, there is the fact that several families are not related to supply networks. They get water from wells that are dry or with water of poor quality.

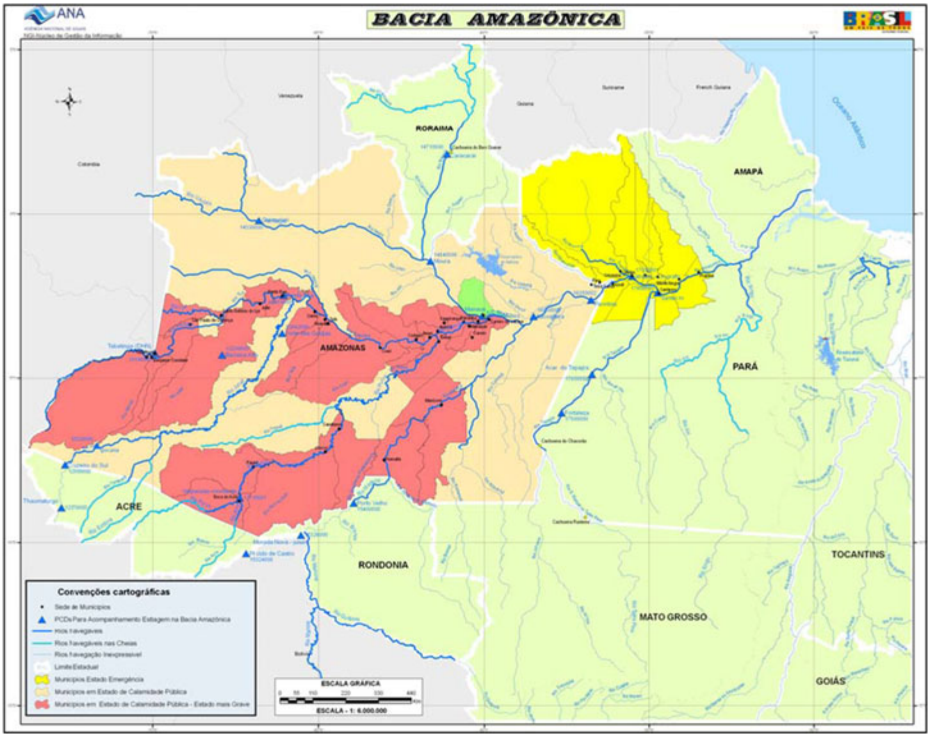

Fig. 2 Brazilian Amazon. Municipalities in state of emergency, state of public calamity on October 19, 2005. Source: ANA Website (www.ana.gov.br/Destaque/Boletim_Amazonas_19out/2005)

The relation between drought and other events, like deforestation, is not well established. However, in regions of Pará, Mato Grosso and Rondonia, where the most affected areas with burning and destruction of the forest can be found, the vulnerability to droughts and floods has increased. The decrease of the effect of water retention in the vegetation and the water percolation into the soil occur. Moreover, this occurrence affects the recharge of groundwater and springs. It also reduces evapotranspiration and runoff. Nevertheless, it increases the volume of sediment in rivers and surface temperature. Based on the presented picture, simulations of the climate in Amazon deforested areas have the following results (Marengo 2004):

- Evapotranspiration decreases between 0.3 and 2.7 mm/day;
- Air temperature increases 0.1 and 3 K;
- Precipitation decreases from 0.1 to 3.1 mm/day**,**
- Surface runoff decreases between 0.1 and 1.1 mm/day.

After the severe drought of 2005, it was thought that the Amazon region inexorably tended to a drier climate. There was even among the population who would never think it could rain more strongly in Amazon. The climate changes were evident with that phenomenon. Climate researchers have not reached a consensus. But, an unexpected event put the Amazonian climate in an opposite situation: a flood happened in the last half of 2008 until the first half of 2009.

3 Result: Episode of Flood in 2009

In the second half of 2008 and in the first half of 2009, floods occurred quite pronounced in the Amazon Basin region. In June 2009, not only did the flooding of the rivers Negro and Solimões, in the state of Amazonas, affect the city of Manaus, but also, various locations within the state of Amazonas. Economic loss was enormous. As far as it was concerned, only in April 2009, the state government indicated losses of around R$ 50 million. However, the capital and other cities were still to suffer the effects of flooding.

In late April 2009, the Geological Survey of Brazil (CPRM) announced that the waters of Negro River, which bathe Manaus, could reach an average of 29.6 m in June when the rainy season ends in the region. According to CPRM report, this would constitute the third biggest flood in 50 years in Amazonas. Losing only to the flood of 1953 (29.69 m) and the flood of 1976 (29.61 m).

During that period, data from the State Civil Defense showed that more than 20,000 families were homeless in Amazon and 41 municipalities were in emergency situations. There was loss of half the fledgling state's agricultural production. In Manaus, the City Civil Defense estimated that 3,000 families could be affected by the flooding in the city and about 200 homes in rural communities needed to be removed.

According to Filizola (2009), the abnormal rise of the Negro River can be attributed to a rare coincidence of flood peaks of the various rivers that comprise it. "It is a rare phenomenon. We have always worried that this happened and it seems it is happening now that (…) there was very strong concentration of rainfall in January in the upper Rio Marañon, Peru." Filizola continues: "In Brazil, the rainfalls were concentrated along the Solimões and Amazon, and along the Jurua and Purus. It joined with the elevation level of the Negro, which is now in time of heavy rainfall and coincided with the flood peak of the Madeira River." To this extent, underscoring the remarkable aspect of seasonality in the hydrological regime of the Amazon Basin.

As time did pass, forecasts of flooding increased. In May it was anticipated that the Negro, in the stretch that bathes Manaus, could reach the quota of 29.95 m. Not only did the Negro, in Manaus, register a flood record in the first half of 2009. At least five other locations also recorded maximum indices of their historical series and they could be presented as Manacapuru, Itapéua, Parintins, Careiro and the community called Forte de Nossa Senhora das Graças, situated in the gutter of Jurua.

The causes of these floods are related to heavy rains that occurred in the headwaters of the Solimões, situated in Peruvian territory: the gutters of Jurua, the Purus, the many Solimões and Amazon were the most damaged, recording large amounts of water in the hydrological stations maintained in those areas.

The Regional Superintendent of CPRM, Marco Antonio Oliveira, said the first broken record in the first half occurred in Forte de Nossa Senhora das Graças, in the most western portion of Amazon. The height of 26.59 m, recorded in 1999, was surpassed on May 3, with the mark of 26.82 m. In Parintins, on June 17, Amazon went up to 9.38 m versus 9 m registered in September 1976. On June 18, Itapeua, in the municipality of Coari, marked the height of 17.47 m. Solimões surpassed the 17.38 m in 1999. Manaus was the following town to beat the record flood. The Negro surpassed its series on June 25 when it reached 29.71 m. On July 1, the Negro has reached 29.77 m noting the record flood. Being the most populous municipality in the state, the urban core of Manaus was affected. According to the Civil Defense of Manaus, 11 districts of the city suffered from the floods. More than 4,000 families were affected by floods beyond neighborhoods and tourist attractions of Manaus.

According to the governor: “The losses of the flood until July 2009 had been estimated at about $ 380 million when, on occasion, after 50 days of mudslides, swollen rivers and flooding, ten cities were practically under water.” Despite all the flood damage, the governor said the Amazonian population had less difficulty to deal with the floods than the drought: “The 2005 drought was more dramatic. During the dry season, the water disappears and it is the water that feeds the fish. Yet we could manage and overcome that crisis.”

In August 2009 the governors of the states in the Amazon region gathered Tocantins to assess joint actions to discuss the effects of the crisis, which was created by floods, and to sign a commitment in order to share experiences and provide solidarity actions (Fig. 3).

It should be mentioned that, in the state of Amazonas, more than 50,000 people have been displaced in the capital and more than 30,000 people, in the country. In early August 2009, with the pace of reduction of four centimeters per day, the station of hydrological monitoring of the Geological Survey of Brazil (CPRM) indicated that the Negro had lowered 63 cm since July 1. It was the date when the biggest flood ever recorded was marked.

3.1 Analysis of Climatological Parameters of Floods

The Amazon region has its climatic regime and, therefore, its hydrological regime that seems to be dependent on events in the Atlantic and Pacific oceans. Changes in surface temperature of the oceans cause changes in atmospheric dynamics. The variability of atmospheric dynamics leads to new settings in rainfall patterns and flow of the Amazon Basin.

The episode, which was dealt with in this study, has intimate connection with a hot region of the Atlantic Ocean, just below the equator, that led to the permanence of the Intertropical Convergence Zone (ITCZ) to the south of its mean position. This configuration generated

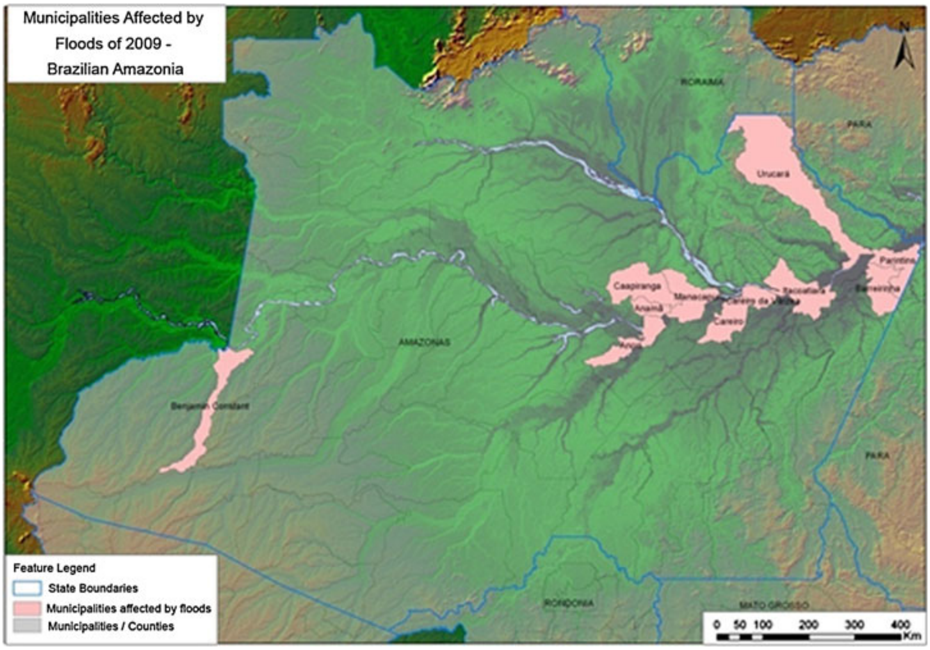

Fig. 3 Brazilian Amazonia. Municipalities affected by floods of 2009

the highest rainfall in some sub-basins to the north and mainly to the northeast of the vast Amazon Basin.

According to the information indicated by MRCP bulletins, issued in the second half of 2008 to the first half of 2009, and CPTEC climate analysis bulletins in the same period, the Amazon Basin faced the action of the ITCZ to the south of its climatology from November 2008 until June. However, other weather phenomena also contributed to the rainfall of the basin, such as, frontal systems, convective clusters and squall lines (SLs), Zones of the South Atlantic Convergence (SACZ) and High Bolivia. The following summary will be presented showing the most active monthly rainfall atmospheric phenomena (CPRM CPTEC).

From the systems described above, the ITCZ was very active in the process of precipitation in the region. Such south position of its climatology was due to the warm waters of the Equatorial Atlantic in the Southern Hemisphere. This ocean-atmospheric condition increased the rainfall in the states of Amazonas, Pará, Amapá, Maranhão and Piauí (Fig. 4).

During April to June 2009, CPRM bulletins indicated that many gauging stations showed elevation above the historic maximum. CPRM bulletins indicated the presence of ITCZ below its climatology as a major cause of the occurred record of oil flow (according to Figs. 5, 6, 7, and 8).

According to the bulletin CPRM of July 2009, levels of the quotas of posts that had values above the historical mark started to recede. This event coincided with the fact that ITCZ began to move to north of the Amazon region. The movement of the sun and the cooling of ocean waters, that caused the system, moved toward the northern hemisphere.

4 Discussions

The knowledge of how to place the functions and interactions between natural systems, biogeochemical and climate cycles is a prerequisite to define optimal strategies for development. Complex interactions between soil, vegetation and climate must be monitored and analyzed so that factors that stimulate the growth of forests, soil conservation and water resources may be established.

Currently, the researchers, who conducted this study, believe there is no clear link of the event with climate changes or global warming. It is advisable to have more studies on the mechanisms leading to surface warming of the Atlantic in the period in question. It is pointed out that, despite there is no clear link of the analyzed event with the signs of climate changes at this stage of research, this relation is not discarded.

Pondering the focussed subject, it should be promoted aimed actions to mitigate the effects of extreme events of drought and flood. In this circumstance, some factors can be mentioned:

Fig. 4 Anomaly of sea surface temperature for the month of May, 2009 (orange areas represent positive anomalies in temperature). Source: Bulletin climate analysis 2009 (www.cptec.inpe.br)

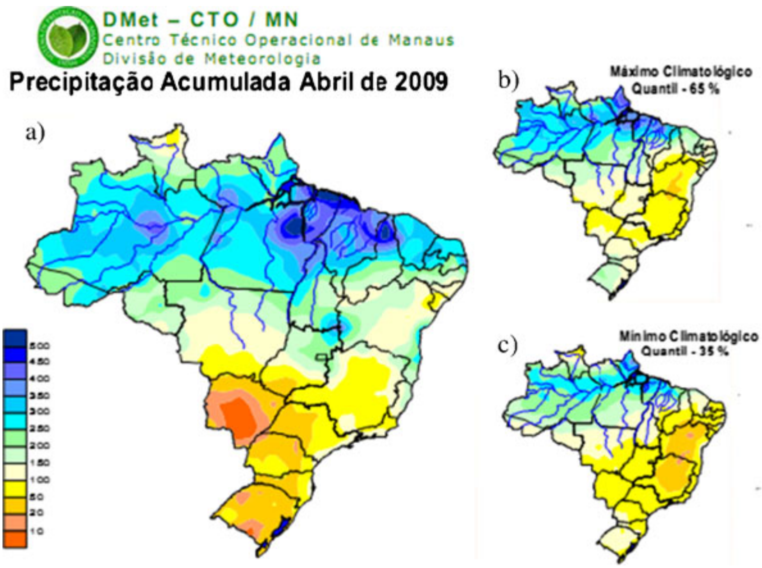

Fig. 5 Cumulative rainfall in April 2009 (*left*), the climatology of precipitation of the maximum (*upper right*) and the normal minimum (*lower right*) for that month. Source: Bulletin 15/2009 CPRM (www.cprm.gov.br)

- Ensure the warning system in drinking water, food and medicine to the entire affected population, with cooperation between the Armed Forces, Civil Defense, Ministry of Health, State and Municipal Governments;
- Distribute water treatment tablets, with cooperation between the Armed Forces, Civil Defense, Ministry of Health, State and Municipal Governments;

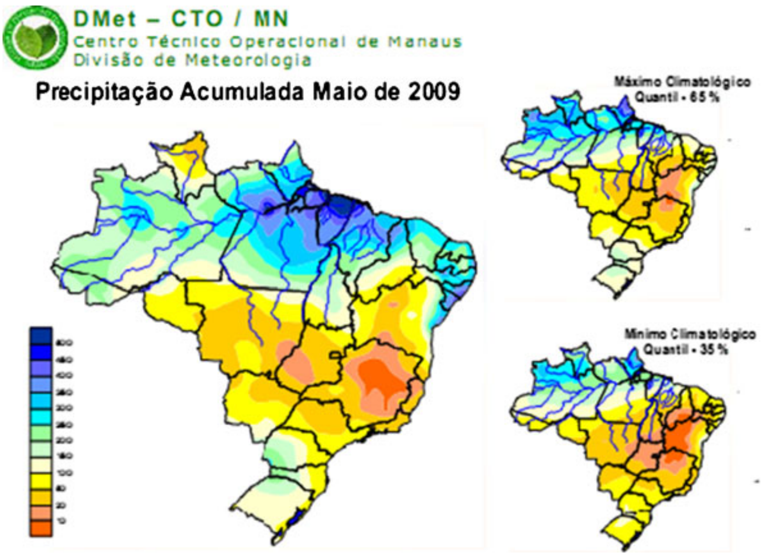

Fig. 6 Accumulated rainfall in May 2009 (*left*), the climatology of precipitation of the maximum (*upper right*) and the normal minimum (*lower right*) for that month. Source: Bulletin 19/2009 CPRM (www.cprm.gov.br)

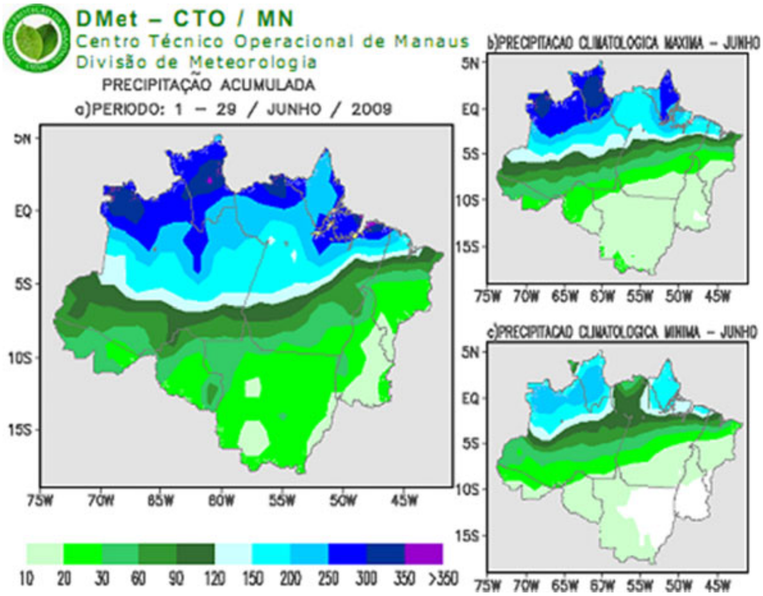

Fig. 7 Accumulated rainfall in June 2009 (*left*), the climatology of precipitation of the maximum (*upper right*) and the normal minimum (*bottom right*). Source: Bulletin 23/2009 CPRM (www.cprm.gov.br)

- Open wells with an appropriate depth to each region, starting a program to guarantee water supply in extreme events in Amazon. It stands out a program of tanks and wells

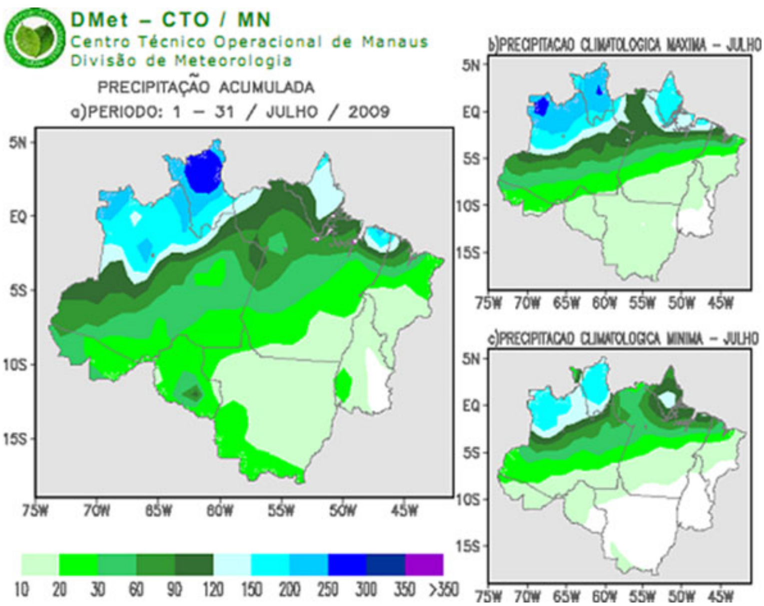

Fig. 8 Accumulated rainfall in July 2009 (*left*), the climatology of precipitation of the maximum (*upper right*) and the normal minimum (*lower right*) for that month. Source: Bulletin 23/2009 CPRM (www.cprm.gov.br)

pump water with solar energy, with support from Geological Survey, Oil companies, Ministry of Health and Water Companies;

- Conduct a quick survey of groundwater, with the support from Geological Survey, Oil companies and the Ministry of Health;
- Keep alert service of drought and flood, informing the population what has occurred and the precautions to be taken in relation to water and food;
- Establish Information System on Water for Extreme Events in Amazon as well as mapping the vulnerabilities to such events;
- Maintain control of diseases in the affected population, mainly, from diseases caused by poisoning of water and food. This enables the population to be aware of food preservation and rational use of water;
- Encourage research to decentralize management of freshwater for drinking water production within the region;
- Encourage program of renewable energy in isolated communities;
- Encourage the development of fish farming with local fish species in rivers and lakes;
- Increase knowledge of tropical biodiversity for food and drugs tailored to periods of extreme events;
- Increase appreciation of the standing forest (developing fruit and leaves) as well as promoting agriculture at various vertical levels within the forest using more agro-forestry techniques;
- Promote agriculture and reforestation on lands already cleared;
- Develop and discuss contingency plans against Droughts and Floods with public authorities and civil society. Meanwhile, it may be increased the integration of the government in its various spheres of power,
- Increase integration of the countries that are part of the Amazon Basin on the theme of water and preservation of ecosystems.

5 Conclusion

Concerning the aspects that are related to the socioeconomic impacts of extreme climatic events in Amazon, it should be noted that floods and prolonged droughts have been affecting this scenario with a considerable frequency. Consequently, they may represent a great importance in any agenda for planning and regional development.

Costs and potential risks are large and they fall on the poor and vulnerable, especially in riparian areas. Issues related to lack of sanitation and general living conditions are precarious and key components of vulnerability. Thus, countering the negative effects of extreme weather events and, also, the climate change may offer an opportunity. Furthermore, it demands the integration of public policies.

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