Water and Climate Change

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Introduction

Two-thirds of the earth's surface is covered by water –approximately 360 million km2 of a total of 510 million. Nevertheless, 98% of the water available on the planet is salty. Water has multiple uses, including fresh water for domestic use; industrial, agricultural; recreational; energy generation; navigation; dilution of waste; establishing a harmonious landscape; preservation of fauna; preservation of flora; irrigation and others.

Brazil has a special place in the world in relation to the availability of water resources. The average annual flow of the rivers on Brazilian territory is about 180 thousand m3/s. This corresponds to approximately 12% of the globe's total water resources of 1.5 million m3/s (Shiklomanov et al., 2000). If waters that originate in foreign territories and flow through Brazil are considered (the Amazon: 86,321 thousand m3/s; Uruguay: 878 m3/s and Paraguay: 595 m3/s), the total average flow reaches 267 thousand m3/s (18% of world supply).

The Amazon has 74% of the country´s fresh water yet is inhabited by less than 5% of the Brazilian population. The lowest average flow per resident is found in the hydrographic region of the eastern Northeast Atlantic, with an average lower than 1,200 m3 per capita per year. In some watersheds in this region, flows are lower than 500 m3 per capita per year.

Other hydrographic regions with relatively low water availability include the Eastern Atlantic, Parnaíba and São Francisco basins. In the semi-arid portion of these regions, where drought has the most serious repercussions, water is a critical factor for the local populations (GEO Brasil, 2007).

Water availability in Brazil depends largely on the climate. The annual cycle of rains and streamflow in the country varies among river basins and in fact the interannual climate variability, associated with the the El Niño and La Niña phenomenon, or the sea surface temperature variability of the in the Tropical and South Atlantic, can generate climatic anomalies that produce severe drought, as occurred in 1877, 1983 and 1998 in the Northeast, 2004-2006 in Southern Brazil, 2001 in the Brazilian Midwest and Southeast and in 1926, 1983, 1998 and 2005 in the Amazon (Marengo & Silva Dias, 2006; Marengo, 2007; Marengo et al., 2008 a, b). In addition, the risks of climate change, whether natural or of anthropogenic origin, have raised great concern in scientific and political circles, in the media and the population in general.

Since the 1980's, scientific evidence about the possibility of climate change on a global scale has sparked growing interest in the public and the scientific community in general. In 1988, the World Meteorological Organization and the United Nations Environmental Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC). The IPCC was made responsible for reviewing existing scientific studies to evaluate possible future climate change scenarios. Its mission is to assess the latest "scientific, technical and socioeconomic information relevant for the understanding of the risk of human-induced climate change".

The process used to produce these evaluations was designed to assure high credibility in both the scientific and political community. Previous evaluations were published in 1990, 1996 and 2001. There are three "work groups": Group 1 evaluates the scientific aspects of the climate system and climate change; Group 2 evaluates the effects of climate changes on nature and society; and Group 3 discusses methods to adapt to and mitigate climate change.

The Fourth Scientific Report of the IPCC AR4 (Trenberth et al., 2007; Meehl et al., 2007) presents evidence of climate change that can significantly affect the planet, especially in the climatic extremes, with greater impact in the less developed countries in the tropical region. The principal conclusions of this report suggest, with reliability greater than 90%, that global warming over the past 50 years has been caused mainly by human activities.

During 2007 alone, according to the UN, 117 million people throughout the world were victims of nearly 300 natural disasters, including devastating droughts in China and Africa and floods in Asia and Africa – with total damages of US$15 billion. Many less developed countries already confront uncertain and irregular rainy seasons and the forecasts for the future indicate that the climate changes will make the water supply increasingly less predictable and reliable. To save water for the future, is not, therefore, to fight for a distant and uncertain goal. The current trends in water exploration, degradation and pollution have already reached alarming proportions and can affect the water supply in the near future if measures are not taken. Climate change means that desertification will sooner or later expel 135 million people from their lands, according to UN estimates. Most of these individuals live in the Third World. UNESCO forecasts that 1.8 billion people may confront critical water shortages in 2025 and two thirds of the world's population may be affected by the problem in the same year. The explosive growth of urban populations is also a cause for alarm of the global threat of water shortage.

In the past, the greatest concern of federal and state governments for water management was how to satisfy the demands of an increasingly larger population, and how to confront the problem of droughts or floods. Recently, climate change has been observed as a possible cause of problems that can affect the variability and availability of water quality and quantity. Changes in the climatic and hydrologic extremes have been observed in the past 50 years, and projections of climate models present great concern for large areas of the tropical region.

Possible impacts of climate change: the Stern Report

The Stern Report presented in October 2006 by the chief economist of the British government (Stern, 2006) maintained that a temperature rise of approximately 3º C could cause droughts in Europe, water shortages for up to four billion people and millions of new cases of malnutrition. Below are some of the consequences forecast for the different levels of increased temperature of the Earth, according to the Stern Report:

- A 1 ºC rise in global temperature – Glacial shrinkage threatens water supply for 50 million people; a small increase in grain production in temperate regions; at least 300 million people would die each year from malaria, malnutrition and other diseases related to climate changes; the death of 80% of coral reefs, in particular the Great Coral Reef.
- A 2 º C rise in global temperature – a 5% - 10% drop in grain production in tropical Africa; 40 million to 60 million more people exposed to malaria in Africa; up to 10 million people more exposed to floods in coastal regions; between 15% and 40% of living species become threatened with extinction; great risk of extinction of species found in the Arctic, in particular polar bears; possibility that the Greenland ice layer would begin to melt irreversibly, which would cause ocean levels to rise up to seven meters.
- A 3 º C rise in global temperature – in southern Europe, periods of severe drought every 10 years; from 1 billion to 4 billion more people confronting periods of water shortage; from 150 million to 550 million more people exposed to threat of hunger; from 1 million to 3 million more people die from malnutrition; possible initiation of collapse of the Amazon forest; increased risk of collapse of the Ice Layer of the Western Antarctic; increased risk of collapse of the circulation system of warm waters of the Atlantic; higher risk of abrupt changes in the monsoon seasons.
- A 4 º C increase in global temperatures – harvests drop 15% - 35% in Africa; up to 80 million more people exposed to malaria in Africa; disappearance of nearly half of the tundra vegetation in the Arctic.
- A 5 º C rise in global temperature – probable disappearance of large Himalayan glaciers, harming one fourth of the Chinese population and a large portion of the Indian population; growing intensification of ocean activity, seriously harming marine ecosystems and probably fish populations; increased sea levels threaten small islands and coastal areas such as Florida State and large cities such as New York, London and Tokyo.

Brazil is vulnerable to current climate changes and even more to those projected for the future, especially climatic extremes. The most vulnerable areas include the Amazon and Northeastern Brazil, as shown in recent studies (Marengo, 2007; Ambrizzi et al., 2007; Marengo et al., 2007). Knowledge of possible future climatic-hydrological scenarios and their uncertainties can help to estimate water demand in the future and also to define environmental policies for future water use and management.

This study evaluated the state of the art of knowledge about climate changes and their impact on water availability in the future, considering long term trend studies of the past fifty years and projections of climatic models until the end of the 21st century. For more information, we suggest reviewing the following studies of the IPCC and of the Climate Report of Brazil's National Space Research Institute (INPE): Trenberth et al. (2007);

Magrin et al. (2007); Bates et al. (2008); Marengo et al. (2007); Ambrizzi et al. (2007); Salati et al. (2007).

Climate of the present and future

In recent years, the continent has experienced a succession of radical events: torrential rains in Venezuela, floods in the Argentine pampas, droughts in the Amazon, hail storms in Bolivia and a record hurricane season in the Caribbean. At the same time, rains decreased in Chile, in southern Peru and in southwest Argentina. With increased temperatures already registered (+1oC in Central and South America over a century, compared to a global average of +0,74oC), the Andean glaciers are receding. The availability of water for human use and generation of electricity is already compromised and the problem will become aggravated in the future, becoming chronic if measures are not taken according to the report of the IPCC GT2 for Latin America (Magrin et al., 2007).

In relation to rains, a trend has been detected in previous IPCC AR4 studies (Trenberth et al., 2007) towards an increase of up to 30% each decade of rain in the Plata River basin and in some isolated areas of the Northeast. For the Amazon, a clear trend of an increase or decrease of rains is not identified (as expected from deforestation), presenting more of interdecadal variations contrasting between the Northern and Southern Amazon (Marengo, 2004). In the Northeast, the trends observed also suggest inter-annual variability associated to the El Nino and to the sea surface temperature gradient in the tropical Atlantic as well as decade-long trends associated to changes in the meridional position of the Intertropical Convergence Zone. Regionally, since 1950, there has been an increase in rains in parts of Southern Brazil, in the Paraná-Prata Basin, in keeping with similar trends in other countries of Southeastern South America. In the southeast, the total annual precipitation appears not to have suffered perceptible changes in the past 50 years.

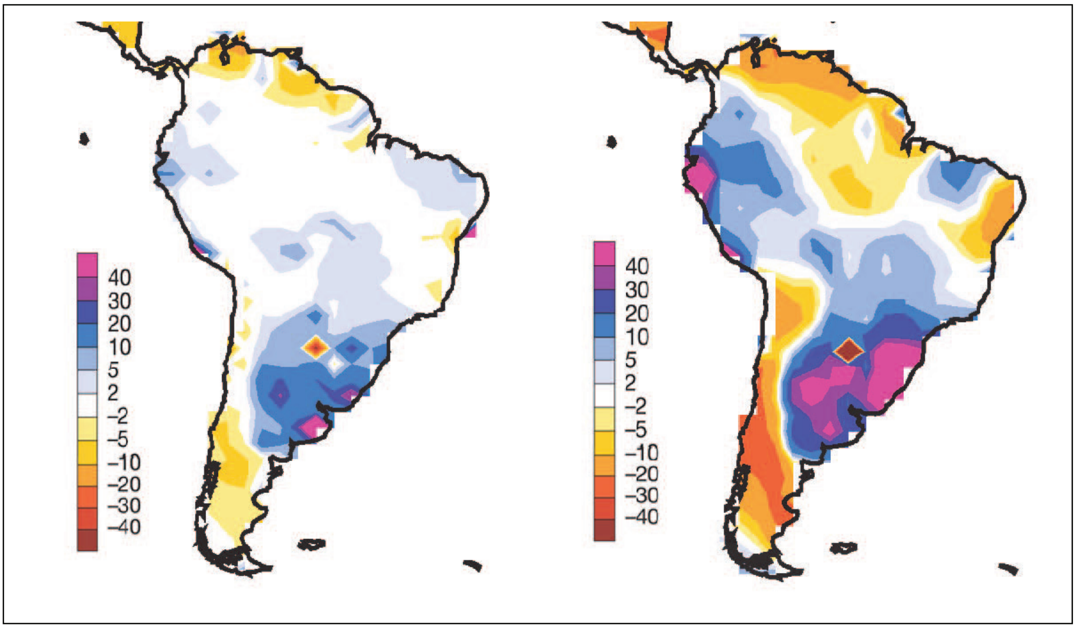
The projections for changes in the regimes and distribution of rain in future warmer climates, derived from the global models of the IPCC AR4, are not conclusive, and there is still great uncertainty because these projections vary with the models and regions considered. In the Amazon and the Northeast, while some global climatic models of the IPCCC AR4 foresee drastic changes in precipitation, other models foresee increases. The average of all the models, in turn, indicates a greater probability for a reduction of rain in regions such as the Eastern and Northeastern Amazon as a consequence of global warming. The IPCC AR4 (Meehl et al., 2007) forecasts reductions in rain in Northern and Northeastern Brazil during the winter months of June, July and August, which can reduce rainfall in the Eastern region of the Northeast, which has its peak rainy season at this time of year.

Hydrology of the present and future

In relation to river streamflow, the trends observed are consistent with the trends in precipitation, with a clear trend towards an increase in the flow of the Paraná and other rivers of Southeastern South America. In the Amazon, in the Pantanal and in the Northeast, systematic long term positive or negative trends were not identified. More important, interannual and interdecadal variations were studied, associated to the natural climate variability, in the same time scale of variability of interdecadal phenomenon in the tropical Atlantic and Pacific Oceans. Analyses of river flows in South America and in Brazil (Milly et al., 2005) indicate increases of 2% - 30% in the Paraná River Basin and in the neighboring regions of Southeastern South America, consistent with the analyses of trends for rains in the region. Important trends were not observed in the flows of the rivers of the Amazon and San Francisco basin. On the west coast of Peru, the positive rainy trends can be explained by the extremely high levels of rains and flows during the El Niño years of 1972, 1983, 1986 and 1998, which markedly affected these trends.

Milly et al. (2005) analyzed the components of the river flows of various models used by IPCC AR4 for the future, compared with the present. Figure 1 a-b shows that the models used by IPCC AR4 (Figure 1a) are representative of the growing trends found in the Paraná-Prata Basin. For the end of the 21st century, the models of the IPCC AR4 suggest reductions in the flows of the São Francisco, Parnaíba, Tocantins, Xingu and other rivers of the eastern Amazon, as well as those in central Chile. In turn, the models also suggest increases in the flows of the rivers on the west coast of South America, close to the Peru-Ecuador basin and in the Paraná-Plata Basin. These projections are very important because the changes in flows can change the frequency of floods and this can damage the ecosystems and affect food production and energy transportation and generation. The increase in the flows are consistent with the increased rains in the future (Meehl et al., 2007).

Some of the flows in Brazil (in the Amazon, Southern Brazil, North and Northeast) have high correlations with the fields of anomalies of ocean surface temperature in the Tropical Pacific and Atlantic Oceans. This suggests a possible association between extreme flows and El Niño, or a heating in the tropical North Atlantic Ocean, as was the case, for example, in 1998, when there were lower flows in Manaus and the Óbidos, and the low levels of the Solimões River



Source: Milly et al. (2005).

Figure 1

(A) Relative change (%) in the flow of rivers in South America (average of nine global models used by IPCC AR4) for the period 1971-2000 relative to the average in the period 1900-1970, from the IPCC's 20th century climate round (20C3M); (B) Relative change in percent of the flows in South American rivers (average of the nine global models used by IPCC AR4) for the period 2041-2060 in the A1B scenario related to the average in the period from 1900-1998 (IPCC 20C3M experiment).

during the recent drought of 2005 (Marengo et al., 2008 a, b). The projections of the IPCC AR4 report for Latin America in 2050 are not very encouraging (Magrin et al., 2007). The increased temperature and the presence of less water in the soil would in fact transform parts of the Amazon into savannah and areas recognized today as semi-arid will suffer a desertification process that also would affect agricultural areas.

Hydrometeorological climate extremes

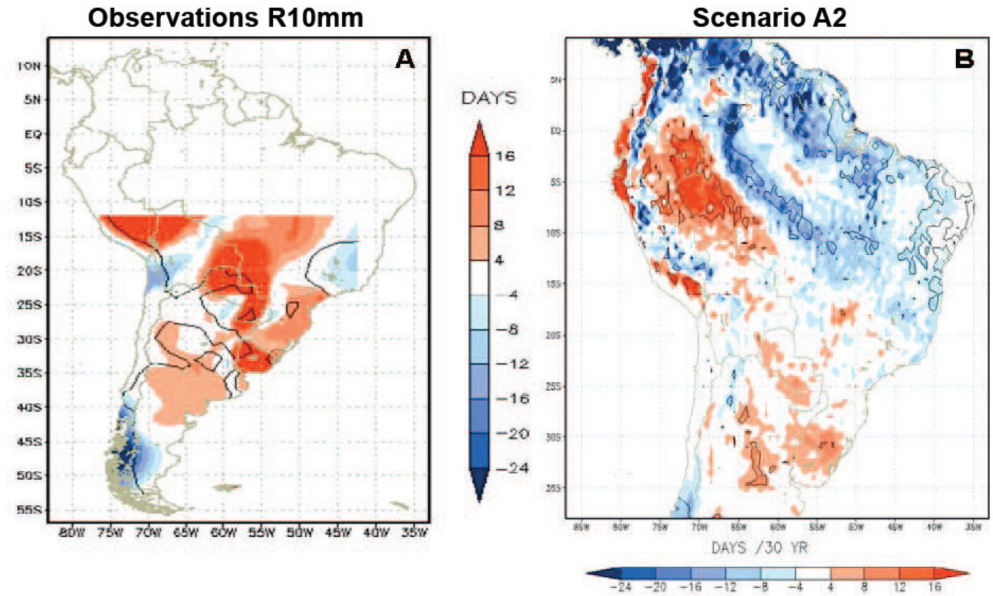
In Brazil's Southeastern and Southern regions, as well as in the Amazon, an intense increase in precipitation has been observed recently, which also has been seen in the past 50 years, as shown in Figure 2a (Marengo et al., 2007). Groisman et al. (2005) identified positive trends for systematic increases in rain and of extremes of rain in the subtropical region, in Southern and Northeastern Brazil. The authors consider that, since 1940, the Southeast has displayed systematic increases in the frequency of intense rains, of up to nearly 58%/60 years. Carvalho et al. (2002) find that in São Paulo, more extreme rain events are observed during the El Niño, which in this State, are sensitive to the intensity of the of the South Atlantic Convergence Zone (SACZ) (Carvalho et al., 2002, 2004).

Haylock et al. (2006) investigated the trends for rain extremes in southeastern South America in the period from 1960-2000. They found trends towards more humid conditions in southern Brazil, Paraguay, Uruguay and in North and Central Argentina. They note that Southeastern South America experienced an increase in the intensity and frequency of days with intense rain, which agrees with the studies of Groissman et al. (2005) for the same region.

Intense rain events in the autumn can be responsible for high flows in the Paraná River in the Pampas of Argentina. Liebmann et al. (2004) show that in São Paulo, on an interannual scale, the number of extreme rain events reveal a correlation with anomalies of the sea surface temperature in the Tropical Pacific and in the Southeastern Atlantic close to the São Paulo coast. The control that the SACZ and the low level jet east of the Andes (SALLJ) have on intraseasonal and interannual scales can be observed in the frequency of intense rain events, associated to the presence of the SACZ and of the SALLJ which, on average, suggest greater frequency of intense rain events in the South and in Southeastern Brazil, when the SALLJ is intense and the SACZ is weaker and shifted to the south of the Northeastern region. Different authors define extreme rain events with different methodologies, using some threshold values or percentiles, which makes a comparison of the results difficult. In Southern Brazil, Teixeira et al. (2007) identify a slight trend towards an increase in the number of extreme rain events, with greater frequency in 1993-1994 and 1997-1998, which were El Niño years.

More recently, Alexander et al. (2006) analyzed trends in annual rain extremes and concluded that these appear to be similar to those of total accumulated rain: positive in southern Brazil, Paraguay, Uruguay and North Central Argentina. They identify positive trends in the number of days with intense and very intense rains (R20 mm) concentrated in a short time, and in the quantity of rain concentrated in events that are indicators of rains that produced floods from 1961-2000. These trends suggest an increase in the frequency and intensity of rain events in southeastern South América. The absence of data in the tropical region prevents a more comprehensive analysis of the extremes in this part of the continent.

The projections for extremes according to the IPCC AR4 (Meehl et al., 2007; Tebaldi et al., 2006) suggest increases in the frequency of rain extremes throughout Brazil, especially in the Western Amazon, in the South and Southeast of Brazil. For the period of 2080-2099, in relation to the present (1980-1999), in scenario A1B, the extreme events of intense rain show an increase in frequency and contribution of the very rainy days in the western Amazon, while in the eastern Amazon and in the Northeast the trend is for an increase in the frequency of consecutive dry days, which is also observed for the north of the Southeast. Recent studies (Marengo et al., 2007; Tebaldi et al., 2006) suggest in fact that



Source: Marengo et al. (2008c).

Figure 2

Trend towards extremes of rain represented by the R10 index (number of days with more than 10 mm of rain), (a) based on observations for the period of 1951-2000, and (b) projected by the regional model HadRM3P for the period 2071-2100 relative to 1961-1990, scenario A2 of high emissions.

the possible scenarios for increased rain in southern Brazil, projected until the end of the 21st century, can be in the form of extreme rain events that are more intense and frequent (Figure 2b). The Western Amazon may experience an increase in the frequency of rain extremes through 2100, which can generate problems of erosion and floods in this region. Nevertheless, the lack of reliable hydrological information in this region does not allow validating the trends simulated for the present.

Regional patterns

Amazon

The situation is chaotic and cause for concern in the Amazon. The entire Amazon River Basin, which includes a number of countries including Brazil, has 70% of the world's available fresh water and is formed by more than a thousand rivers. But this exuberant and essential presence is threatened. The situation became even more complicated in 2005. A strong drought – the worst in the past 103 years – hit the eastern Amazon and some rivers fell six centimeters per day. Millions of fish rotted and died in the beds of the Amazon River tributaries that serve as a source of water, food and means of transport for river communities

(Marengo et al., 2008 a, b; Zeng et al., 2008; Aragão et al., 2007). The chances for the occurrence of periods of intense drought in the Amazon region can increase from the current 5% (a strong drought every 20 years) to 50% in 2030 and up to 90% in 2100 (Cox et al., 2008).

Northeast

The Northeast has only 3% of fresh water. In Pernambuco, there are only 1,320 liters of water per person per year. The United Nations recommends a minimum of two thousand liters. According to IPCC (Magrin et al., 2007) and Inpe reports (Marengo et al., 2007; Ambrizzi et al., 2007), the semi-arid region will tend to become more arid. The frequency and intensity of droughts will rise and the availability of water resources will decrease. This will have impacts on the vegetation, the biodiversity and activities that depend on natural resources.

In Northeastern Brazil, the biggest problem will be the increased drought and the lack of water. The region can pass from being a semi-arid to an arid zone, and the consequences of this change will affect the nutrition, sanitation and health of the local population. More than 70% of the cities of the Northeast's semi-arid region with population above 5,000 people may experience crises in the water supply for human consumption by 2025, despite the mega project to transpose water from the São Francisco River, according to a study by the National Water Agency. Supply problems should affect nearly 41 million inhabitants of the semi-arid region and its surroundings, according to researchers in the agency, who estimate a growth in population and in the demand for water in about 1,300 municipalities of the nine states of the Northeast and northern Minas Gerais.

By 2050, half of the agricultural lands can be harmed, with an "elevated" degree of certainty, exposing millions of people to hunger, according to specialists. From 50 – 150 million people will suffer from the lack of water (reaching 400 million in 2080). The underground water deposits of the Brazilian northeast can receive less than 70% of the recharging. The semi-arid region of the Northeast is on the route to desertification.

La Plata Basin

In Brazil's southern region, the systematic increase of rains can also be observed in the hydrological records, where the flows of the Jacuí River, in Espumoso and in Passo Bela Vista, have positive trends (Marengo, 2007). The same can be said in relation to the flows of the Paraná River, in its lower stretch and of the Uruguay and Paraguay in Corrientes. Since the mid 1970's, changes have appeared in the regime of rains (as was also detected in the Amazon) and since 2001-2003 there has been a change in phase. The series of flows in the Paraná River basin presents an important non-seasonality between the periods before and after the 1970's, with an increased flow varying by about 30%. This period coincides approximately with the epoch of flows above the average observed in the Paraná, Uruguay and Paraguay Rivers and in the Iguaçu River, with trends towards increased rain in the basin, average about 6% higher from 1971 - 1990 than from 1930-1970 (Tucci, 2003; Obregon & Nobre,2003). There is broad evidence that changes in land use in the Upper Paraná, Paraguay and Uruguay river basins may have contributed to a 28% increase in the average flow of the Paraná River since 1970. Tucci at al. (1998) perceive that this increased flow in the rivers took place after large areas had been deforested or other changes in land use. At higher altitudes, in the region of the Plata Basin, the IPCC AR4 (Meehl et al., 2007) present projections for possible increases in rain and flows up to 20% higher during the months of the southern summer (DJF), by the second half of the 21st century. This suggests that, for this region, the future would present a continuity of the variability in rains and flows observed during the past 50 years (Trenberth et al., 2007), which perhaps indicates greater confidence in these projections for this region.

Discussions and conclusions

As presented in this report, there is still not a clear and certain picture of the possible impacts of climate change on the spatial and temporal distribution of the continent's water resources. The uncertainties still represent obstacles for the operational and managerial planning of water resources, but this fact cannot be used to avoid immediate actions.

One of the first actions would be to establish research and monitoring programs to evaluate the risks related to climate changes. Regions such as the Northeast and the Midwest-Southeast, are highly vulnerable because of their dependence on electrical energy and because of the presence or absence of water.

In these regions, the climate changes (especially in the form of increased air temperature) can increase the risk imposed by population growth, industrialization and changes in land use associated to agriculture and husbandry. In the Amazon, the problems are associated to a possible loss of biodiversity and impacts on the hydrological cycle which, in the long term, can increase the risk of rain extremes in southern Brazil, as a consequence of changes in the pattern of transport of atmospheric humidity from the Amazon to Southern Brazil.

The scientific evidence indicates that climatic changes represent a serious risk to water resources in Brazil. Not only the future climate changes represent risk, but climate variability as well; one need only recall the droughts in the Amazon, the Northeast, the South and the Southeast of Brazil in the past ten years, which have affected the regional and national economy. The impact of climate variations and changes can be added to other non-environmental factors, such as political and social aspects, and in combination can generate high costs for society.

The climate projections suggest that in the Amazon and in the Northeast rains may be reduced by up to 20% by the end of the 21st century, in a scenario of high emissions. Nevertheless, southern Brazil will experience an increase of rains in the form of extreme rain events. In different locations, the combination of high temperatures and more rains or high temperatures and less rains can have different impacts in different parts of Brazil and South America.

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Abstract – This study reviews state-of-the-art knowledge on climate change and water in Brazil and South America. It discusses some of the results of the IPCC's (Intergovernmental Panel on Climate Change) studies and Inpe's Climate Report as refers to observational studies of climate variability and future projections of climate and of the components of the hydrological cycle until the end of the 21st century, for the major basins in the continent. Among the most important factors discussed are the economic and management aspects of water resources in different regions of Brazil, and how that may change in a climate change scenario.

Keywords: Water resources, Climate variability, Climate change, Streamflow.

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