Executive Summary

The Scientific Basis of Climate Change

Contribution from the working group 1 to the first national assessment report of the Brazilian Panel on Climate Change (GT1 RAN1 PBMC)

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INTRODUCTION

This document presents the principal contributions from Volume 1 of the Primeiro Relatório de Avaliação Nacional (RAN1), the first national assessment report on climate change from Brazil. This volume has been structured according to the scope previously defined by Grupo de Trabalho 1 (GT1, the first working group) of the Painel Brasileiro de Mudancas Climáticas (PBMC, the Brazilian Panel on Climate Change) primary authors of the chapters.

The surveys synthesized herein result from an extensive evaluation of the existing scientific literature, an evaluation which sought: (i) to show the implications for Brazil of Working Group 1's principal points from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC); (ii) to list and discuss the principal scientific studies since 2007, with emphasis on those directly related to climate change in South America and Brazil.

ATMOSPHERIC ENVIRONMENTAL OBSERVATIONS AND SURFACE PROPERTIES

Climate time series are an indicator of the complex interactions of the earth's climate system, representing the combined effect of oscillations in diverse time scales common to the climate system from anthropic actions. Generally, distinguishing natural from anthropic oscillations is a difficult task, because it is often based on time series of observations made during relatively short periods. Thus, caution is necessary when attributing causes to the oscillations observed.

Brazil is a country of continental dimensions, with a great diversity of climate regimes and influences, making it more difficult to obtain observational data series for long time periods (for example, the beginning of the 20th century). Figure SEF.1 shows the average seasonal precipitation regimes in South America. The seasonal rainfall cycle is affected by interannual variations that can change it, such as the occurrence of drought during the rainy season, or an overly abundant wet season. El Niño and La Niña are important causes of interannual variability. [GT1 2.2.1]

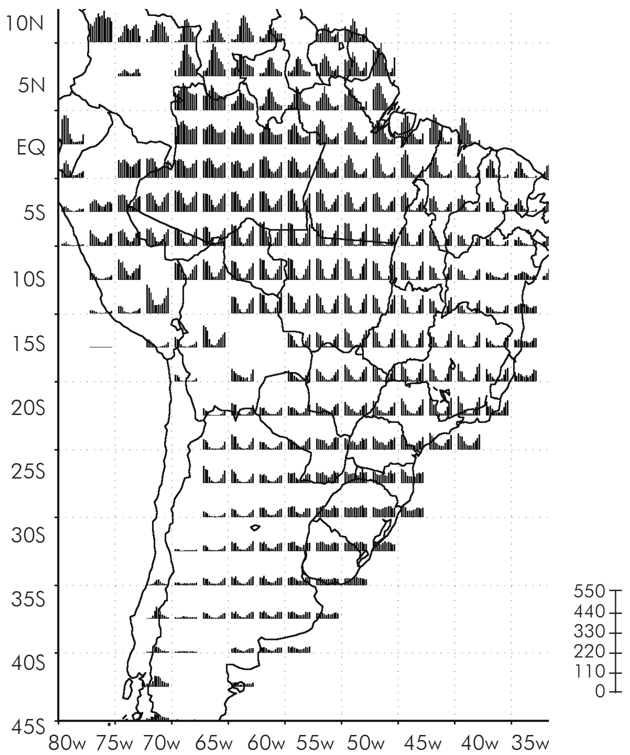
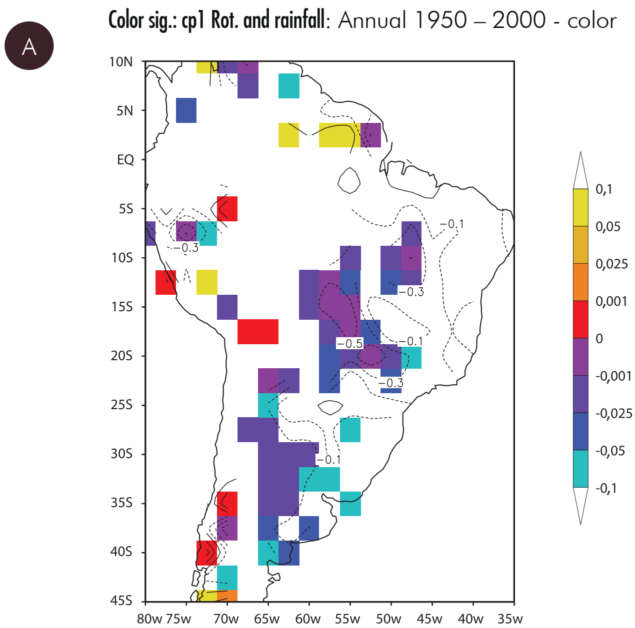


Figure SEF.1.. Annual precipitation cycles in regions at 2.5°×2.5° latitude-longitude, calculated from at least 25 years of data in the period 1950 to 2005. [GT1 2.2.1].

The first mode of interdecadal variability of total annual precipitation indicates that from 1950 to 2000, there was an oscillation of rainfall in the northeast of Argentina and the center-west of Brazil, with a weaker, opposite oscillation in the country's northern region. The passage of time shows an interdecadal variation with an increasing rainfall trend in both areas, primarily between 1970 and 2000 preceded by a period of reduced rainfall trend in these regions from 1950 to 1970. Some studies indicate that this mode is significantly associated with another, called the Atlantic Multidecadal Oscillation (AMO), which involves the interdecadal variability of the sea surface temperature (SST) in the Atlantic Ocean. [GT1 2.2.3].

The correlations of the SST trend mode with time series of average precipitation (1950-2000) in South America (Figure SEF.2a) suggest an increase in precipitation in the south and parts of the center-west of Brazil and the southern part of the Amazon region, and other areas in the lower Paraná and La Plata river basin, such as the northeast of Argentina and Uruguay. [GT1 2.2.4]

This pattern is confirmed by analyzing the precipitation trend for the period 1951 to 2000 (Figure SEF.2b), when negative trends are observed in the north and west of the Amazônia biome, yet positive trends are observed in its southern region, as well as in the center-west and south of Brazil, along with an absence of trend in the northeast of the country.



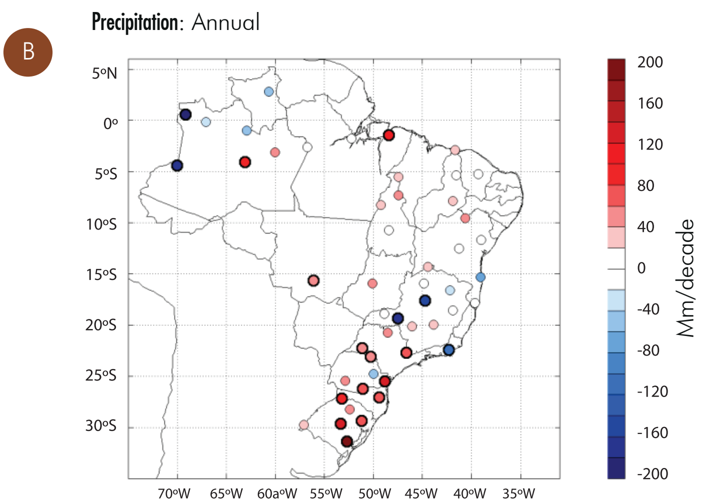


Figure SEF.2. (a) Correlation coefficients (isoclines) between the SST variability mode (trend mode) and average annual precipitation in the period 1950 to 2000. Negative coefficients (positive) indicate an increase (reduction) in precipitation in the period. The colors represent the significance levels (for positive and negative correlations); (b) total annual precipitation trend in the period from 1951 to 2000 (millimeters (mm) per decade-1). Circles with wide contours indicate statistical significance of the Mann-Kendall test at the level of 0.05.

Studies of the air temperature trend using meteorology station data from South America are mostly limited to the period between 1960 and 2000. The most significant results refer to index variations based on the minimum daily temperature, which indicate an increase of hot nights and reduction of cold nights in most of South America, with a consequent decrease in the daily temperature range, especially in the spring and autumn. These results are more robust for the meteorology stations located on the western and eastern coasts of the continent, and are confirmed for time series in longer periods. [GT1 2.3.2]

Reanalysis data since 1948 shows that the temperature has increased slightly in the atmosphere more in the tropics than the subtropics of South America during the austral summer, with annual average surface temperature in the tropics showing a positive trend. For example, Fig.SEF.3 shows the linear trend of area expansion of temperature increases, where these were higher than 18°C between 1949 and 2009.

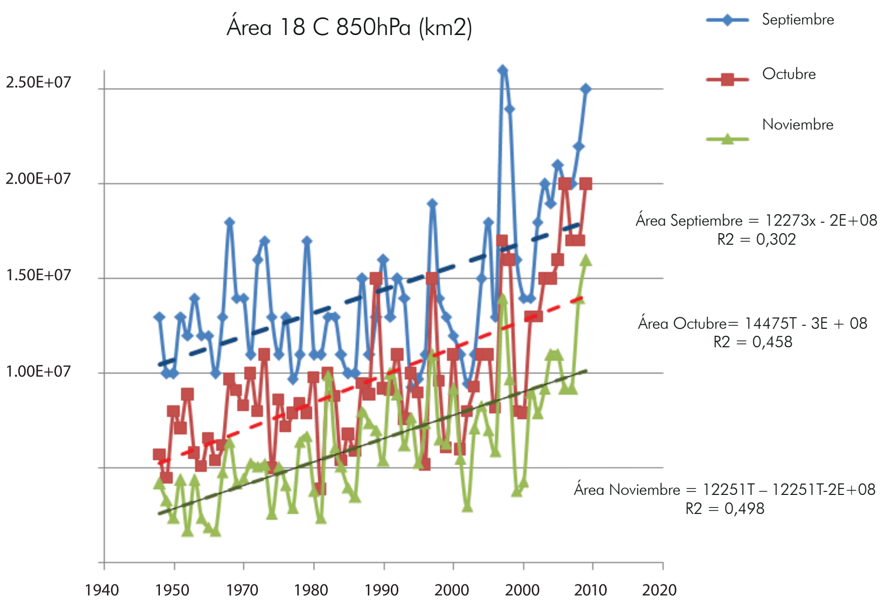


Figure SEF.3. Temporal evolution of the area with temperatures ≥ 18oC in 850 hectopascal (hPa) in South America (1948-2009). Linear tendencies are indicated in the figure.

Scientific Gaps in Atmospheric and Surface Observations

An accurate assessment of temperature and precipitation trends in South America on a decadal and multidecadal scale is limited due to the unavailability of data and their non-homogenous spatial distribution. Additionally, quality control of data and measurement methods increase uncertainties in the evaluations. These limitations are even more critical in tropical regions such as the Amazônia and Pantanal biomes in northern and western Brazil, for which lack of data remains a problem.

COASTAL AND OCEANIC OBSERVATIONS

The oceans play an important role in the earth's climatic balance. Due to the planet's large spatial extension and high thermal capacity of water, it is indisputable that the increase of the heat content in the oceans and rising sea levels are robust indicators of global warming. Recently, various efforts have been made to reevaluate historical data and climate change indicators for more reliable interpretations for longer periods of time. [GT1 3.1]

Those analyzed by the IPCC-AR7 (2007) and other recent studies point to variations in the heat content and rising sea levels on a global scale. Variations in these properties promote counter actions in the characteristics of different bodies of water, which result in changes to the patterns of ocean circulation.

Consequently, changes in the circulation of the oceans lead to changes in how heat and other biological, physical and chemical properties are redistributed on the Earth's surface.

The large majority of scientific studies done in the last five years have irrefutably confirmed the warming of ocean waters. In recent decades, the sea surface temperature (SST) in the Atlantic Ocean has increased. [GT1 3.2.1; 3.3.1]

There are indications that the salinity of the tropical and equatorial Atlantic Ocean has been increasing in recent decades [GT1 3.4], primarily in the layers above the thermocline. In the South Atlantic Ocean, there are also indications of increased salinity in the subtropical gyre, reinforcing the trend for the subtropical region to become warmer and more saline. [GT1 3.2.3]

Yet in high latitudes, where the water bodies that occupy the bottom of the global oceans are formed, a reduction of salinity by 0.1 to 0.5 is noted North of 45oN, from the surface to the bottom. There is also evidence of reduced salinity in the top 500 meters (m) of the South Atlantic Ocean, while at the mid-latitudes an increase of salinity associated with the north side of the South Atlantic Current is observed within the subtropical gyre, with a reduction of salinity on its south side. Since a significant trend of fluvial discharge is not observed in the Atlantic, such changes are apparently due to changes in the Evaporation-Precipitation (E-P) component over the oceans, and changes in the process of deep water formation at high latitudes.

There is clear evidence of an increase of heat content in the upper layers of the ocean. [GT1 3.3.1] Recent results for the period 1993 to 2008, based on a large data set from expendable bathythermograph (XBT), Argo profiling boats and other instruments, show that the heat content in the layer from 0 to 700 m of the global ocean is increasing at an average rate of 0.64 ± 0.29 watts per square meter (W/m-2) across the planet. This increase of heat storage throughout the depths covered by the Argo profiling boats is an indication that the ocean is heating below 700 m as well.

It is assumed that similar phenomena are occurring in the South Atlantic Ocean. In fact, analyses obtained from marker buoys appear to indicate that the South Atlantic shows a positive trend in variation of ocean heat content in the last six years. Studies based on data on anomalies in rising sea surface temperature obtained by satellite, as well as data from fixed buoys from the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) Project both indicate a positive trend in the retroflection region of the Agulhas Current in the period 1993 to 2002. [GT1 3.3.1]

There are strong indications that the characteristics of events from El Niño in the Pacific Ocean have been changing in recent decades. [GT1 3.6] As a result, there has been a change in modes of variability of the SST in the South Atlantic. These changes in SST patterns encourage below average or average precipitations in the Brazilian north and northeast, and more rains in the south and southeast of the country.

Various studies in recent years have shown that as a consequence of the change in wind patterns, the transport of water from the Indian Ocean to the South Atlantic (a phenomenon known as leakage of the Agulhas) has increased. [GT1 3.5.3] These changes are observed through analyses of data obtained by satellite, in situ measurements and modeling results.

The sea level is rising, and variations from 20 to 30 centimeters (cm) are expected by the end of the 21st century, and in some places by the middle of this century or before. [GT1 3.7] Few studies based on in situ observations have been performed on the coast of Brazil. Yet rates of sea level rise have been reported by the Brazilian scientific community since the end of the 1980s and beginning of the 1990s. Estimates found in the literature on Brazil are: Recife, Pernambuco (1946 to 1987): 5.4 centimeters per decade (cm/dec); Belém, Pará (1948 to 1987): 3.5 cm/dec; Cananéia, São Paulo (1954 to 1990): 4.0 cm/dec; Santos, São Paulo (1944 to 1989): 1.1 cm/dec. [GT1 3.7]

In some areas of the southern and southeastern coasts of Brazil, the increased frequency and intensity of extratropical cyclones may increase the recurrence of extreme events such as high waves, strong winds and intense rains. [GT1 3.7.3]

Along the Brazilian coastline there are various stretches of irregularly distributed erosion associated with the environmental dynamics of river base levels. Readjustments of the shapes and sediments of beaches on ample stretches of the coast of the northeast of Brazil, caused by the effect of waves on sedimentary rock, as well as changes to coastal transport, will also imply erosion and localized sedimentary accumulation. [GT1 3.10]

Scientific Gaps in Oceanic and Coastal Observations

The intensification of the erosion process observed at various locations on the Brazilian coast in the last decade is the result of changes in the wind and wave patterns along the coast, as well as the rising mean sea level. However, in Brazil there is no system of observation of these variables, so it is not possible to obtain quality, continuous time series data to understand and quantify the phenomena, and consequently propose specific mitigating measures.

The expanse of the Brazilian coastline, which spans tropical and subtropical regions, has a variety of physiographic features, including coral reefs and mangrove forests, with a diversity of structures that is barely monitored in time scales. The diversity of characteristics in which reefs and mangrove forests develop requires medium and long-term monitoring at representative points along the Brazilian coastline.

In the case of coral reefs, despite privileged indicators of climatic changes, continuous measurements of the changes to diversity and mortality due to thermal stress remain very limited in Brazil. At the same time, the fact that mangrove forests ecosystems are extremely adaptable to the environmental variations where they are located requires even more observation time (decades) to differentiate responses considered to be normal in relation to those that would be manifested in response to new environmental conditions.

BRAZILIAN PALEOCLIMATIC INFORMATION

Paleoclimatic and paleogeographic records available in the literature show strong and abrupt oscillations in the temperature gradient between the high and middle latitudes of the North Atlantic Ocean and its equatorial part, which cause abrupt variations of pluviosity, both in the rainfall regime associated with the South American Monsoon System (SAMS) and in the area directly affected by the Intertropical Convergence Zone (ITCZ).

In the millennial time scale, strong and abrupt oscillations were observed in the meridional temperature gradient of the tropical Atlantic Ocean, as well as in the pluviosity associated with SMAS and ZCIT. [GT1 4.2] The analyses confirm that the changes in insolation to the Earth in orbital time scale (i.e., dozens of thousands of years) were the primary cause of modifications to precipitation and ecosystems of the tropical and subtropical regions of Brazil, primarily those regions influenced by SAMS.

High insolation values of summer into the Southern Hemisphere were associated with periods of strengthening of the SAMS and vice-versa. [GT1 4.2.3]

The causes of these abrupt climatic changes (those that occur on a large geographic scale) typically last for several hundred to a few thousand years, and occur in a time interval of decades or less, causing substantial ruptures in human societies and natural systems. [GT1 4.3.1] These appear to be caused by pronounced changes in the intensity of the Atlantic Meridional Overturning Circulation (AMOC). Periods of weakening of this circulation cell were associated with an increase in precipitation of tropical and subtropical regions in Brazil.

Paleoclimatic information on the last millennium in Brazil is extremely fragmented and sparse. In the tropical and subtropical regions of South America to the Equator, the Little Ice Age (approximately 1400 to 1700 AD) was characterized by an increase in precipitation, which is probably associated with a strengthening of the SAMS, possibly controlled by the reduction of the SST in the North Atlantic Ocean, and reduced intensification of the AMOC. [GT1 4.8.1]

Figure SEF.4. shows a selection of reconstitutions of precipitation for the Last Glacial Maximum (LGM) and precipitation differences between the simulations corresponding to the LGM and the present.[GT1 4.9.3] The majority of paleoclimate records selected show more arid conditions (orange circles) during the period. Yet some regions show more humid conditions (blue circles). Circles with both colors indicate differences in the interpretations of the data from paleoclimatic reconstructions. For each record a graph is also shown of the simulated seasonal precipitation cycle. The values were normalized by their standard deviation. The best correspondences between the two data sets is noted on points 11, 13, 14 and 15, indicating dryer conditions for the LGM in relation to the present, and on sites 3, 4, 7 and 12 showing more humid conditions during the LGM.

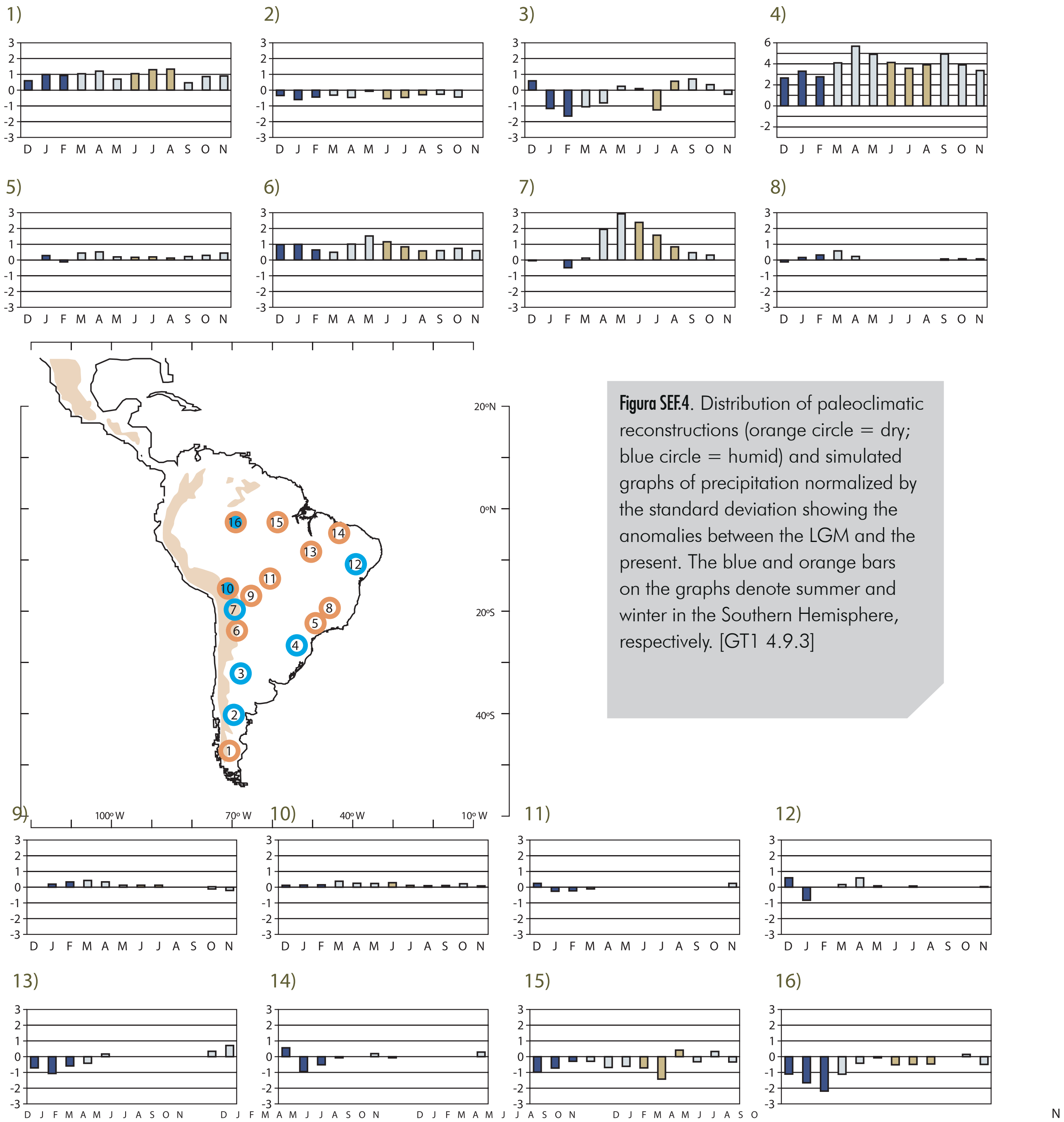


Figura SEF.4. Distribution of paleoclimatic reconstructions (orange circle = dry; blue circle = humid) and simulated graphs of precipitation normalized by the standard deviation showing the anomalies between the LGM and the present. The blue and orange bars on the graphs denote summer and winter in the Southern Hemisphere, respectively. [GT1 4.9.3]

Scientific Gaps in Brazilian Paleoclimatic Information

Knowledge about paleocirculation changes in the South Atlantic Ocean remains limited and fragmented. Extensive regions of the eastern continental margin of South America do not have any study with reliable minimum time resolution or age model. Further, the complete absence of studies that deal with abrupt changes from the last glaciation, and which treat the last interglacial, represent an important barrier in the sense of using past circulation scenarios of the western portion of the South Atlantic as analogues for future climate studies.

Studies of indicators of the relative sea level on the continental platform are equally scarce. There is a gap that needs to be filled so that when and how the relative sea level inundated the platform and advanced to the Holocene Climate Optimum (HCO) can be understood, along with periods of rapid elevation of the relative sea level typical of the last deglaciation. Note that there are also reef occurrences that may provide additional information about the behavior of the relative sea level.

Studies that have produced detailed curves of the behavior of the relative sea level on the northern continental shelf are inexistent and need to be developed. Further, the use of climate models and field data together represent an advance in the treatment of relative sea level variations that will permit the identification and quantification of local and regional factors with greater efficiency.

The climate mechanisms associated with the last millennium in Brazil are not consolidated, and the number of paleoclimatic and paleogeographic records available in tropical environments (and subtropical) is particularly limited. In order to fill in the existing gaps and improve our understanding in regard to multidecadal and secular natural climate variations, it is necessary to search for, collect, analyze and interpret new paleoenvironmental records.

BIOGEOCHEMICAL CYCLES AND CLIMATIC CHANGES

In Brazil, profound and variable changes to the climate are expected in different regions of the country [GT1 5.1], which will affect the country's aquatic and terrestrial ecosystems. The country has six biomes (Amazônia, Mata Atlântica, Pantanal, Caatinga, Cerrado and Pampa), which encompass some of the largest rivers in the world, including the Amazonas, Paraná and São Francisco, as well as an 8,000 km coastline that has at least seven large estuary zones and the entire continental shelf.

In terms of soil carbon and nitrogen stock, the largest stocks, up to one meter deep in the soil, were found in the Mata Atlântica, followed by Amazônia and the Cerrado biomes. It is important to emphasize that there is an exponential decrease of carbon and nitrogen concentrations in relation to soil depth.

In terms of ecosystems, those with the largest stocks of carbon and nitrogen above the soil are the Mata Atlântica and Amazônia biomes. In the latter, as well as in the Pantanal, carbon and nitrogen stocks are greater in the biomass above the soil, while in the rest of Brazil's territory, the largest stocks are concentrated in the soil.

It has been observed that the Amazônia biome is absorbing carbon from the atmosphere at a rate of 0.11 to 0.50 milligrams of carbon per hectare per year (Mg C ha-1 year-1). This carbon absorption is very significant, highlighting the important environmental service that the Amazônia rainforest performs by removing high levels of CO2 from the atmosphere.

The Cerrado is showing atmospheric CO2 absorption at a rate of 0.1 to 0.3 Mg C ha-1 year-1. Also observed is the better quantification of above-ground biomass stock for all of the Brazilian biomes, particularly for Amazônia, with carbon stocks that vary from 95 to 250 Mg C ha-1.

Significant work was also done to quantify the carbon stored in the soil in all of the Brazilian biomes, with the high values observed in the Mata Atlântica standing out, with values from 190 to 280 Mg C ha-1. [GT1 5.4]

The transfer of nitrogen is significantly greater in the Amazônia and Mata Atlântica forest systems than in the woody-herbaceous systems such as the Cerrado and Caatinga. Despite large differences in soil carbon stocks, the variations of flows of CO_2 to the atmosphere (when carbon is fixed through photosynthesis it returns to the atmosphere) were not elevated among the biomes, principally if we exclude Amazônia, where flows of CO_2 were clearly greater.

The flow of N_2O from the soil to the atmosphere is also considered a loss of nitrogen from the system. In this case, the differences are more accentuated between the biomes, with the Amazônia rainforest having the greatest flows, followed by the Mata Atlântica, while very low flows were detected for the Cerrado.

In terms of biological nitrogen fixation (BNF), the largest entries are associated with the Amazônia and Mata Atlântica forests systems, followed by the Cerrado, and finally the Pantanal and Caatinga, which have an annually-fixed quantity of nitrogen that is significantly less than the three biomes cited above. In regard to atmospheric deposition of nitrogen, the values were similar among the biomes, in the majority of cases below the values that enter via BNF, and slightly more elevated in relation to the flows of N_2O to the atmosphere.

Nitrogen stocks in the soil and biomass were quantified for most of the Brazilian biomes. A low quantity of the first was observed in the soils of the Amazon rainforest region: about 1 milligram of nitrogen per hectare (Mg N ha-1). As for the Mata Atlântica biome, studies show a level of between 14 and 20 Mg N ha-1.

It has still not been possible to determine the BNF values for all of the Brazilian ecosystems, where it has been detected that the Pantanal and Caatinga values vary from 2.6 to 11 kilograms of nitrogen per hectare per year (Kg N ha-1year-1).

The most critical projection for the Amazônia biome is the possible savannization of the forest (also known as Amazon forest dieback), which would cause significant losses of carbon stocks in the soil and vegetation. According to the HadCM3 model of the Hadley Center, in this scenario, eastern Amazônia would be replaced by savannah-like vegetation. [GT1 5.5.1]

Yet other researchers, using a larger compilation of global climate models, disagree with the theory of savannization of the Amazon rainforest, and present simulations that do not reproduce the environmental conditions or forests response so that this process is established.
In the event that the process of savannization does occur in part of the Amazon rainforest, such changes would be reflected not only in the carbon cycle, but also in the cycle of nitrogen and regional climate.

The Mata Atlântica biome stores significant quantities of carbon and nitrogen in its soils, primarily at higher altitudes. The air temperature increases predicted for the southeast of Brazil would cause an increase of processes of respiration and decomposition, generating an increased loss of carbon and nitrogen into the atmosphere.

Similar to the Mata Atlântica, the soils in the southern grasslands of the Pampa biome retain a significant stock of carbon. Therefore, the air temperature increases predicted for the future would increase CO_2 emissions into the atmosphere from this region.

The primary productivity of the Cerrado may be reduced as a result of the climate changes projected for this biome. The increased air temperature will probably result in a reduction of photosynthesis by plants of the Cerrado, implying a possible decrease of its biomass. Additionally, during the dry season, due to water stress, this vegetation type becomes a source of carbon for the atmosphere.

Therefore, an increase in the duration of this period would imply a reduction of the primary productivity of the Cerrado, and a potential rise of its vulnerability to fire. The mounting of fire occurrences would result in lesser stocks of biomass and nutrients through deep runoff, erosion, transport of particles and volatilization. [GT1 5.5.3]

In addition to an increase in the number of dry days and air temperature, projections for the Caatinga biome show a reduction in total rainfall and increased variability of precipitation patterns.

The Caatinga is a biome expected to undergo increased alteration of its precipitation regime, with a significant reduction of rain, which may result in profound changes to the functioning of this ecosystem. The occurrence of more intense and frequent droughts is one possible consequence of these changes to the climate. [GT1 5.5.4] Note that this ecosystem already suffers from pronounced water stress and has low rates of carbon stocks, which may be further reduced with the intensification of dry weather. [GT1 5.5.4]

Scientific Gaps in Knowledge of Biogeochemical Cycles

Short and long-term observations of the processes that regulate the stocks and flows that govern the functioning of Brazilian ecosystems are lacking. This is particularly critical for the Pampa, Pantanal and Caatinga biomes. However, a larger volume of information can be found on Amazônia and the Cerrado. It is only recently that studies have been developed on the Mata Atlântica, but still, these are concentrated on a few small areas.

Carbon and nitrogen stocks are very sensitive to climate changes, and the mechanisms of water stress and increased air temperature are not well known for any of the Brazilian biomes. The possible biological compensation mechanisms still need to be better studied for all of them.

There is still insufficient information on the impacts of climatic changes on the functioning of the southern grasslands, or Pampa, which store considerable carbon stocks in their soils. The low temperatures contribute to the accumulation of organic material in the soil; thus, an increase of air temperatures as predicted would lead to an increase of decomposition rates, thereby increasing emissions of CO2 into the atmosphere. Similar to the Mata Atlântica, it is still not possible to predict if this increase in emissions would be compensated by an increase in the ecosystem's liquid primary productivity.

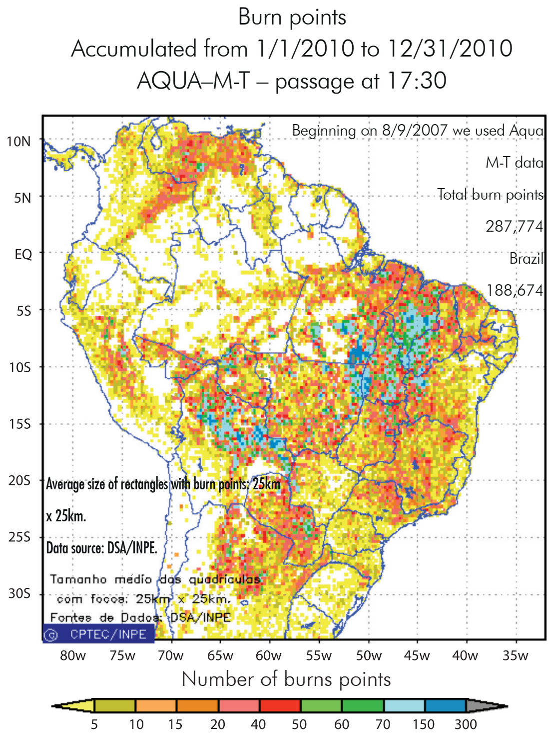
ATMOSPHERIC AEROSOLS AND CLOUDS

Through various studies carried out in Brazil, it was observed that particles of atmospheric aerosols have strong effects on the balance of atmospheric radiation and mechanisms of cloud formation and development.

The majority of Brazilian studies on atmospheric aerosols and clouds were performed in the Amazônia rainforest, on the effect of emissions from forest burning on the radiative balance and mechanisms of cloud formation and development.

As can be observed in Figure SEF.5 below, it was observed in 2010 that forest burning emits enormous quantities of particles into the atmosphere. To the left is shown the total number of burn points, and to the right is the spatial distribution of the aerosols' optical depth (AOD, wavelength = 550 nanometers), obtained by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor.

A strong association between burn points and distribution of aerosols is observed, not only in the Amazônia biome but throughout the Brazilian territory. The aerosol optical thickness observed is extremely high, and at these levels the aerosols have strong effects on precipitation health and the photosynthetic rates of carbon fixation by vegetation. [GT1 6.3.1]



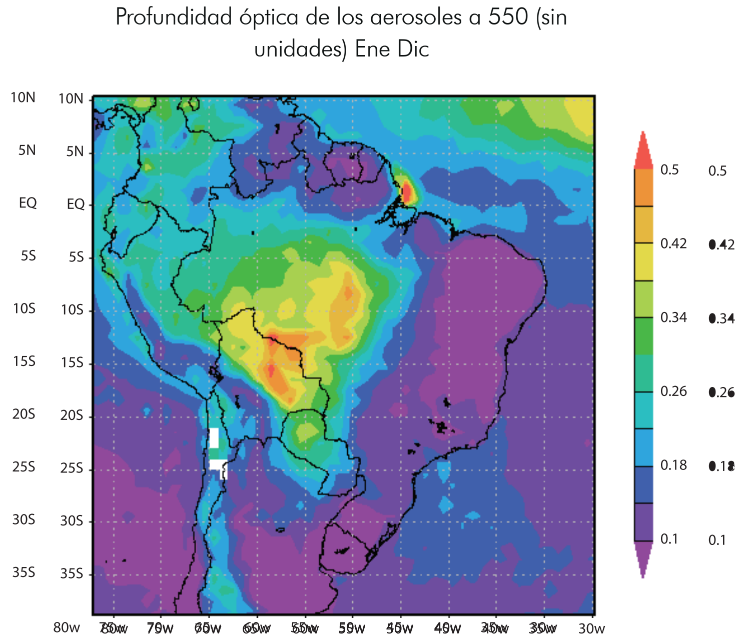


Figure SEF.5. Above (left), number of burn points in 2010. [GT1 6.3.1]

Various studies have been carried out in the Amazon region to quantify the emission factors of aerosol particles from forest burning. However, there is still no complete, formal national inventory of particle emissions from burnings and industrial or natural sources.

One important highlight in Brazil is the large quantity of studies that have been done to analyze the role of aerosols on the formation and development of clouds in Amazônia and other biomes. These scientific studies permit the careful analysis of the role of aerosols on cloud formation and development.

It is more difficult to quantify the role of aerosols on the rate of precipitation, as this question is still open not only in Brazil, but worldwide. Contradictory results were observed in the literature (increase or reduction in precipitation) due to the increase in the quantity of aerosols from burnings. This may be a consequence of the various atmospheric thermodynamic conditions of the different experiments. The balance between atmospheric thermodynamic effects and the role of aerosols remains an open question in the national and international scientific literature.

Urban regions are responsible for a significant contribution of emissions of particulate matter, primarily from automobiles. Although not the majority of total emissions, aerosol particles from urban emissions play an important role in the urban climate and public health of Brazilian cities. [GT1 6.3.1]

Table SET.1 below, synthesizes the information regarding concentrations of aerosols in some Brazilian locations. We observe that the metropolitan region of the city of São Paulo has a high concentration of fine particulate matter, higher than the current standard of air quality of particulate matter (PM) 2.5, and also higher than the standard recommended by the World Health Organization (WHO) of an annual average concentration of 10 micrograms per cubic meter air ($\mu g/m^3$). The recommendation is exceeded in various Brazilian cities.

Table SET.1. Average concentration in μg/m3 of fine and black carbon inhalable particulate matter in six Brazilian capital cities from 2007 to 2008, and in areas subject to burnings with relative contribution of black carbon of PM2.5 = fine inhalable particles less than 2.5 μg (micrograms).

	PM10	PM2.5B	C%	BC
SÃO PAULO	34[+]	28±14[b]	11±6	38±14
RIO DE JANEIRO	-	17±11[b]	3,4±2,5	20±7
BELO HORIZONTE	-	15±8[b]	4,5±3,33	1±13
CURITIBA	-	14±10[b]	4±4	30±11
PORTO ALEGRE	-	13±10[b]	5±4	26±11
RECIFE	-	7±3[b]	1,9±1,1	26±12
RONDÔNIA[c] (estação seca)	83±64	67±557	±6	11±2
ALTA FLORESTA[d] (estação seca)	37±25*	63±55	8±6	

[+]CETESB (2011); ref. ano 2009, [2]Andrade *et al.* (2012), [c]Artaxo *et al.* (2002) [d]Maenhaut *et al.* (2002)
*inclui apenas moda grossa. [GT1 6.3.1]

Across the board, in urban regions and rural areas with burning, there is a significant increase of fine particulate matter. Additionally, fine particles have a longer tropospheric residence time, which makes their transport from their source over long distances efficient. For example, the smoke from biomass burning in the Amazon rainforest reaches significant portions of South America, having a large effect on direct and indirect radiative forcing. [GT1 7]

Additionally, because a significant portion of the particulate matter occurs in the form of black carbon, when suspended this smoke has the capacity to heat middle levels of the troposphere, generating atmospheric stability and inhibition of deep convection.

In 2002 in the Rio Amazonas basin, the project Large-Scale Biosphere Atmosphere Experiment in Amazônia – Smoke Aerosols, Clouds, Rainfall, and Climate (LBA/SMOCC) [GT1 6.3.3], took measurements in a pasture region of the Brazilian state of Rondônia, which covered aperiod of intense burning activity (September), transition (October) and the beginning of the rainy season (November). An increase of particles from 450 in the rainy season to 5,260 in the dry season was observed, due to the strong emissions from burnings in Rondônia. [GT1 6.3.3]

It was also observed that this large number of particles occurs primarily starting at 50 nanometers (nm) in diameter, a size range in which the aerosol particle already has significant capacity to work as cloud condensation nuclei (CCN).

A large increase in CCN concentration in the Amazon rainforest as a consequence of emissions from forest burning was also observed. Comparison between polluted and clean days shows a concentration of CCN at least, five times greater for the polluted days. Average values of concentrations less than 200 cm-3 for the clean regions, and greater than 1200 cm-3 for the polluted regions, were recorded.
Similarly, studies showed that fine particles, the range in which CCN predominate, are predominately composed of secondary organic material formed by oxidation of biogenic precursors, while large particles, important for ice nucleation, consist of biological material emitted directly by the forest. [GT1 6.3.3]

Various studies on the effects of aerosols on cloud formation and development work with the hypothesis that if the indirect effects (and also semi-direct) manifest in polluted conditions as a consequence of the reduction of collision and coalescence processes, or increase in stability, there should be a reduction in stratiform precipitation in comparison to cleaner conditions in the same environment.

Yet when samples without rain, with rain and with intense rain (>5 mm h-3) were compared, these studies concluded that large-scale atmospheric conditions are more important for the development of precipitation than concentration of aerosols. The results of studies of electrification in the Amazon region suggest that the absence of distinction between the electrical parameters of the polluted and clean regimes in Amazonas river basin, places in doubt the role of aerosols in the intensification of electrification of clouds, and reinforces the idea that the dynamic of large-scale atmospheric conditions is extremely influential. [GT1 6.4]

Specifically in regard to aerosols in Brazil and South America, regional modeling (RegCM3 and BRAMS) has shown the potential impacts of aerosols from biomass burning on large scale atmospheric circulation, with modifications on the behavior of the South American monsoon due to the increase of thermodynamic stability in the southern Amazônia biome. These authors propose that increases in the stability and pressure on the surface, along with divergent outflow in this region, may reinforce cyclone activity and increase precipitation in the southeast of Brazil, Paraguay and the northeast of Argentina.

It was observed that the transport of dust from the Sahara has an impact on the concentration of ice nuclei in the central Amazon region, contributing to the formation and development of convective clouds in its entire area. [GT1 6.2]

Gaps in the Question of Aerosols and Clouds

Generally speaking, it is necessary to increase our knowledge of processes of production and transport of aerosols on the South American continent, including natural and anthropic local and remote sources. It is also fundamental to improve our understanding of the influence of aerosols on cloud formation, when they serve as CCN and ice nuclei (IN), including the role of their spatial and temporal variability.

Our understanding is also limited in regard to the microphysical properties of clouds over the South American continent, including observations of hot clouds and mixed-phase clouds already carried out over the Brazilian territory, and possible implications for radiative properties and the water cycle. Attribution of the effects of aerosols and thermodynamic changes from the atmosphere on the mechanisms of cloud formation and development is important, as well as representation of these in numeric models of general and limited-area circulation.

In urban areas of Brazil, there are no studies that report measurements of the concentration of numbers of nanoparticles. It is important that this type of measurement is done so that it is possible to better study the effects of particles on the health of the population, as well as the influence of nanoparticles from urban emissions on cloud microphysics.

NATURAL AND ANTHROPIC RADIATIVE FORCING

It is important to know the quantitative contribution of each climate agent to surface temperature variations in Brazil. However, more modern and sophisticated climate models still need to be developed in order to provide consistent results for climate change predictions: there are still great divergences between predictions of temperature, cloud cover, precipitation, etc., developed with different models, not only for Brazil but for the entire planet. The concept of radiative forcing, defined in Panel SEP.1, is an intermediate step that in principle does not need climate models for calculation, and thus the values of radiative forcing may be interpreted more objectively.

Panel SEP.1 –Definition of radiative forcing

Radiative forcing due to a climate agent is defined as the difference in liquid irradiance in the tropopause, between a reference state and a perturbed state due to the climate agent. The temperatures of the surface and of the troposphere remain fixed, but the stratosphere attains radiative balance. The reference state can be the absence of the climate agent, or its impact in a given situation or time, for example, the beginning of the Industrial Revolution (approximately 1750) adopted by the IPCC (Forster et al., 2007).

In scales of dozens to hundreds of years, the most significant climatic effects in Brazil are the radiative effects from clouds, radiative forcing from greenhouse gases, and anthropic forcing from land use changes and aerosols (smoke) from anthropic burning. Table SET.2 presents a compilation of results found in the scientific literature on the principal radiative effects of climatic agents in Brazil.]

The compiled results show that clouds constitute the most important climatic agent in terms of radiation balance over the Amazônia biome, reducing radiative flow on the surface by up to 110 Wm 2, and contributing to radiative forcing by about -9.8 Wm 2 on top of the atmosphere. This means that under current conditions, the clouds in this Amazônia region play an important role in cooling its climate system.

Various studies have quantified the forcing from anthropic aerosols in the Amazon region. One average weighed by some of the results compiled in this chapter resulted in an average radiative forcing of -8.0±0.5 Wm 2, indicating that the smoke emitted by burnings contributes to cooling the planet, contradicting the theory that heating is caused by anthropic greenhouse gases. However, it is very important to emphasize that aerosols and greenhouse gases have very different scales of time and space. While aerosol particles remain in the lower atmosphere for an average of some days to weeks, greenhouse gases remain from dozens to thousands of years.

Table SET.2 presents a compilation of results of measurements of radiative forcing in various Brazilian regions, for diverse conditions. We observe a strong change in the radiative balance observed or modeled, with average daily values of cooling on the surface up to -110 watts per square meter (w/m^2), while on top of the atmosphere, values of -10 to -20 w/m^2 were reported.

The atmospheric column, due to the effect of black carbon emitted by burning, may represent warming values from +30 a +40 w/m^2. This strong overall warming on the outer planetary layer alters the normal vertical temperature profile, inhibiting convection, a process critical to the formation and development of clouds.

Table SET.2 Quantification of radiative forcing from anthropic aerosol from land use changes, and from the radiative effect of clouds over Brazil and South America.

Agente	Região	Condição[a]	Valor[b] (Wm^{-2})	Fonte dados
Nuvens	Amazônia	SUP, 24h[c]	[-110; -50]	Modelo climático, satélite
		SUP, 24h[c]	-76	Modelo climático
		TDA, 24h[c]	+26	
Uso do SoloA	mazônia	TDA	-23,7±2,9	Satélite, modelo radiativo
		TDA, 24h-	7,1±0,9	
Aerossol antrópico: Efeitos Diretos	Amazônia	SUP, 24h[d]	-39,5±4,2	Sens. remoto, modelo radiativo
		ATM, 24h[d]	+31,2±3,6	
		TDA, 24h[d]	-8,3±0,6	
	Amazônia	TDA, 24h[c]	-16,5	Modelo climático, medidas *in-situ*
	Atlântico tropical	TDA, 24h[e]	-1,8	Satélite, modelo radiativo
		ATM, 24h[e]	+2,9	
	América do Sul	TDA, 24h[	-8; -1]	Modelo climático, satélite
		SUP, 24h[	-35; -10]	
	América do SulT	DA, anual[	-1,0; -0,2]	Satélite
	Amazônia	TDA-	13,0±3,9	Satélite, modelo radiativo
		TDA, 24h-	7,6±1,9	
	Amazônia	TDA, 24h	-5,6±1,7	Satélite, modelo radiativo
	Floresta		-6,2±1,9	
	Cerrado-		4,6±1,6	
Aerossol antrópico: Efeitos Indiretos	Hemisfério Sul	TDA, 24h[c], alb	-0,70±0,45	Revisão da literatura
	Global, sobre continentes	TDA, 24h[c], ind	-1,9±1,3	
	Atlântico tropical	TDA, 24h[e], alb	-1,5	Satélite, modelo radiativo
		TDA, 24h[e], ind	-9,5	
	América do SulT	DA, 24h, ind[	-5; +20]	Modelo climático, satélite
	América do Sul	TDA, anual, alb	[-0,10; -0,02]	Satélite
	Atlântico tropical		[-5,00; -0,05]	
Total aerossóis e nuvens	Amazônia	TDA, 24h[c]	-9,8	Modelo climático, medidas *in-situ*
	Atlântico tropical	TDA, 24h[e]	-11,3	Satélite, modelo radiativo
		SUP, 24h[e]	-8,4	
	América do Sul	TDA, 24h[	-10; +15]	Modelo climático, satélite
		SUP, 24h[	-35; -5]	

a) Indicates the vertical position in the atmospheric column (TDA: top of the atmosphere; SUP: surface; ATM: atmospheric column) for the estimate in question, the time domain calculation (instantaneous value, 24 hour average or annual average), and behavior of the indirect effect analyzed (alb: albedo; ind: total indirect effects); b) Values in brackets indicate minimum and maximum intervals presented in the references. When available, the uncertainties presented by the authors are indicated; c) Presumed time domain (not informed explicitly in the reference); d) State of reference with 0.11 optical depth of aerosols; e) State of reference with 0.06 optical depth of aerosols.

Land use changes in different regions of Brazil change the surface albedo, causing radiative forcing from the alteration of reflectivity of the surface compared to the natural surface. Analysis of alteration of the albedo due to deforestation in the Amazon rainforest is estimated at -7.3±0.9 Wm 2, a high value if compared with warming from greenhouse gases (approximately 2 Wm 2), which shows that changing an area from forest to pasture or agricultural field results in a large change to the atmospheric radiative balance. Note that this value is similar to the forcing from anthropic aerosols; however, it is important to emphasize that deforestation in Amazônia biome is virtually permanent in that the majority of degraded areas do not return to become virgin forests, while aerosols from burning have an average lifespan of days.

Gaps Identified on the Topic of Natural and Anthropic Radiative Forcing

Most of the regional studies carried out in Brazil have been focused on the Amazônia biome. Studies on the other Brazilian biomes are necessary for an understanding of the complex interactions between the balance of atmospheric radiation and increased concentration of greenhouse gases and aerosols, as well as the effect of the surface albedo change. Large-scale modeling studies also need to be performed, with dynamic chemical models coupled with codes of radiative transfer for large-scale studies.

EVALUATION OF GLOBAL AND REGIONAL CLIMATE MODELS

Global and regional climate modeling has made great advances in recent years, in terms of representation of processes and phenomena critical for the study of climate change. Brazil has stood out in this area through the development of regional and global atmospheric, atmospheric and ocean-atmosphere models. Patterns of seasonal and interannual variability of the El Niño Southern Oscillation (ENSO) are well simulated by the Instituto Nacional de Pesquisas Espaciais/Centro de Previsão de Tempo e Estudos Climáticos (INPE/CPTEC)'s Modelo de Circulação Geral da Atmosfera (MCGA). This is a model of general circulation of the atmosphere built by a joint effort of Brazil's National Institute of Space Research and the Center for Weather Forecasting and Climate Studies.

In this case, it reproduces the pattern observed of precipitation anomalies over South America associated with ENSO, with excess precipitation in southern Brazil and a deficit in the northeast, since the success rate of the results depends on the type of ENSO. [GT1 3.6.3]

When the ENSO signal is strong, that is, when the SST anomalies are intense in the equatorial Pacific Ocean, the precipitation anomalies simulated for southern Brazil correspond more closely to the observations. [GT1 8.4.1]

The displacement of the Intertropical Convergence Zone (ITCZ) observed over the Atlantic Ocean is generally well reproduced by Brazilian models. However, there is a deficiency in the correct representation of its seasonal migration. Yet the most recent advances implemented in the Modelo Brasileiro do Sistema Climático Global (MBSCG, the acronym of the Brazilian Earth system model), resulted in a substantial improvement in the representation of atmospheric convection and precipitation over the Amazônia biome and the tropical Atlantic Ocean, with notable impact on the reproduction of the seasonal migration of the ITCZ. [GT1 8.4.2]

The pattern of the South Atlantic Convergence Zone (SACZ), one of the primary components of the South American Monsoon System is also well-represented numerically in the scale of interannual and interseasonal time. [GT1 8.4.2] The atmospheric characteristics associated with the SACZ, in extreme cases of precipitation in the southeast, obtained in observational analyses, are equally reproduced in the analyses of extreme cases, performed based on the numerical results. [GT1 8.4.4]

Generally speaking, the present climate in parts of South America such as the entire Amazon biome, the northeast and southern regions of Brazil, the northwest of Peru and Ecuador, as well as southern Chile, is better reproduced than that of the southeast and center-west of Brazil's territory.

Assuming that the capacity to simulate the climate in the future is the same as in the present, we can give greater credibility to climate projections for the future in the areas with fewer errors. [GT1 8.6]

Uncertainties in the Simulations of the Global and Regional Models

The uncertainty in the formulations of numerical models to represent the climate system is reflected in the magnitude of systematic errors in the simulations. This evaluation of the errors, in turn, also contains uncertainties arising from the quality of the observations, with the network over South America being deficient from a spatial and temporal point of view. Uncertainties about the observational measures directly affect the robustness of the evaluation of the climate models.

In specific terms, knowledge about the efficiency of global and regional climate models in correctly reproducing seasonal precipitation patterns and the various systems important to the climate of South America and Brazil, such as the SACZ and ITCZ, among others, depends on the expansion and maintenance of observational systems that permit the obtaining of quality continuous meteorological and climatological data sets.

SHORT AND LONG-TERM ENVIRONMENTAL CHANGES: PROJECTIONS, REVERSIBILITY AND ATTRIBUTION

The results of the regional climate projections in the different biomes of Brazil for the beginning (2011 to 2040), middle (2041 to 2070) and end (2071 – 2100) of the 21st century are summarized in Figure SEF.6. [GT1 9] The percentage changes in rain and temperature (°C) are relative to the values of the current climate (end of the 20th century). Figure SEF.6 shows projections of changes in rain and temperature for the summer (December to February – DJF) and winter (June to August – JJA).

Depending on the future global scenario, with low or high greenhouse gas emissions (GGEs), such values may oscillate between ~5% and ~20% in precipitation and ~1°C and ~5°C in temperature. The projections indicate a significant reduction of rain in a large part of the center, north and northeast of the Brazilian territory. [GT1 9] The future climate scenarios suggest an increase in extreme droughts, primarily in the Amazônia, Cerrado and Caatinga biomes, with these changes increasing in the middle and end of the 21st century.

In regard to air surface temperature, all of the projections indicate warmer future climate conditions. [GT1 9]

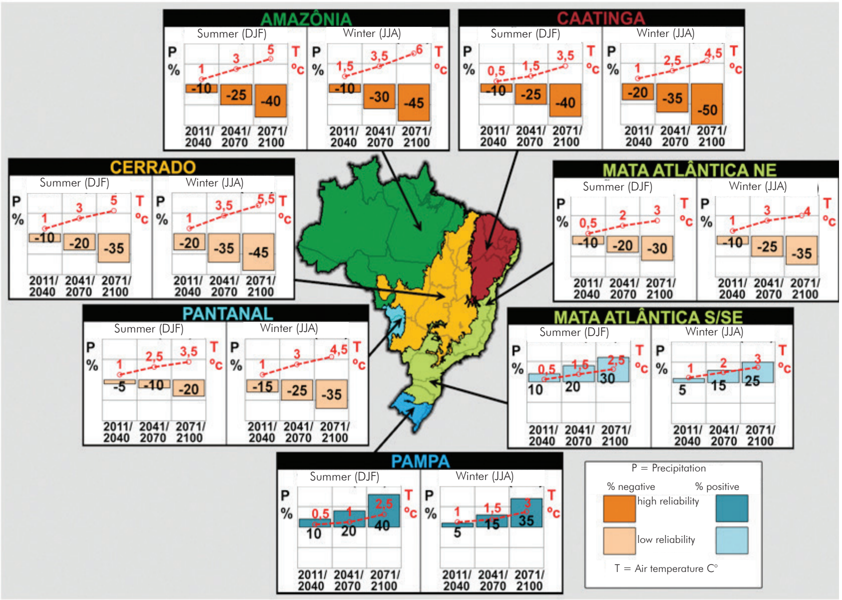


Figure SEF. 6. Regional climate projections in the Brazilian Amazônia, Cerrado, Caatinga, Pantanal, Mata Atlântica (northeast and south/southeast sections) and Pampa biomes, for the beginning (2011 to 2040), middle (2041 to 2070) and end (2071 - 2100) of the 21st century, based on the scientific results of global and regional climate modeling. The regions with different colors on the map indicate the geographic domain of the biomes. The keys are found at the bottom right corner. [GT1 9]

Generally speaking, the climate projections perform relatively better in the north and northeast (Amazônia and Caatinga) and south (Pampa) of Brazil, and worse in the center-west and southeast (Cerrado, Pantanal and Mata Atlântica). As Figure SEF.6. illustrates, based on global and regional scientific climate modeling, **the projections for the Brazilian biomes are as follows below:**

AMAZÔNIA: A reduction of 10% in rainfall distribution and a temperature increase of between 1° and 1.5°C by 2040, then maintaining the trend of rainfall decrease from 25% to 30%, and temperature heating up by between 3° and 3.5°C in the period from 2041-2070. It is also forecast that there will be 40% to 45% less rainfall volume and a temperature rise of 5° to 6°C of by the end of the century (2071 to 2100). While climate changes associated with global changes may compromise the biome in the long-term (end of the century), the current question of deforestation resulting from intense land-use activities represents a more immediate threat to the region. Observational and numeric modeling studies suggest that if 40% of the rainforest is deforested in the future, a drastic change in the water cycle will occur, with a reduction of 40% in rainfall during the months from July to November, and prolonged drought in the dry season, in addition to surface temperature warming by up to 4°C. Thus, regional changes resulting from deforestation, combined with global changes, constitute propitious conditions for the savannization of the Amazon rainforest, a problem that tends to be more critical in its eastern zone.

CAATINGA: Air temperature is forecast to heat up between 0.5° to 1°C and precipitation is estimated to decrease between 10% and 20% during the next three decades (by 2040). For the period from 2041 to 2070, a gradual rise in the temperature of 1.5° to 2.5°C, and a reduction of between 25% and 35% in rainfall patterns has been calculated. At the end of the century (2071 to 2100), projections indicate significantly hotter conditions (increase in temperature between 3.5° and 4.5°C) and aggravation of the regional water deficit, with a reduction by practically half (40 to 50%) of rainfall distribution. These changes may unleash the process of desertification of the Caatinga.

CERRADO: Forecasts indicate a surface temperature increase of 1°C and a rainfall percentage reduction between 10% and 20% during three decades, i.e., until 2040. An increase in air temperature from 3° to 3.5°C is expected for the middle of the century (2041 to 2070), along with a reduction of 20% to 35% in rainfall. At the end of the century (2071 to 2100), the air temperature increase will reach values between 5° and 5.5°C, along with a more critical reduction in rainfall of between 35% and 45%. Seasonal variations are expected to become more pronounced.

MATA ATLÂNTICA: Because this biome spans areas from the south and southeast of Brazil to the northeast of the country, the projections point to two distinct regimes.

Northeast section: Relatively low temperature increase of between 0.5° and 1°C, with a decrease in precipitation level of 10% by 2040, maintaining the warming trend of between 2° and 3°C, with rainfall reduction between 20% and 25% by the middle of the century (2041 to 2070). Up to the end of the century, conditions of intense heat (increase of 3° to 4°C) are predicted, along with a drop in rainfall volumes of 30% to 35%.

South/southeast section: Projections predict a relatively modest temperature increase of between 0.5° and 1°C by 2040, with an increase of 5% to 10% in rainfall volumes. In the middle of the century (2041 to 2070), these trends are predicted to be maintained, with a gradual rise in temperature of between 1.5°C and 2°C, and 15% to 20% higher rainfall levels. Towards the end of the century (2071 to 2100), the same trends become more pronounced, with the temperature increasing by between 2.5°C and 3°C, and rainfall by 25% to 30%.

PANTANAL: The estimates are of an increase of 1°C in temperature and a reduction of between 5% and 15% in rainfall patterns by 2040. This trend will be maintained until 2070, with rainfall decreasing to values between 10% and 25%, and temperature heating up by 2.5° to 3°C. Up to 2100, conditions of intense heat will predominate (a warming of between 3.5 and 4.5°C), with a heightened reduction in rainfall patterns of 35% to 45%.

PAMPA: In the period until 2040, regional climate conditions will prevail, with 5% to 10% more rain and up to a 1°C temperature increase, with this trend being maintained between 1° and 1.5°C, along with intensification of rains by between 15% and 20%, until the middle of the century (2041 to 2070). At the end of the century (2071 to 2100), the projections are more severe, with a temperature increase of 2.5° to 3°C, and rainfall levels rising by 35% to 40%.

Uncertainties

Scientific uncertainties about climate change projections are inherent to the climate system, a result of the non-linear and complex interactions intrinsic to natural phenomena. Thus, multiple approaches involving modeling and observations are necessary to minimize uncertainties, and should be employed together.

Although the last decade has seen substantial improvements in earth system science (with more complete formulations of physical, chemical and biological processes, including their complex interactions, within the models of the global climate system), combined with a significant technological advance in computational simulation, the climate and environmental projections generated by climate modeling have various levels of uncertainties, including the following mentioned below.

i) Uncertainty of emissions scenarios

Global emissions of greenhouse gases are difficult to predict, due to the complexity of socioeconomic factors, such as demography, composition of energy sources, land use activities and the global course of human development;

ii) Uncertainty of the natural variability of the climate system

The physical and chemical processes of the global atmosphere are chaotic by nature, and the climate is sensitive to minimal changes (non-linear variations) that are difficult to measure through observational data and results from modeling;

iii) Uncertainties of the models

The capacity to model the global climate system is a big challenge for the scientific community, with limiting factors being the still incomplete representation of processes such as the global and regional carbon balance, the role of aerosols in the global energy balance, and the representation of biogeochemical cycles and anthropic factors such as deforestation and burning (clouds are also important sources of uncertainty in the climate models) [GT1 6]. On the other hand, although the same emissions scenarios are used, different models produce different climate change projections, thus constituting another source of uncertainty, which may be minimized through the application of sets of global and regional simulation models (ensembles) [GT1 8].

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