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Brazil and climate change: vulnerability, impacts and adaptation

Centro de Gestão e Estudos Estratégicos
Ciência, Tecnologia e Inovação

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Summary

Preface

This book reports studies carried out by the Center for Strategic Studies and Management (CGEE) since 2004. The first results were published in the Cadernos NAE nº 3, Mudança do Clima Vol. I, in 2005. During 2008, the initial outcomes, that identified some of the possible impacts caused by climate change in Brazil, was updated and expanded, in order to map and analyze the most significant vulnerabilities, to survey possible risks and impacts arising, and to give preliminary recommendations for the conception and adoption of adaptation measures to face climate change. These more extensive finds were published as a collection of articles in the CGEE Journal Parcerias Estratégicas nº 27, Mudança do Clima no Brasil: vulnerabilidade, impactos e adaptação, December 2008. The articles were submitted by the authors and discussed by a select group of representatives from public and private bodies in a workshop, before being finalized for publication in the Journal.

To write the articles, ten renowned Brazilian specialists were invited to address a specific theme, in some cases leading a team of experts:

- Carlos Nobre: Climate change scenarios for the end of the 21st century in South America;
- Thelma Krug: Forests;
- Magda de Lima: Agriculture and agricultural land;
- Vanderlei Canhos: Biodiversity;
- José Marengo: Semi-arid regions;
- Marcos Freitas: Water resources and energy;
- Claudio Neves and Dieter Muehe: Coastal zones;
- Wagner Ribeiro: Urban zones;
- Ulisses Confalonieri: Human health.

Afterward, during 2009, CGEE organized five regional workshops, with an attendance of 100 participants (see Annex), in order to undertake the formulation of recommendations for initiatives in science, technology and innovation (ST&I) within each theme, to tackle the subject of vulnerability, impacts and adaptation (VIA) related to climate change. Each meeting dealt with the following topics:

- Water resources and energy (COPPE, Rio de Janeiro – 17th March);
- Coastal zones, urban zones and human health (IEA/USP, Sao Paulo – 14th April);

- Agriculture and agricultural land (CGEE, Brasilia – 5th May)
- Forests and biodiversity (CGEE, Brasilia – 21st May)
- Semiarid regions (CETENE, Recife – 16th June).

Based on the finds of the workshops, structured in matrices, on the articles written by the specialists, on the National Plan on Climate Change and other related documents, it was formulated a comprehensive outline of recommendations, offering information able to assist the definition of a National Agenda for ST&I related to VIA, taking in account the opportunities and challenges gathered by global climate change in sectors that are strategic for Brazil's economic and social development.

These activities were developed by CGEE in the framework of a Management Contract under the supervision of the Ministry of Science and Technology (MCT).

Finally I would like to provide special thanks to Marcelo Poppe for coordinating the studies and to his team of specialists, Jörgen Leeuwestein, Antônio Magalhães, Ana Carolina Perico and Mayra Juruá, who worked extremely hard to ensure that the CGEE achieved its aim successfully.

Lucia Carvalho Pinto de Melo
President of CGEE

Introduction

According to the 4th report by the Intergovernmental Panel on Climate Change (IPCC) "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and oceans temperatures, widespread melting of snow and ice and rising global average sea level". The Panel's systematic analyses indicate that the increasing average global temperature of the planet will be even greater in the future and demonstrate that this warming is caused by the accumulated anthropogenic emissions of greenhouse gases (GHG), mainly carbon dioxide (CO_2), from burning of fossil fuels, and methane (CH_4) and nitrous oxide (N_2O), generally derived from agricultural activities. So an increase in average global temperatures between 2 and 4.5°C is expected by the end of the century.

The subject of climate change is already part of international economic and political reality with repercussion in various fields of knowledge, and demanding scientific and technological developments and the adoption of innovations. The risks associated with the growth of climate vulnerability bring about increased commitments and corporate responsibilities with mitigation measures and adjustment of production processes and consumption patterns. The question of adaptation to climate change has become increasingly important in negotiations of the Climate Convention. Accordingly, the IPCC report indicate that the Non-Annex 1 countries (developing countries) may have more difficulty in coping with these impacts and addressing the rising costs of adaptation to climate change.

Even though Brazil is not among the most vulnerable group of countries in the world, global climate change can manifest itself in the country in several areas: increased frequency and intensity of floods and droughts; agricultural losses and threats to biodiversity; changes in hydrological regimes with impacts on the hydropower capacity; increase of endemic diseases carrier, amongst other consequences. Furthermore, the increase in sea levels could affect Brazilian coastal regions, especially the seaboard cities.

Brazil has already adopted many fresh initiatives assembling expertise in the matter of climate change: under the responsibility of the Ministry of Science and Technology (MCT), the launching of the Brazilian Network on Global Climate Change (RedeClima), the foundation of the National Institute for Climate Change Science and Technology (INCT - MC), and the creation of the Center of Earth Systems Science (CCST), inside the National Institute for Spatial Research (INPE); and under the responsibility of the Ministry of Environment (MMA), the statement of the National Plan on Climate Change (PNMC) at the end 2008, and the establishment of the Brazilian Panel on Climate Change, together with the MCT. These new initiatives came up to enhance the previous institutional apparatus bodies in charge of this subject, like the Inter-ministerial Commission on Global Climate Change (CIMGC), acting also as Designed National Authority (DNA), and the National (FBMC), States and Cities Climate Change Forums, with a motivation and mobilization character.

To carry knowledge on this subject to a level consistent with the requirements and importance of the theme, the science and technology sector needs to enhance the integration of vulnerability and impacts research, development and innovation into the science and technology agenda, in order to be able to establish adequate criteria to build and implement adaptation strategies in a rational way, aiming to guarantee a sustainable future for the Country.

1. Brazil and climate change – the context

Carlos A. Nobre

1.1. Introduction

Brazil and Latin America are not, broadly speaking, part of the group of countries or regions that are most vulnerable to climate change in comparison to other developing countries. Almost all African and South Asian countries fit this same category, as well as small ocean islands. Most of the vulnerability of these countries in this century will be – and to a certain extent already is – a consequence of access to water and susceptibility to floods. However, that does not make Brazil a 'climate-change-proof' country.

It is therefore fundamental to ask to what extent Brazil is vulnerable to climate change. The Brazilian economy relies considerably on renewable natural resources and more than half our GDP is related to them, especially in terms of agriculture, hydroelectricity, biofuels, bioenergy, wind power and solar energy, among others. As such, the Brazilian economy is potentially vulnerable to climate change, as it might result in a substantial decrease in the use of renewable natural resources, both those currently being used and those which could be used in the future.

Secondly, it must be pointed out that climate change, as well as the current climatic variability, accentuates the social vulnerability of the poorest people. This is due to their difficulty in overcoming problems caused by climate change and becoming more adaptable. The country's stage of development still presents major social and regional discrepancies and more than half our population may be considered poor, which also means they are particularly vulnerable to the climate change that is predicted, especially the inhabitants of rural areas in the semi-arid Northeast and the poor people living on the outskirts of Brazilian cities and low-lying coastal areas.

And finally, in terms of the environmental and ecological aspect, when we take into account the mega-diversity of our tropical country and the relatively low ability of fauna and flora species to adapt to abrupt change, it may be inferred that our biological heritage is highly vulnerable to climate change.

To sum up, the country may present some significant socio-economic and environmental vulnerability to climate change. It is strategically vital, therefore, to increase scientific knowledge about the possible impacts of the climate change that is expected to take place in this century in every sector, system and region in the country. This knowledge becomes even more relevant in terms of agriculture, water resources, renewable energy, human health, ecosystems and biodiversity, coastal areas, cities and industry. Based on this knowledge, our main vulnerabilities to climate change may be identified and public policies can be elaborated and implemented to reduce them and increase the ability to adapt of the population, the economy and, as far as possible, the ecosystems.

After the worldwide repercussions of the Fourth Evaluation Report of the Intergovernmental Panel on Climate Change (IPCC), parts of which were published in 2007, Brazil also seems to have woken up to this environmental issue, which is unprecedented in human history. A series of national initiatives has been taking place. In the scientific field, a Brazilian Network of Research on Climate Change (Rede Clima) is a noteworthy initiative created by the Ministry of Science and Technology in an effort to generate scientific information to help the country overcome the challenges of global environmental change. Several Brazilian states have flourishing research programs to explore the topic. As far as public policies are concerned, a National Policy and a National Plan on Climate Change are currently being elaborated and awaiting approval that will ideally serve as a legal marker to direct the country's actions in mitigating climate change and increasing adaptability.

The following articles in this volume present a current overview of what is known about global climate change in key sectors for sustainable development and which may be substantially affected. They also present for special discussion the vulnerability of each sector and the adaptive actions necessary.

1.2. Definitions

For the purposes of these studies subsequent to this introductory chapter, the following definitions will be adopted for: climate change, impacts, vulnerability, adaptation, capacity for adaptation and mitigation, based on the definitions of the Intergovernmental Panel on Climate Change (IPCC).

Climate change: refers to any change in climate which may occur through time due to natural variability or human action. This use differs from that of the United Nations Framework Convention on Climate Change, in which 'climate change' refers to a change in climate which may be directly or indirectly attributed to human activity and which alters the composition of the global atmosphere, an additional change to that caused by natural climate variability observed throughout comparable periods of time.

Impacts: refer to the effects of climate change on natural and human systems. Two types of impact may be distinguished, depending on the degree of adaptation.

a) *Potential impact*: every impact which may occur due to projected change, without taking adaptation into account.

b) *Residual impact:* the impacts of climate change which may occur after adaptation has taken place.

Vulnerability: is the degree of susceptibility or a system's incapacity to deal with the adverse effects of climate change, including climate vulnerability and the extreme events of weather and climate. Vulnerability varies according to the type, size and pace of climate change, as well as the variation a system is exposed to, its sensitivity and its adaptive capacity

Adaptation: refers to the adjustment of natural or human systems to real or expected climate changes or their effects, which regulates or exploits beneficial opportunities. Different types of adaptation can be identified:

a) *Anticipatory adaptation*: refers to the adaptation which occurs before the impacts of a change in climate can be observed. It is also referred to as pro-active adaptation.

b) *Autonomous adaptation*: refers to the adaptation which is not a conscious response to climate stimuli, but is caused by ecological change in natural systems, by changes in the market and in the wellbeing of human systems. It is also referred to as spontaneous adaptation.

c) *Planned adaptation*: refers to adaptation resulting from deliberate decisions and policies based on the knowledge that changes have occurred or that they may occur, and that this action is necessary for the desired state to be maintained or recovered.

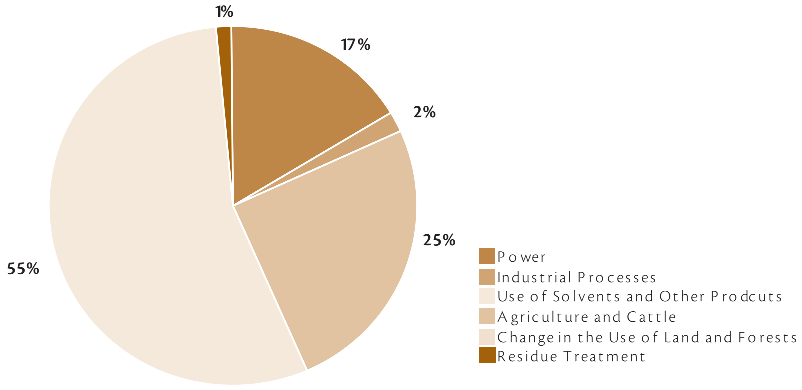
d) *Adaptive capacity:* refers to the capacity of a system to adjust to climate change (as well as to climate variability and extreme weather and climate events), moderating possible damage, taking advantage of opportunities or dealing with consequences.

e) *Mitigation:* refers to some form of human intervention to reduce the human influence on a climate system. It includes strategies for the reduction of greenhouse effect gas emissions and also for the increase in the provision of sinks for these gases.

1.3. Brazilian emissions and the potential for mitigation

In the general picture of Brazil's emission of greenhouse effect gases (especially CO_2, CH_4 and N_2O), shown in Figure 1-1, 55% of these emissions are a result of change in vegetation, specially deforestation in the Amazon and in the *Cerrado* [a savanna formation typical of central Brazil and some Northeastern areas – trans] and a further 25% are a consequence of agriculture, mostly methane emitted by ruminant animals. In this situation Brazil differs greatly from other developed countries and even from emerging economies like China and India: whereas in these countries the burning of fossil fuels is responsible for about 60% to 80% of emissions, in Brazil, on the other hand, 80% of emissions come directly or indirectly from agriculture (or the deforestation necessary to open new areas for it) and only 17% from burning petrol, coal and natural gas.

Without considering emissions caused by change in land use, *per capita* CO_2 emissions for Brazilians would be around 0.5 tons of carbon per year, a relatively low figure compared to the world average, comparable to that for India and much lower than the figures for industrialized countries, which are typically above 2.7 tons per inhabitant per year and above 5 tons for the USA. This is due to the fact that Brazil's power system is relatively 'clean'. However, if we consider that 75% of Brazilian emissions of carbon dioxide – the main greenhouse effect gas – are caused by deforestation, *per capita* emissions are more than 1.5 tons per year, the highest level of *per capita* emissions for a developing country, higher than that of China (approximately 1.1 tons per capita/year) and these emissions have been rapidly increasing during recent years.



Sources: Brazilian Ministry of Science and Technology and Brazilian Ministry of Environment.

Figure 1-1: Percentage of Brazilian Emissions of Greenhouse Effect Gas (CO_2 equivalent) by sectors, based on the Emissions Inventory of 1994. For the calculations above, the Global Warming Potential for CH_4 was considered to be 21 times higher than that of CO_2.

To mitigate emissions in Brazil, it is of the utmost urgency to reduce deforestation. After all, the largest part of the Brazilian greenhouse gas emissions is a result of deforestation and the burning of forests, which is mainly done to make room for cattle-raising. Among the economic activities that involve changing the use of the land in the Amazon and in the Brazilian Cerrado, those which are responsible for CO_2 emissions – cattle-raising, soy crops, wood, etc. – and which are carried out in all the areas that have already been altered within the Amazon Rainforest and Cerrado biomes, represent around 1% of Brazilian GDP. If we take into account economic activities directly related to the expansion of the agricultural frontier in a given year, that percentage is reduced to a statistically insignificant fraction of GDP, creating a very unfavorable ratio between emissions caused by deforestation and burning in these areas, and the GDP they generate. From this point of view a large part of Brazilian emissions is actually not related to the country's real economic growth, in contrast to China and India, for instance, and is similar to what happens in other tropical nations such as Indonesia.

The global goals established for emission reductions require the contribution of Brazil to the global effort for mitigating global warming, which faces us with the obligation to reduce our emissions from deforestation. To considerably reduce deforestation in the Amazon forest to near-zero values, it must first be realized that there are large areas in Brazil that have already been deforested, are degraded or abandoned. An estimated 150,000 km^2 of these areas are estimated to exist in the Amazon area alone. These areas should be prioritized in the expansion of the agricultural chain of production, from family farms to agribusinesses, but using modern agricultural techniques.

Another trend with great potential arises from the environmental services of the Amazon ecosystems, especially from their great biological capacity for carbon absorption in the biomass. The tropical climate also favors the rapid growth of plants, which makes large-scale reforesting recommendable in deforested areas to remove CO_2 from the atmosphere through photosynthesis and contribute to the mitigation of emissions. Reforesting projects, which can take the form of Clean Development Mechanisms (Mecanismos de Desenvolvimento Limpo – MDL) as proposed by the Kyoto Protocol, have been used only sparingly even though Brazil presents the highest current and future potential in the world for this type of project to increase the provision of carbon gas sinks.

So far, environmental motivation has not been enough to cause a change of behavior regarding the Amazon. However, the value of the environmental services that can be rendered by a standing rainforest is starting to attract much attention, mainly due to the potential economic value associated with these services by a new mechanism currently being analyzed within the ambit of the Climate

Convention, this is the mechanism known as the REDD (Reduction of Emissions from Deforestation and Degradation). Based on data gathered by the INPE (Brazilian Institute of Research and Statistics), the total deforested area for 2004 was approximately 27,000 km^2 in the Brazilian Amazon. Between 2005 and 2007 a reduction of deforestation of the order of 60% was recorded. Thus 17,000 km^2 of forest were prevented from being deforested (as opposed to the historic average of 20,000 km^2 of deforestation per year), which represented avoiding the emission of around 220 million tons of carbon into the atmosphere. If the global carbon market had already started pricing carbon emission reduction by avoided deforestation at the time, this would have been equivalent to US$ 2.2 billion in assets, provided that the remuneration basis had been US$ 10 per ton of carbon emission avoided.

This potential must define deforestation control as Brazil's first strategy in mitigating emission, and the recently-created Amazon Fund, which has already received a substantial subsidy from Norway – US$ 140 million initially, rising to US$ 1.1 billion by 2015 if Brazil continues to show deforestation level reductions – is already a demonstration of the far-reaching potential of these practices.

Other important mitigating factors are biofuels and bioenergy, although Brazilian production of biofuels must avoid becoming the cause of an additional factor in the deforestation of the tropical forest. To replace about 10% of the annual consumption of gasoline, more than 25 million hectares have to be given over to sugar cane. Even though there are enough under-productive cattle grazing areas that can be converted to sustain this potential growth and keep it outside the Amazon area, if this potential is actually fulfilled it could drive cattle-raising activities deeper into forest areas, especially through the relocation of cattle-raising activities from the Cerrado to the Amazon region.

Although it is imperative to mitigate emissions as the only morally acceptable long-term solution, the inevitability of some level of climate change occurring anyway means that equal emphasis should be given both to the accelerated reduction of worldwide emissions over the next decades as well as to the need to adapt to climate changes that have already become inevitable. Can Brazil play a leading role on both fronts?

1.4. Is it possible to choose between mitigation and adaptation?

in a best-case scenario, even if global emissions are reduced by 80% by 2050, compared to 1990, even if the peak of emissions occurs, at best, in 2015 and from there starts to decrease, nevertheless, a high level of global warming and climate change has already become inevitable and temperatures will rise by about 2° C by the end of the century, according to the predictions of the IPCC. The logical course we should take is adaptation associated with actions for mitigation, at least in order to deal with what has already become inevitable.

Mitigating climate change is vital, and it is up to the present generations to change attitudes and behaviors. If that goal is not accomplished within the next 30 or 40 years, we run the risk of watching the worst-case scenario take place in which a temperature increase could exceed 4° C by the end of this century. Adapting is the alternative to becoming victims to the risk that can no longer be entirely eliminated.

If the knowledge we have today concerning the working of the climate system had been available to previous generations, those of our parents or grandparents, and some form of reaction had taken place, maybe there would have been time to avoid most of the climate change. The critical reaction period to avoid the rapid growth of emissions would have been the post-World War II period. But, on the contrary, what happened was that a spirit of optimism took over the planet after the end of the War and energy appropriation increased exponentially to support an unprecedented demographic boom and the rebuilding of Europe, Japan and other regions. No-one imagined that collateral damage could occur.

The difference between that generation and the current one is in the possession of knowledge, and that places a higher burden of responsibility on those who are now building the planet that will be left to our descendants. If the course of events is not changed, human experience will leave to the next generations a planet at an incomparably higher level of environmental crisis than the one we inherited from our parents.

Brazil is currently responsible for 3-4% of global emissions of greenhouse gases. The Brazilian middle class has a pattern of emission that does not differ much from that of European countries. As happens there, one example of our consumption pattern is to use a 2-ton vehicle to transport a single person – 96% of the energy is used to move the structure, and not the passenger. This pattern is absolutely unsustainable if all inhabitants of the planet seek this pattern of energy consumption, and places our future at great risk.

Yet, it is this very middle class that has the greatest capacity for adaptation, resistance and change. It can look for and incorporate solutions for life in a world that is hotter and suffers the effects climate of change. Brazil's problem is in the two-thirds of its population that does not have that capacity, thus increasing the country's vulnerability regarding the necessary adaptation.

But adapt to what? In the first place, we need reliable climate scenarios. At a global level, future estimates for climate scenarios still present considerable levels of uncertainty, mainly in the projections of hydrological cycles, in the particular details of regional climates and in determining how climatic extremes may change. This makes it difficult to study impacts and, therefore, identify vulnerabilities.

To provide these answers, Brazilian science is starting to take its first steps, albeit with some difficulty. One of the first obstacles to overcome is that of enormously expanding our knowledge base of how climate is changing in the country: Brazil has practically no observation site with long-term studies of how physical and biological systems are responding to the climate change that are already happening. Likewise, there are extremely few locations with such studies in the developing world. Other than the records that show surface temperatures have risen by about 0.75° C in the country in the last 50 years and that rain is more abundant in the South, little more is known about how climate is changing in Brazil and what consequences of these changes may already be felt.

Despite the challenge of acquiring new knowledge on how climate is changing and on impacts and vulnerabilities, the last two years have been particularly fruitful and promising in breaking the stalemate and starting to fill these gaps. For one thing, high-resolution regional climate scenarios from space have been made available to give predictions up to the end of the 21st century (Marengo et al. 2007 and Ambrizzi et al. 2007). These scenarios have made it possible to start impact studies in several sectors: agriculture, renewable energy, ecosystems, human health, drainage basins, the economy, mega-cities, semi-arid regions, etc., besides other studies on impacts on the coastal regions and the biodiversity of the main Brazilian biomes. The initial results of these impact studies are summarized in the chapters to follow, but in general they allow us to predict that our society, economy and environment present clear indications of being vulnerable to climate change on several levels, and that most of the impacts are negative and require adaptation policies.

1.5. Final comments

The global financial crisis the world has been facing since the end of 2008 can lead to an economic recession of uncertain connotations. On the one hand, it may cause a reduction in the rapid growth of the last years, and consequently a decrease in the growth of greenhouse effect gas emissions into the atmosphere. It is worth mentioning that in the 2000-2007 period there was an average 3.5% per year increase in fossil CO_2 emissions, a completely unsustainable figure in view of the need to stabilize the atmospheric concentrations of greenhouse gases. On the other hand, the concern of the world's nations with short-term economic issues may detract focus, attention and even political will from their commitment to significantly decreasing emissions within the terms of the United Nations Framework Convention on Climate Change for the post-Kyoto period (post-2012). These commitments should to be fulfilled by the time of the Conference of the Parties to the Kyoto Protocol, to take place in December 2009 in Copenhagen, Denmark.

Even though it is virtually impossible to predict the evolution of complex social systems, it is possible to realize that humanity faces a great crossroads. It could follow the course that has been the basis of the development model of the 19th and 20th centuries, based on cheap fossil energy but with growing environmental consequences – global warming, for instance – and whose impacts have become inevitable, or it can choose a path less well-marked but perhaps the only one that can take us to a safe haven for sustaining life on Earth. This path demands, in terms of the reduction of global warming risks, a radical 'de-carbonization' of the systems of production and consumption on a global scale and a growing use of renewable natural resources. This path offers challenges and opportunities to Brazil.

Firstly, we should focus on the reduction of emissions in all sectors of the country, especially with a view to slowing down the expansion of the agricultural frontier into the rainforest and the Cerrado in order to reduce Brazilian emissions to less than half of our current levels. Public policies guided by modern scientific and technological knowledge of agronomy, must maximize and intensify the use of areas that have already been altered within these two biomes. This practice should be linked to value-adding policies for primary forest and agricultural products through industrialization. This would allow us to gain time for the development of a new economic paradigm for the Amazon based on standing forests and the exploitation of the economic and social potential of the extraordinary biodiversity of the tropical ecosystems. The absence of models for economic and social development based on biodiversity resources and ecosystem services in any other immensely diversified tropical country in the world that could be copied in Brazil makes the current model more difficult to break. There is no other option but inventing an entirely new model based on Science, Technology and Innovation, expanding our current basic and applied research units, and creating new ones as well as massively staffing these institutions with researchers and engineers.

Could Brazil become an 'environmental power' in the 21st century, or even the first developed tropical country? The challenge for an entire generation is that of inventing a new development pattern for Brazil based on S,T&I, which recognizes that the rational uses of our abundant renewable natural resources and biodiversity could be the great boost for our sustainable development which would allow the country not only to become one of the countries with the lowest rate of ***per-capita*** emissions in world, but also a model of development for tropical countries.

2. Scenarios for climate change for South America for the end of the 21st century

Carlos A. Nobre
Gilvan Sampaio
Luis Salazar

The best tool to project scenarios of probable climate changes for the future are the mathematical model systems of the global climate (GCMs), which deal in a quantitative (numerical) form with the behavior of the climate divisions (atmosphere, oceans, cryosphere (areas of snow and ice), vegetation, biogeochemical cycles, etc.) and their interactions. These models allow us to simulate probable scenarios of climate evolution in several scenarios of emissions of Greenhouse Effect Gases (GEGs). There are, however, two great uncertainties in using these models. The first is the lack of knowledge about the precise future trajectory of GEG emissions and atmospheric aerosols, which depend on human decisions about the environmental and in the socioeconomic path society wishes to follow, and which ones will be actually implemented. The second uncertainty comes from the fact that the mathematical models are imperfect representations of nature, and different climate models differ considerably in their predictions for the future, even when given the same scenario for the evolution of the concentration of GEGs and aerosols in the atmosphere. The means to deal with both these uncertainties is to use several scenarios for GEG emissions, and different climate models.

Figures 2-4 show climate scenarios for the years 2071-2100 for 15 different global climate models and two scenarios for GEG emissions provided by the Intergovernmental Panel on Climate Change – IPCC ("World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset"): A2 is the 'pessimistic' scenario, in which the pattern of GEG emissions observed during recent decades is maintained; this implies arriving at the year 2100 with concentrations of CO_2 in the atmosphere of about 850 ppmv; and B1 is a scenario with fewer emissions, or the 'optimistic' scenario, which inclines to the stabilization of the GEG emissions, keeping the concentration at the end of the century down to 550 ppmv (NAKICENOVIC and SWART, 2000).

The analyses of these scenarios show greater differences in anomalies of precipitation and temperature among the different models than among the different scenarios for the same model. As expected, the greatest sources of uncertainties in the scenarios of regional climate change are associated with the prediction of the different GCM. The warming predicted for South America varies from 1-4°G in the B1 scenario and from 2-6°C in the A2 scenario. In conclusion, the climate will be hotter according to any of the scenarios and climate models. This analysis becomes more complicated when dealing with changes in rainfall, since the different models present differences in magnitude and also in the anomaly signal. Generally speaking, the most affected areas in South America would be Amazonia and the Northeast of Brazil, through processes relating especially to the intensity and location of the Intertropical Convergence Zone (ITCZ). Among these processes two stand out, the probable weakening of the Hadley cell in the Northern Hemisphere (causing an ITCZ to the north, since the temperature gradient in this hemisphere would decrease), and the increased concentration of atmospheric water vapor in the equatorial region. However, the inconsistency is large: while some models show positive anomalies in precipitation over parts of the Amazon and the Brazilian Northeast, others show negative anomalies (GIORGI and FRANCISCO, 2000; Oyama, 2003), even though the Mid-east of the Amazon and the North of the Northeast are considered places of relatively great climatic predictability (MOURA and HASTENRATH, 2004). What comes into play here are the different ways in which each model represents the global physical and hydrological processes and resulting regionally in the limited representation of the mesoscale convective systems (such as mesoscale convective complexes or instability lines). These mesoscale convective systems, together with the ITCZ, both in Amazonia and in the Brazilian Northeast, are of the greatest importance to the local precipitation regimes (SATYAMURTY et al., 1998). Therefore the present state of science does not allow us to establish definite scenarios for changes in the hydrological regime.

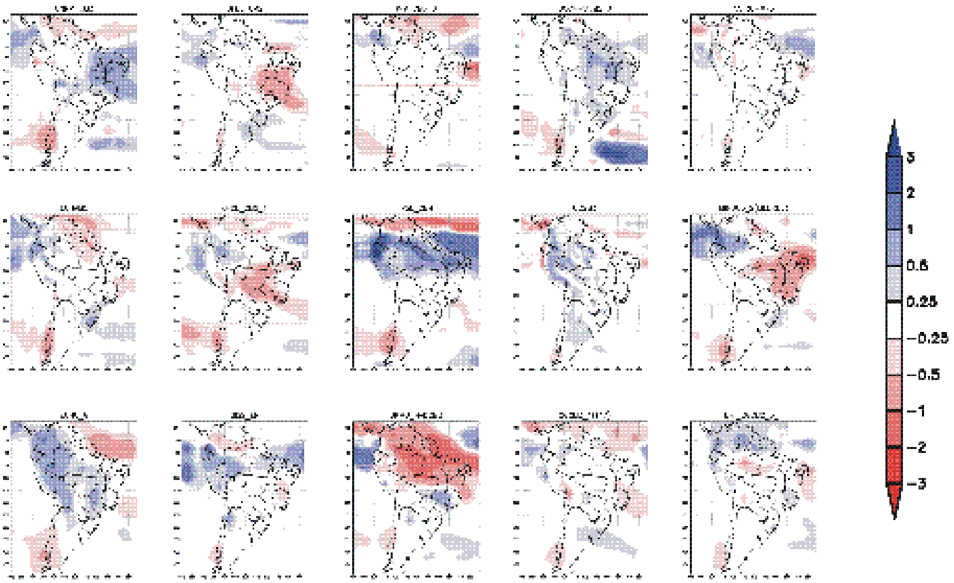


Figure 2-1: Projections of precipitation anomalies (mm/day) for South America for the years 2071-2100 (B1 scenario) relative to the base period 1961-1990 for 15 different global climate models available from the IPCC.

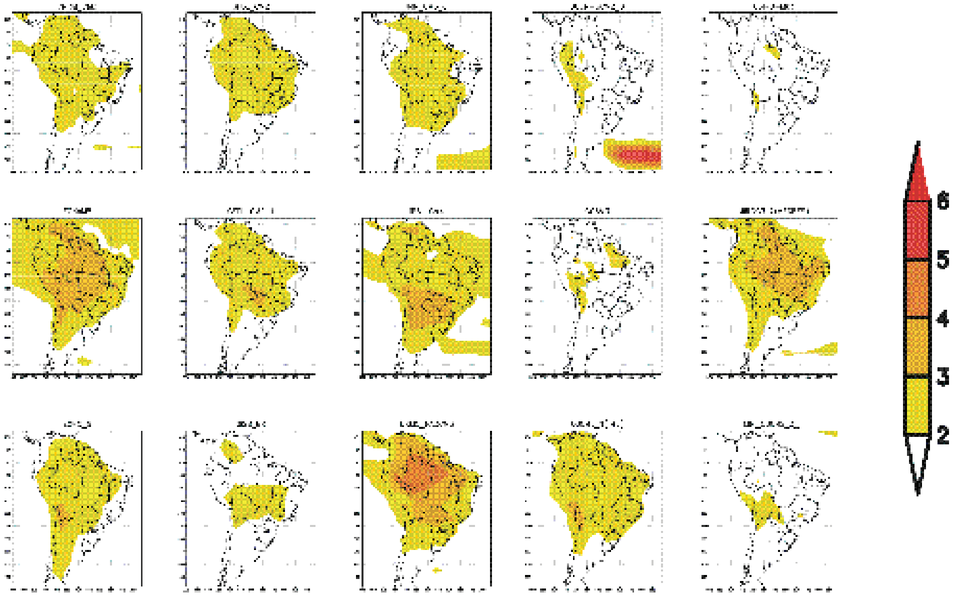


Figure 2-2: Projections for temperature anomalies (°C) for South America for the years 2071-2100 (B1 scenario) relative to the base period 1961-1990 for 15 different global climate models available from the IPCC.

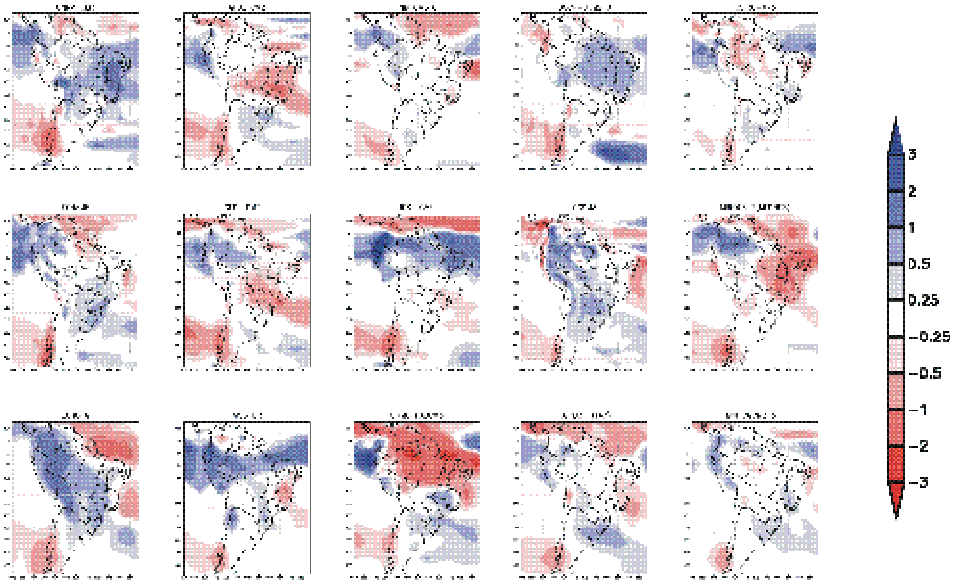


Figure 2-3: Projections of precipitation anomalies (mm/day) for South America for the years 2071-2100 (A2 scenario) relative to the base period 1961-1990 for 15 different global climate models available from the IPCC.

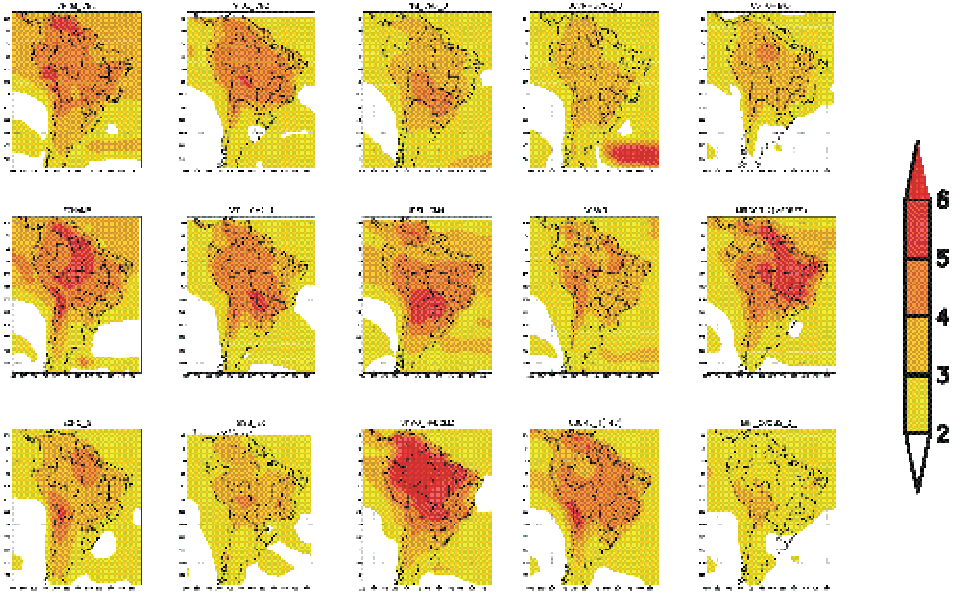


Figure 2-4: Figure 4. Projections for temperature anomalies (°C) for South America for the years 2071-2100 (A2 scenario) relative to the base period 1961-1990 for 15 different global climate models available through the IPCC.

Figure 2-5 presents the precipitation and temperature anomalies for the Amazon projected by 15 different models for the A2 and B1 scenarios. As described in the previous analyses, there is much variation in the precipitation anomalies projected between the different models in terms of magnitude and the anomaly signal until the end of the 21st century. The difference between the precipitation anomalies for different models suggests there are still uncertainties in scenarios for future climate projections, which indicates the need to improve the representation of the physical processes such as clouds, precipitation, aerosols and the interaction of vegetation and climate. It is hoped that for the next IPCC report the global climate models used will also consider the dynamic of the vegetation in such a way that changes in vegetation will be reflected in changes in the climate and vice-versa. In the analysis of the temperature for Amazonia, all the models agree with the anomaly signal, with average levels of warming among all the models of 4°C (2°C) for scenario A2 (B1) for the end of this century. The temperature anomaly increases with time as the century goes by and is larger for the more 'pessimistic' scenario (A2).

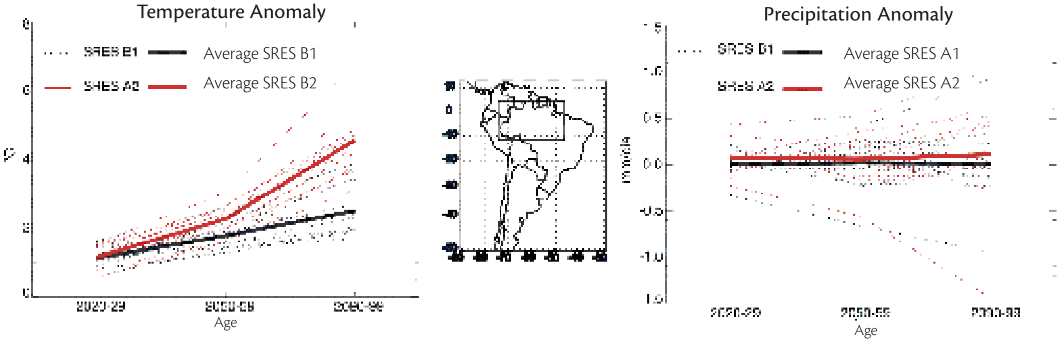


Figure 2-5: Precipitation and temperature anomalies for the Amazon region (the selected area on the map) of 15 global climate models for the emission scenarios A2 (red lines) and B1 (blue lines). The thick line represents the average of all models.

It is important to emphasize that the global climate models used to make the previously described future projections have spatial resolution between 200 and 400km of latitude and longitude, that is, a low spatial resolution. There is, however, a technique to change the low spatial resolution of global climate models to finer scales by downscaling the projections of these models using higher resolution regional climate models over the area of interest, and using global climate models for the border data (AMBRIZZI et al., 2007).

In order to produce climate change scenarios on a higher spatial scale (50km) for South America, the projects entitled "The Characterization of the Present Climate" ("Caracterização do Clima Atual") and "Definition of the Climate Changes for Brazilian Territory Throughout the 21st Century" ("Definição das Alterações Climáticas para o Território Brasileiro ao Longo do Século 21"), (MARENGO et al., 2007, MARENGO and AMBRIZZI, 2006) used three regional models (ETA/CPTEC-Inpe, RegCM3 and HadRM3P) to prepare climate change scenarios. This regionalization exercise used the global scenarios from global climate models from the Hadley Centre for Climate Prediction and Research in the United Kingdom. These regional models foresee for the end of this century an average temperature increase for Amazonia of 2°-4°C and a 1mm/day to 4mm/day decrease in precipitation, especially in the East of Amazonia (Figure 2-6). According to Ambrizzi at al. (2007), the most intense climate changes for the end of the 21st century in comparison to the present climate will happen in the tropical region, specifically Amazonia and Brazil's Northeast. These two regions make up what could be called the 'hot spots' of climate change, in terms of both socioeconomic component and biodiversity.

The projections derived from these regional models (AMBRIZZI et al., 2007) may be distorted by reason of the fact that simulations of the global climate model from the Hadley Centre were used to provide the area limits for bringing together the regional models, since this global climate model is the one that foresees very dry and hot climates for Amazonia and the Northeast, in comparison with various other results of the rest of the IPCC models.

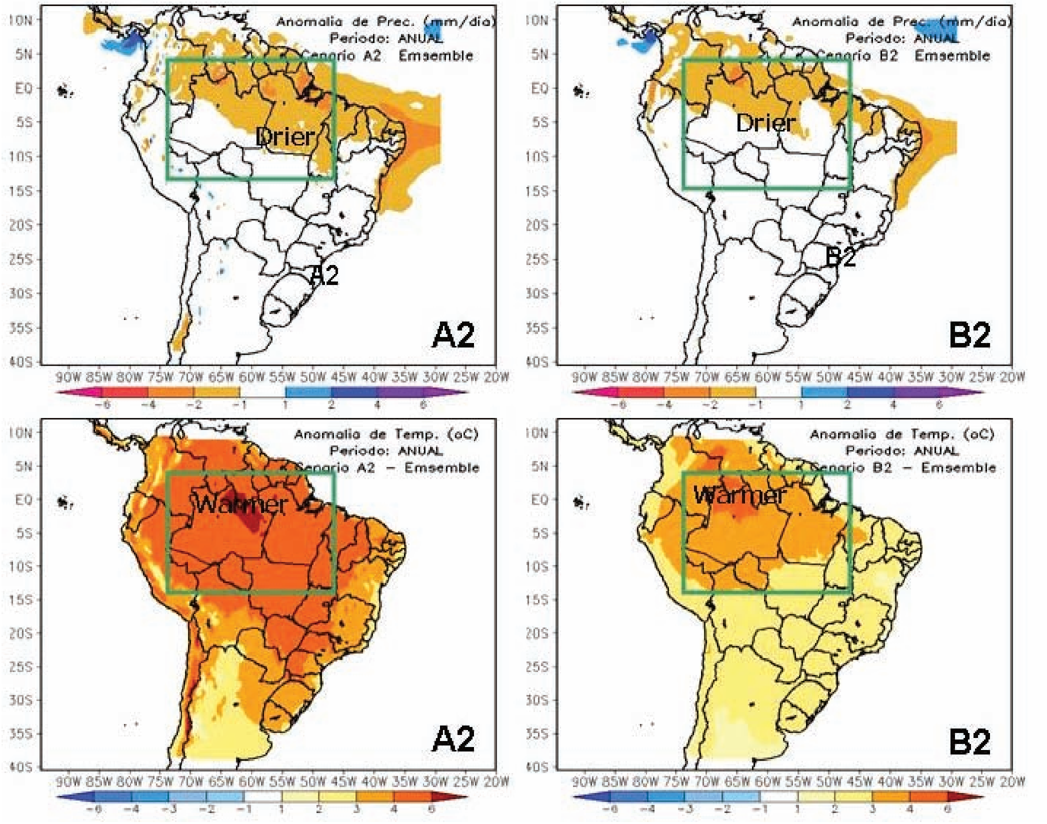


Figure 2-6: Annual precipitation anomalies (upper panel, measured in mm/day) and temperature (lower panel, measured in °C) (for South America, from 2071-2100) compared to 1961-90, A2 scenarios of high rate of emissions and B1 scenarios of low rate of emissions. The projections represent the arithmetical average of scenarios produced by the Eta/CPTEC regional models. RegCM3 and HadRM3P (50 km resolution).

Source: Ambrizzi et al. (2007).

Soon, the progress of scientific knowledge about the operation of the complex climate system will reduce the uncertainties in projections of modifications of climate change on a regional scale. However, one of the important projections concerns the most significant occurrences of extreme climates and intense events, such as droughts, rainy seasons, tornados, severe storms, floods, etc. The extreme events occurring in Brazil in recent years and their serious consequences show the need for an adaptation strategy for the country. With the expected increase in the frequency of extreme events, many sectors of economic activity will need to adapt. The industrial sector of dam construction and major engineering projects, for example, since the periods between the occurrences of floods may change. More frequent storms have a serious effect on farming activities, not to mention the decreasing fertility of the soil.

The possibility of increased climatic extremes automatically takes us back to the problem of the vulnerability to these changes of populations and ecosystems. Social vulnerability to climate effects may be defined as "an aggregation of characteristics of a person or group which determines the capacity of foreseeing, surviving, resisting and recovering from the impacts of the dangerous climate factor" (BLAIKIE et al., 1994). The IPCC defines it as "the degree of susceptibility of individuals or systems or of inability to respond to the adverse effects of climate change, including climatic variability and extreme events" (McCARTHY et al., 2001). A good measure of the adaptive capacity to potential future climate changes is evaluating how populations deal with the natural variability of the present climate and what happened in the historical past. In this respect, it is possible to notice a significant difference in the answer to variability and to extreme climate events in developed and developing nations. The seasonal droughts in the Northeast, the floods and inundations, and the landslides in metropolitan and mountain regions repeatedly show that the vulnerability of the country's population to such extremes is very high. This being the case, we must foresee that, maintaining present development conditions, Brazil's vulnerability to climate change will probably be just as high, which may be a significant obstacle to the country's future and sustainable development. With a warmer climate there will be more water vapor in the atmosphere and an acceleration of the hydrological cycle. This is one of the most reliable climate change projections. Acceleration of the hydrological cycle results in the increase of severe and intense storms. Landslides on hillsides, inundations and floods are two natural disasters responsible for the large number of victims in Brazil, especially in the metropolitan regions of Rio de Janeiro, Recife, Salvador, and Belo Horizonte, and of the Serra do Mar and Serra da Mantiqueira as well as being responsible for repercussions in terms of health, with the increase of mortality-morbidity. Therefore, the civil defense and public health departments must take into account that such disasters will tend to become more frequent with time if global warming continues.

Extreme events, such as the drought of 2005 in the West and Southwest of Amazonia may become more frequent with the increase of CO_2 and the decrease of aerosols. It is likely that the temperature increase in the tropical North Atlantic Ocean may be a result of the 2005 drought in Amazonia, since there was no El Niño episode and the most affected region was the Southwest of Amazonia, while droughts caused by severe El Niño episodes happen in the North and East of that region. This resulted in a decrease in the intensity of trade winds in the Northeast and in humidity transportation from the tropical Atlantic to the Amazon region. However, according to Marengo et al. (2007) , the causes of the 2005 drought in Amazonia are not related to El Niño, but to three possible interconnected coefficients: 1) the tropical North Atlantic Ocean being abnormally warmer than usual; 2) the reduction of the intensity of humidity transportation by the trade winds from the Northeast to the South of Amazonia during the climax of the summer season; and 3) the decrease of vertical movement over that part of Amazonia, resulting in reduced connective development and reduced precipitation. These three coefficients are dynamically consistent since the warmer waters of the tropical North Atlantic Ocean induce rising atmospheric movements over this region, lowering atmospheric pressure, and to compensate, descending movements over the drought region in the West-southwest of Amazonia, consequently increasing atmospheric pressure. This pattern of pressure anomalies would reduce the intensity of the trade winds, transporting humidity from the ocean to Amazonia (NOBRE et al., 2007).

2.1. The impact of climate changes on ecosystems

This chapter deals with the issue of possible change in the large Brazilian biomes (Figure 2-7) as a response to the scenario of climate changes shown in the Figures 2-5. The geographical distribution of vegetation communities and its relationship with the climate have been examined with biogeographic models or biome models. These models use as a parameter the fact that the climate has dominant control over the distribution of vegetation. The biogeographic models may simulate a possible vegetation (without the effects of land and soil usage) basing itself on certain climatic parameters such as temperature and precipitation, among others. Due to the simplicity of these models and the existence of global empirical rules about natural vegetation and climate, these models have been used to evaluate the impacts of the climate changes on vegetation cover (KING and NEILSON, 1992; CLAUSSEN and ESCH, 1994, NOBRE et al., 2004, SALAZAR et al., 2007). Oyama and Nobre (2004) developed a model of potential vegetation (CPTEC-PVM) which succeeds in representing the global distribution of the different biomes, and on a regional scale, the biomes of South America, where other widely used models such as the Biome (Prentice et al., 1992) and the Biome 3 (HAXELTINE and Prentice, 1996) have some shortcomings.

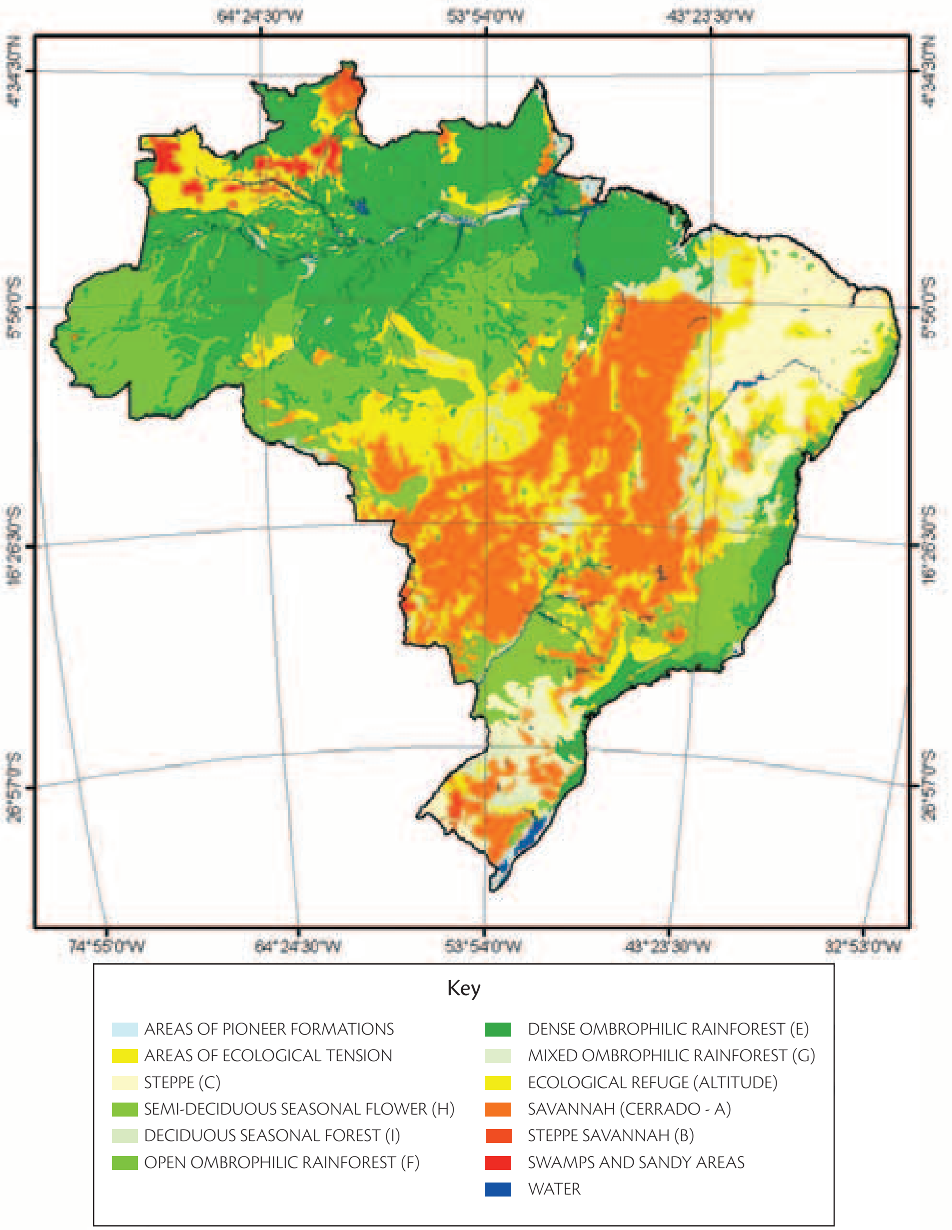


Figure 2-7: Main Brazilian biomes (Source: MMA – Ministério do Meio Ambiente)

Source: MMA

Firstly, it must be mentioned that natural ecosystems as a whole do not have an innate capacity for migration or adaptation to the magnitude of the projected climate changes on the timescale in which they are currently happening, that is, decades. Ecosystems migrate or adapt naturally to climate fluctuations occurring over many centuries and millennia. Therefore, we must expect significant rearrangements of the biome, with severe consequences to the maintenance of the biological megadiversity of the Brazilian biomes, with the probable result of significant biological impoverishment.

In order to quantitatively evaluate the probable alterations and redistributions of biomes in South America for the 21st century in response to the climate change scenarios, Salazar et al. (2007) used the CPTEC-PVM potential vegetation model (Oyama and Nobre, 2004) to calculate biomes balanced against the outcomes of 15 global climate models prepared for the Fourth Evaluation Report of the International Panel on Climate Changes (IPCC/ER4), shown in Figures 2-5. Climate scenarios A2 and B1, which represent high and low CO_2 emissions, respectively, were analyzed. The horizontal resolution of the models varies from 1.5 to 4°C, which shows that this analysis was carried out on a large scale.

Figure 2-8 displays the present potential vegetation and the redistribution of biomes projected with the CPTEC-PVM potential vegetation model for South America in the A2 scenario for the years 2090-2099 using the fifteen models analyzed. Taking an average of these projections, for tropical South America, there is projected increase of the savanna areas (as the Cerrado invades Pará) and a replacement of the Caatinga [dry scrubland characterized by thorny bushes – trans.] by semi-desert in the drier area of the Northeast of Brazil (NOBRE et al., 2004). Model HADCM3 in particular has the most extreme scenario for Amazonia, envisaging even a complete extinction of the Amazon forest (COX et al., 2000). Simply put, the temperature increase prompts a greater level of evapotranspiration (the sum of water evaporation on the surface with that of plant transpiration), reducing the amount of water in the soil, even if the rainfall levels do not drop significantly. This factor alone may initiate the substitution of the existing biomes for others better adapted to climates with less water accessibility for plants (for example, tropical savannas taking the place of tropical forests, caatinga replacing tropical savannas, and caatinga being replaced by semi-deserts).

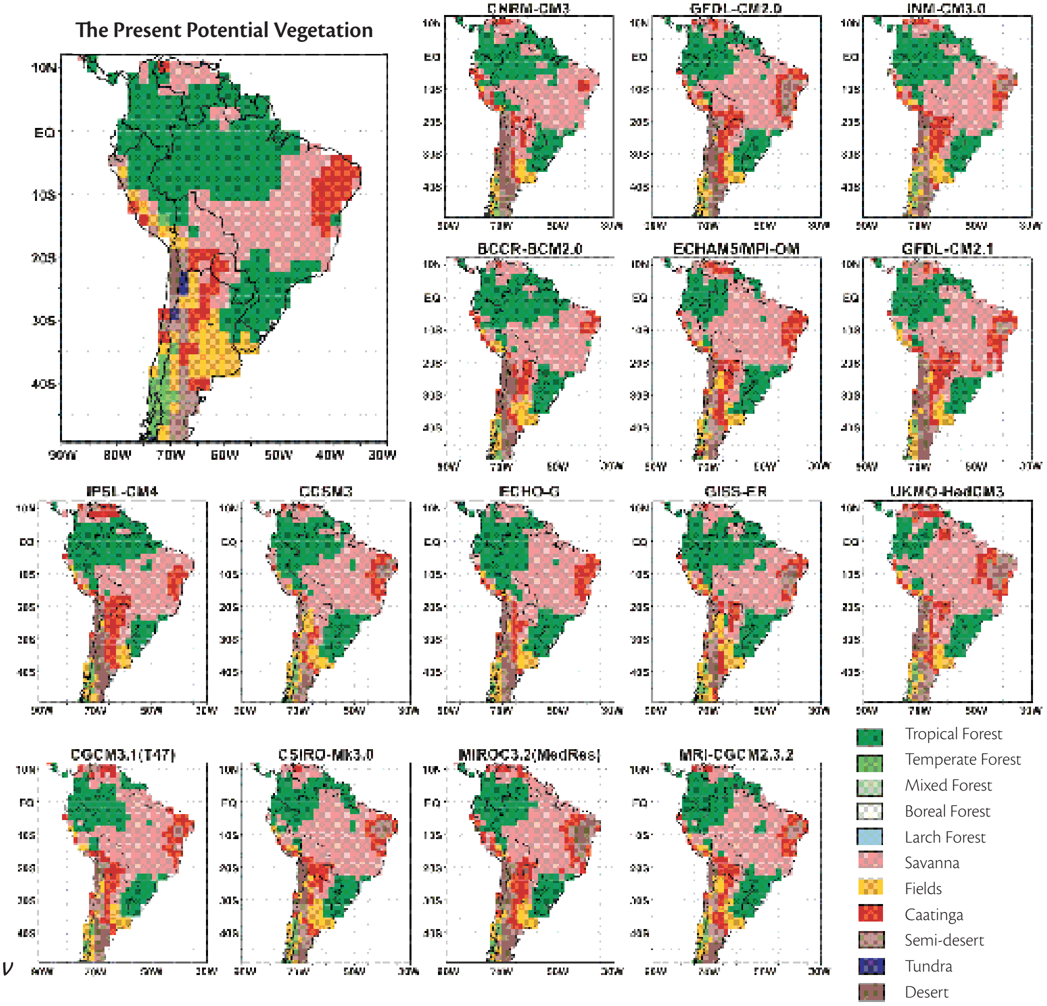


Figure 2-8: Projected distribution for natural biomes in South America for the years 2090-2099 from 15 GCMs for the A2 scenario. The upper panel to the left represents the possible biomes with the present climate (it represents the potential biomes, but not the distribution of present vegetation, which is a result of the changes in the vegetation covering and land use).

Source: Salazar et al., 2007.

Figure 2-9 presents the gradient points where over 75% of the 15 models (>11 models) predict the same future situation (where a certain biome persists, disappears, appears or the models do not agree on its future condition) of the tropical forest and the savanna for both scenarios analyzed on three different dates in the 21st century. For tropical South America, the results suggest that for the scenarios analyzed, where the models agree, there will be areas where the tropical forest will reduce in size and be replaced by tropical savanna. There is a lack of agreement between the models for this region because of the different projections for precipitation and temperature. In both scenarios, for the years 2090-2099 the tropical forest in Colombia and to the West of Amazonia remains, and the Atlantic Rainforest spreads to the South of Brazil (Figures c and f).

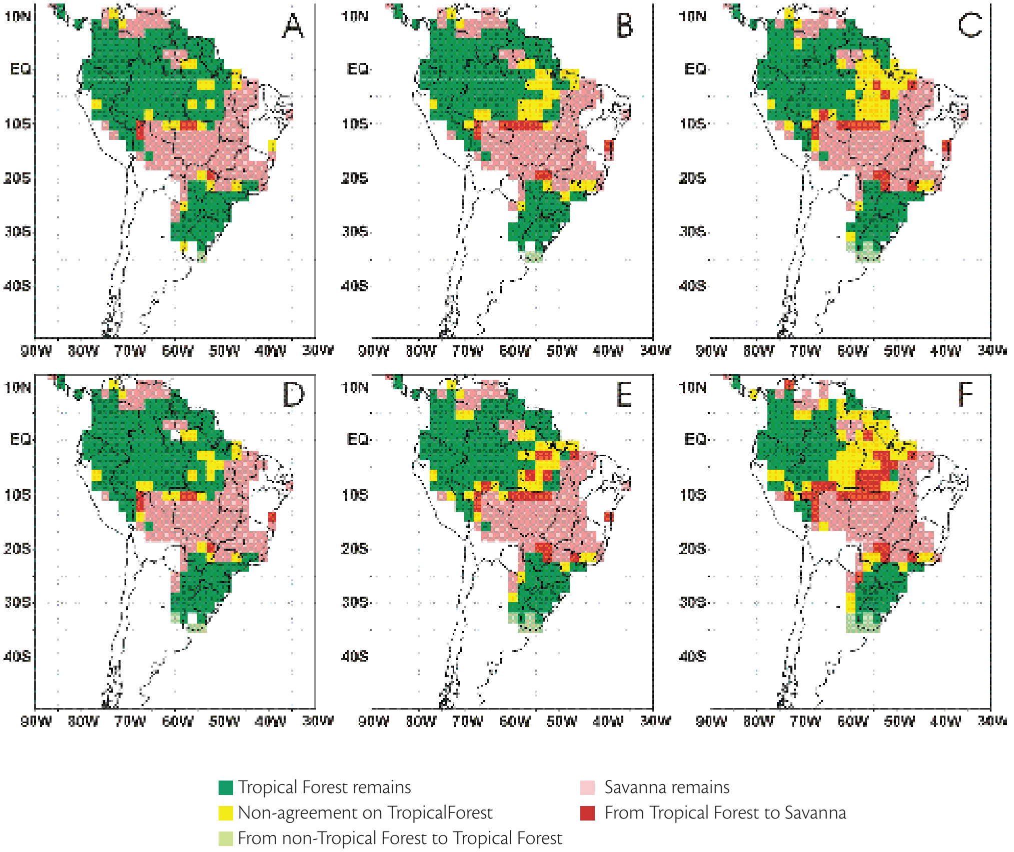


Figure 2-9: Gradient points where over 75% of the models (more than 11 models) agree with the future condition of the tropical forest and the savanna, regarding the present potential vegetation, which will result in the following possibilities: the tropical forest remains; the savanna remains; the savanna replaces the tropical forest; the tropical forest is replaced by a non-tropical forest. The Figure also shows the gradient points where there is no agreement between the different models for the years (a) 2020-2029, (b) 2050-2059, and (c) 2090-2099 for the B1 scenario and (d), (e), and (f) for the A2 scenario. (Source: Salazar et al., 2007).

Source: Salazar et al., 2007.

Generally speaking, it is possible that there will be a reduction in the areas covered by tropical forest (18% [8%] disappear, 30% [23%] of non-agreement for the A2 [B1] scenario and the years 2090-2099) and a corresponding increase in the areas covered by savanna. Other projections on vegetation change show a decrease in the forest areas of South America (for example, Scholze et al., 2006, Cook and Vizy, 2007) or a die-back of the forest (for example, Jones et al., 2003; Cox et al., 2000; 2004). Taking into consideration the fact that the natural time scale for ecosystem migration, which is measured in centuries and millennia, is much longer than the scale of climate changes (decades), the latter have the potential to deeply affect the ecological diversity of plants and animals.

Lapola (2007) conducted other experiments with an updated version of the CPTEC-PVM, which includes the carbon cycle and the biome of the seasonal tropical forest. The results show that in the Southeast of Amazonia the models do not agree regarding the replacement of the forest by savanna. This outcome reveals the effect of CO_2 fertilization, which favored conservation or change for large scale biomes in places where there is a temperature increase, therefore, precipitation must decrease even more for the savanna to replace the forest. This indicates that the effect of high levels of CO_2 on the tropical forest is critical and requires more detailed studies.

We must add to climate changes due to the global warming those due to changes in vegetation cover. The projections foresee that the deforestation of the Amazon tropical forest will result in a warmer and drier climate for the region (NOBRE et al., 1991, SAMPAIO et al., 2007, COSTA et al., 2007). The numerous simulations of the climate effects of the replacement of the forest in Amazonia by pasture land produced by these studies and the observations of the Abracos projects (GASH et al., 1996; GASH and NOBRE, 1997) and LBA (A Large-Scale Biosphere-Atmosphere Experiment in Amazonia; <www.cptec.inpe/lba>) point out that there is a temperature increase of between 0.3°C and 3.0°C, an evapotranspitarion decrease of between 15% and 30% and a precipitation reduction of between 5% and 20% due to the vegetation change from forest to pasture land. This temperature increase is higher than that foreseen for the B1 scenario, but extremely lower than that foreseen for the A2 scenario for the end of the 21st century. It is probable that the effects of temperature increase caused by global changes and those that have occurred because of deforestations will feed each other synergistically, increasing the danger of forest fires, for the drying of vegetation in the dry season and thus its flammability are both increased at higher temperatures (NEPSTAD et al., 1999), which increases the vulnerability of tropical ecosystems.

According to Scholze et al. (2006), the danger of forest loss in some parts of Amazonia is more than 40% for scenarios that present a temperature anomaly higher than 3°C. On the other hand, if there is a tendency to increased precipitation, these would act to oppose the reduction of rain due to deforestation and the final result would, therefore, be more favorable to the conservation of the ecosystems and species.

In addition to this, some studies have shown that a plant's stoma does not open as much when there are high concentrations of CO_2 (FIELD et al., 1995), which directly reduces the flow of humidity from the surface to the atmosphere (SELLERS et al., 1996). As a result, the air temperature near the surface may increase due to the higher ratio of sensible heat flow and latent heat flow. In a place like Amazonia, where much of the precipitation humidity comes from the evaporation of the surface, the reduction of the stomatal aperture may also contribute to decreased precipitation (BETTS et al., 2004).

If large areas of Amazonia are replaced by savanna, the relative degree of aridity may increase since vegetation adapted to fires has less transpiration. According to Scholze et al. (2006) there is the probability of greater frequency of fire (>60% risk at temperatures > 3°C) in many areas of South America. In Hutyra et al. (2005) it is shown that forests in areas where there is high frequency of drought (>45% of drought probability) may turn into savannas, if the aridity intensifies as foreseen by climate change scenarios (COX et al., 2004; FRIEDLINGSTEIN et al., 2003). Therefore, about 600,000 km^2 of forest are in danger of disappearing (>11% of the total vegetation area). Hence increased aridity may lead to the division of Amazonia (HUTYRA et al., 2005), with a wedge of tropical savannas invading in an easterly direction from the Cerrado region in Central Brazil, dividing the forest from the Atlantic coast to the Andes.

When the forest is subdued to periods of unusual dryness, there is a higher probability of forest fires. These can consume hundreds of thousands of acres and inject large quantities of smoke and aerosols in the atmosphere, which in turn will affect the population and possibly delay the beginning of the raining season and decrease the amount of rain on the region (ANDREAE et al., 2004). Taking into consideration the climate change scenarios from the HadCM3 model to the IPCC/AR4, the dry season could last two or even three months more than usual on most of Amazonia, which would increase the 3 to 4 months of dry season to 5 to 6 months in central and eastern Amazonia. This addition to the dry season would lead to an increased danger of fire and a change in the rainfall climatology that would encourage the replacement of the forest by the savanna (LI et al., 2006). These ecological impacts affect the possibility of tenable management of the forest in that region, which is a basic premise for the regional economy (BROWN et al., 2006). On the whole, the evidence of these studies helps us see consistency in the results presented in Figure 9 of calculations concerning biome redistribution in tropical South America, especially in terms of the hypothesis of the 'savannization' of parts of Amazonia.

The Amazon forest contains a large part of the world's biodiversity, for over 12% of all flowering plants are found in Amazonia (GENTRY, 1982). Therefore, threats to the existence of the Amazon forest mean severe dangers to biodiversity. There are, however, few studies about the effects of climate change on the distribution of species. On a global level, Thomas et al (2004) calculated the risk of extinction of species for areas that cover about 20% of the Earth's surface, and found that between 15% and 37% of species would be in danger of extinction by the year 2050. This research was done taking into consideration three scenarios of climate change: 1) minimal change (temperature increase of 0.8-1.7°C and CO_2 increase of 500 ppmv), 2) medium change (temperature increase of 1.8-2.0°C and CO_2 increase of 500-550 ppmv), and 3) maximum change (temperature increase of over 2°C and CO_2 increase of over 550 ppmv).

At a regional level, the simulations carried out by Miles et al. (2004), based on future scenarios of the HADCM2Gsa1 (which assumes an annual increase of 1% of CO_2 concentration) examined what could happen to the distribution of 69 species of angiosperms in Amazonia between 1990 and 1095. They concluded that by the year 2095 conditions could make it impossible for 43% of the species to survive, with maximum impact in the Northeast of Amazonia and better conditions for the preservation of species on the Amazon plains in the extremes of western Amazon, and recommended the extension of protected areas to the West of the region as a way of maintaining a significant resistance of Amazonian biodiversity to climate changes.

Essentially, this is the same conclusion that came out of the results from the biome models mentioned above. In order for the affected species to reach new bioclimatic zones, dissipation and migration must occur over hundreds of kilometers (Hare, 2003). Many of these modeling experiments do not take into consideration non-climatic influences such as changes in land use, deforestation, water accessibility, pests and diseases, forest fires and other factors that may limit the migration and dissipation of species (CASE, 2006). In their work, Sala et al. (2000) studied biodiversity change for the year 2100, considering some of these aspects, and discovered that for the tropical biomes, the main agents affecting biodiversity are changes in land use and climate changes.

Similar conclusions may be applied to the impacts of the projections of climate change on agro-ecosystems. Generally speaking, there is a tendency towards decreasing water accessibility in parts of Amazonia, the Northeast and the Mid-west, with a few exceptions, which could damage agriculture especially in the Northeast and Mid-west. In the South and Southeast, these projections show smaller changes in the hydrological regime. However, for projections of impact on agriculture and therefore vulnerability evaluation, we must take into consideration the effects of temperature and concentration of carbon dioxide, the so-called 'fertilization' effect of CO_2, since usually a large increase in average temperature occurs outside its optimal range, it is prejudicial to crops, while the increase in the concentration of CO_2 usually results in a greater productivity for crops.

2.2. Impacts of climate change on agro-systems

A small number of studies have dealt with the question of the impacts of climate change on Brazilian agriculture. Some of the studies have used scenarios of future climate change based on global climate models and have tried to estimate the positive and negative effects on the productivity of wheat, corn and soy crops (SIQUEIRA et al., 2001; TRAVASSO et al., 2004) or the impact of climate change on the frequency of diseases in wheat-growing in the South of Brazil (FERNANDES et al., 2004). On the other hand, some studies have analyzed the agro-climatic risk of growing coffee in climatic extremes (MARENGO, 2001; PINTO et al., 2002; ASSAD et al., 2004). For São Paulo, for example, Pinto et al. (2002) estimate that with an increase of 3°C in average temperature and 15% in rainfall, only 15% of the state's area would be suitable for the cultivation of Arabica coffee, and with an increase of 5.8 °C, only 1.1%, even bearing in mind that there would be no more risks of frost in these scenarios. In the present climate, 40% of the state is suitable to this kind of cultivation.

Generally speaking, the many studies about impacts on the agricultural productivity of crops of corn, wheat and soy do not allow firm conclusions in the sense that the effect of temperature increase contributes to reducing productivity, which could also be caused by a greater frequency of diseases, but that could be evened out, to some degree, by the increased concentration of carbon dioxide. Specifically for the cultivation of coffee in the South-southeast of the country, the studies generally show that the agro-climatic risk to this cultivation could increase considerably because of the higher temperatures, even taking into consideration the less frequent frosts. It should be noted that all the studies used mathematical models to estimate the impacts on agriculture; however we lack better validation of the results as a result of field experiments.

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3. Impact, vulnerability and the adaptation of forests to climate change

Thelma Krug

3.1. Introduction and concepts

The understanding of the potential impacts of climate change in forest ecosystems is exceptionally important to Brazil, as the country possesses around 30% of the world's tropical rainforests (FAO, 2005) and has more than a half of its territory covered by native forests, which are distributed between its six biomes[1], especially in the Amazon and in the Cerrado (savanna). The primary forest in the Legal Amazon covers an area of approximately 3.5 million km^2 including the Cerradão, which is a forest form of the savanna biome that, from the physionomical point of view is a forest, but forestally it is more similar to the savanna in its actual sense[2] while the savanna (savanna park [a form of savanna haracterized by the presence of trees grouped on slightly raised areas of land – trans.] savanna stricto sensu, savanna field, etc.) occupies around 2 million km^2, distributed throughout central Brazil. The other biomes have less dense forest covering. The Mata Atlântica (Atlantic Rainforest), for instance, has less than 7% of its original vegetation coverage[3]. It is interesting to observe that nearly 60% of the world's forests are located in only seven countries in the world (Russia, Brazil, Canada, the United States, China, Indonesia and the Democratic Republic of the Congo) and these countries will be affected to a greater or lesser extent by climate change. Globally speaking, forests cover 30% of the total surface of the Earth and the ten countries which are richest in terms of forests are responsible for 2/3 of the total area of forests. A total of 57 countries have less than 10% of their area covered by forests and 34% of these forests are intensively used for the production of wood.

In this document, 'impacts' refer to the negative and positive consequences which result from climate change. For example, a change in the amount of rainfall can benefit areas where there is a lack of water (positive impact) and be harmful in places that are prone to flooding (negative impact).

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[1] [AMAZÔNIA], Cerrado, Caatinga, Pantanal, Mata Atlântica and Pampas. Map of Biomes in Brazil IBGE, 2004. Available at <www.ibge.gov.br>.

[2] [SEE RIBEIRO, J.F.; WALTER, B.M.T.] *Vegetação Florestal* – Cerradão. Available at Embrapa. <www.agencia.cnptia.embrapa.br>

[3] Preliminary estimate from the SOS Mata Atlântica Foundation and from the National Institute for Space Research for the period 2000-2005.

A system can be differently affected by climate change depending on the magnitude, rate and duration of change, and also on the tolerance and capacity of the system to adapt to the changes. It is natural to expect that an average increase of 1.5 °C in the temperature will have a smaller impact than an increase of 3 °C; and the faster the change is, the greater its impact on social, economical and environmental systems. As an example to illustrate this, a heat wave, even though it is temporary, may last several weeks or months, and the longer it lasts the greater will be its impact.

3.1.1. Vulnerability and adaptation

All systems are able to react to a stimulus, often seeking a reduction of the negative consequences this stimulus may cause. Climate change promotes a series of changes in climate variability that become new kinds of stimuli, therefore forcing the systems to respond**.** *Adaptation*, in this document, refers to any kind of adjustment of a system as a result of a climatic stimulus. *Adaptive capacity* refers to the degree to which a system is capable of making such adjustments.

The adaptation can be autonomous when it is related to the automatic responses of a system in reaction to a stimulus when trying to overcome its impacts. Vegetation, for instance, reacts to climate changes in air temperature by increasing or decreasing its respiration.

Another form of adaptation is *planned adaptation* that refers to the group of strategies and conscious actions implemented to minimize impacts. Planned adaptation complements autonomous adaptation, especially in cases where the system is not sufficiently able to overcome an impact.

The resilience (ability to adapt naturally) of some systems to climate change depends on the rate and magnitude of the change. There can be critical limits above which some systems may no longer have the ability to adapt themselves to changes without radically altering their functional state and the integrity of the system. Dramatic changes may lead to metamorphoses in the physical environment of a region, imposing limits to adaptation.

Vulnerability refers to the degree to which a system is susceptible to the negative impacts of climate change.[4] Adaptation and vulnerability are related concepts, as the vulnerability of a system is determined by its capability to adapt: the greater the capability, the lower the vulnerability**.** *The process*

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[4] The IPCC defines vulnerability, in the summary report of the Fourth Evaluation Report (IPCC, 2007), as the susceptibility to being damaged. Vulnerability to climate change is the degree in which a system is susceptible to, or unable to cope with the adverse effects of climate change, including the variability of climate and extremes. Vulnerability is a function of the type, magnitude and rate of variation to which a system is exposed, its sensitivity and its capacity for adaptation

of adaptation begins with an assessment of the vulnerabilities. It relates the expected impacts of climate change to the social, environmental and economical realities of a region, thus leading to an identification of the necessities and the priorities for action. The evaluation of vulnerabilities allows the community to start a process of adaptation within the context of its economic, technical and social situation. The cycle ends with the implementation of the identified actions.

The vulnerability of a system can be defined as the difference between the potential impacts and the capability of the system to implement autonomous and planned adaptation, which means: vulnerability = potential impacts – autonomous capability – capability of adaptation. For example, we may imagine a forest system being more frequently and intensively affected by the occurrence of drought. A potential impact on this system could be increased risk of forest fire, so in this sense every single event capable of starting a fire could result in severe damage to the forest. However, the vulnerability of the forest is not only determined by the impacts *per se*, but also by the capability of the forest to overcome them. Some forests will be more vulnerable than others, because of their ability to adapt. This ability can be enhanced by measures for planned adaptation aimed at reducing the vulnerability of the system. For example, the implementation of plans to fight fires or for controlled burning provides strategies to stimulate the adaptation of a forest.

The vulnerability of systems to climate risks can be analyzed in different ways: their vulnerability to the current weather; their vulnerability to climate change in the absence of means of adaptation and mitigation, and their residual vulnerability when the capabilities for adaptation and mitigation no longer exist.

Vulnerability to climate change can be increased by stresses not related to the weather and to factors such as sharp population increase and urbanization, deforestation, industries in high-risk areas and inappropriate use of natural resources. In the specific case of deforestation, Dynamic Global Vegetation Models[5] based on scenarios[6] of future tropical deforestation and future climate change indicate that deforestation will probably produce a great loss of carbon, even if we take into consideration the uncertainties about the rates of deforestation, on a global level. Analyzing the result of every model, net emissions that would lead to an increase of the concentration of carbon dioxide in the atmosphere from 29-129 ppm[7] (Cramer et al, 2004) are projected for the 21st century. The doubt about the magnitude of the impacts caused by the increase of the concentration of carbon dioxide,

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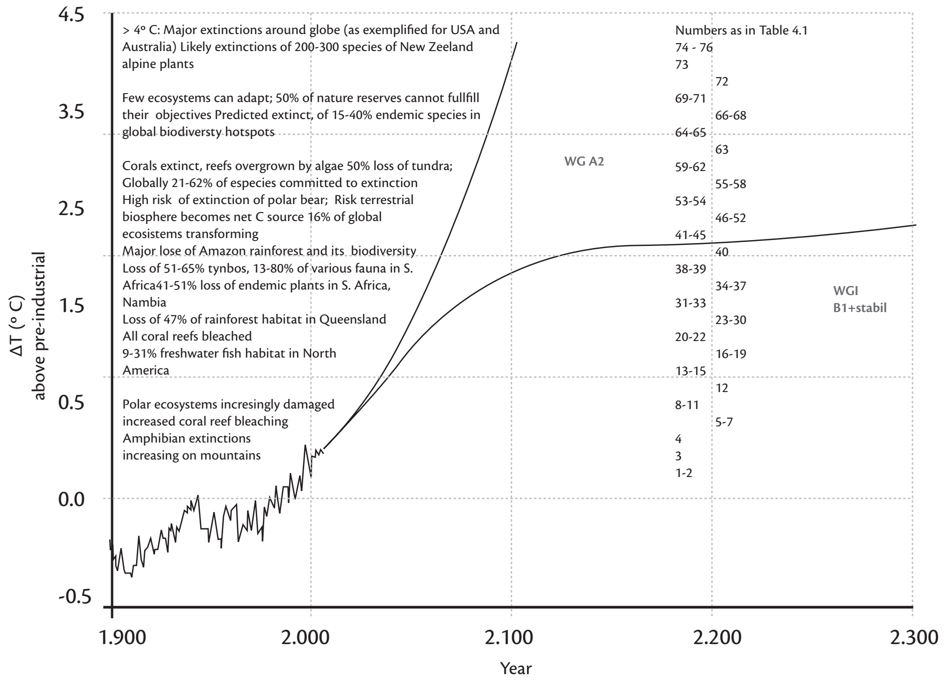
[5] Dynamic Global Vegetation Models are models based on processes that include the coupling of biogeochemical flow with the dynamic of vegetation (productivity, dynamic competitiveness of the vegetation, growth, disturbances, mortality and others).

[6] A plausible and often simplified description of how the future may develop. It is based on a group of coherent and internally consistent hypotheses about the driving forces and their most relevant relationships. The scenarios may derive from projections, but are normally based on additional information from other sources.

[7] Parts per million. Refers to the ratio between the number of molecules of a constituent in a volume of the atmosphere and the total number of molecules of all the constituents in that volume.

by the changes in temperature and precipitation and by future deforestation in the concentration of CO_2 in the atmosphere, points to a need for better estimates of current and future deforestation rates on a global level.

Some studies (Phoenix and Lee, 2004; Meehl et al, 2007; Callaghan et al., 2005) show that some ecosystems and species will be very vulnerable to climate change, especially at high latitudes, as in the boreal forests for example. Nevertheless, the Amazon is also considered a vulnerable ecosystem, particularly due to the reduction of precipitation, varying from substantial to moderate projected for some regions by some climatic models, and this may result in a transition of the state of the current forest to another less flourishing one, or even to grasslands (Cox et al., 2004; Cramer et al., 2004; Woodward and Lomas, 2004). Significant loss of the Amazon rainforest is expected to happen with the increase of 2.5°C in average temperature over the average temperature of the pre-industrial era (IPCC, 2007a) according to the Figure below, which is a reproduction of Figure 4-4 of the evaluation report of Working Group II of the IPCC.



The Figure represents a compendium of projected risks caused by critical impacts of climate change on the ecosystems for different levels of the annual average global increase in temperature Δ*T* relative to pre-industrial climate patterns. It is important to note that the impacts do not take into consideration the additional stresses on species because of the destruction of habitats, fragmentation of the landscape, introduction of invasive species, alterations in the system of burning, pollution (such as nitrogen deposits) or, for plants, the beneficial effect of the increase in atmospheric concentration of carbon dioxide. The red curve shows the anomalies of temperature observed for the period 1900-2005. The two grey lines present examples of a possible evolution of temperature as time passes, showing examples of the largest and the smallest trajectory for the future evolution of the expected ΔT Simulations are illustrated of the average responses for (i) the emission scenario A2 and (ii) the extended scenario B1, where the radiative forcing after 2100 was kept constant at the same level as in 2100.

It is anticipated that the ecosystems least vulnerable to climate change will be the savannas and various types of cerrado, but there are still considerable doubts concerning the effects of fertilization by carbon dioxide[8] and the alteration of some natural systems caused by disturbances like the occurrence of fire, plagues and diseases. Fertilization by carbon dioxide means an improvement in the growth of plants as a result of the increase in the concentration of carbon dioxide (CO_2). Depending on their photosynthesis mechanism some plants are more sensitive to changes in atmospheric concentration of CO_2. C3 plants (the great majority of trees and agricultural products like rice, soy, wheat, potatoes and vegetables) normally have a better response to CO_2 than C4 plants (grasses and sugar cane). The increase in the concentration of carbon dioxide in the atmosphere and the deposits of nitrogen are two factors which have been associated to the increase in the capability of the forests to store carbon dioxide in recent decades, resulting in a greater net extraction of carbon.

So far, it has not been possible to estimate precisely the actual contribution of deforestation to the annual global CO_2 emissions. The Intergovernmental Panel on Climate Change (IPCC) indicates that in the last two decades, the flux of CO_2 caused by changes in the use of land was dominated by tropical deforestation, but the differences between different estimates are significant: while Houghton (2003) estimates an annual loss of carbon for tropical America at around 0,8 ± 0.3 GtC in the 1990s, Achard et al. (2004) present corresponding estimates of between 0.3 and 0.4 GtC, and DeFries et al. (2002) between 0.2 and 0.7 GtC [9] (IPCC, 2007b). According to the IPCC (2007c), from 1970 to 2004, the biggest increase in CO_2 emissions was associated with power generation and road transportation (26%) and with industry (19%). Agriculture (14%), use of land, changes in the use of land and forests (17%), residential and commercial buildings (8%) and treatment of waste (3%) increased at smaller rates.

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[8] The improvement in the growth of plants as a result of the increase in the concentration of carbon dioxide (CO2). Depending on their photosynthesis mechanism, some plants are more sensitive to changes of atmospheric concentration of CO2. C3 plants (the great majority of trees and agricultural products like rice, soy, wheat, potatoes and vegetables) normally have a better response to CO2 than C4 plants (grasses and sugar cane). The increase in the concentration of carbon dioxide in the atmosphere and the depositing of nitrogen are two factors which have been associated to the increase in the capability of the forests to store carbon dioxide in recent decades, resulting in a greater net extraction of carbon.

[9] To obtain more details see Table 7.2 in Chapter 7 of the Fourth Evaluation Report of Working Group I of the IPCC.

Forests have great potential for mitigating climate change, which includes forestation and reforestation activities, forest management, reduction of deforestation, handling of forest products, use of forest products to produce bioenergy so that it can substitute fossil fuels and improvement of forestry species aiming to increase biomass productivity.

There is today, within the remit of the United Nations Framework Convention on Climate Change, an effort to reduce the emissions caused by deforestation and degradation in developing countries. Even though this may be understood as an effort at mitigation, it also has a component of adaptation for preserving the wealth of species, the continuity of the forest ecosystems, and resilience. On the other hand, it is estimated that the negative impacts of climate change will contribute to the destruction and degradation of forests, promoting emissions of greenhouse effect gases and increasing global warming.

3.2. Climate change and natural variability

The fourth and last evaluation report of the IPCC associates the chances of the occurrence of many aspects related to future climate change, including alterations in surface temperature, rise of sea levels and the occurrence of extreme events. However, it is important to note the importance of estimating regional variations of climate change, so the potential impacts of this change on different biomes and on biodiversity can be assessed more precisely.

Some models used by the IPCC project, over the next two decades, an increase in the average global temperature of around 0.2°C per decade. Even if all greenhouse effect gases and aerosols were kept constant at the same levels detected in 2000, a warming of around 0.1°C per decade is projected. The precipitation scenarios, however, point to a probable[10] increase at high latitudes and a probable decrease in most subtropical regions, which may reach as much as 20% in 2010, according to one of its scenarios[11]. Nonetheless, IPCC recognizes that there are great uncertainties in the results of the models used, especially those related to tropical precipitation. The future climate scenarios presented by the IPCC models show, for the Amazon, positive anomalies of rain for one model, whereas the remaining models show a decrease in rainfall, even in different magnitudes (Marengo, 2006). Projections of seasonal changes in average temperature and precipitation until the end of the 21st century, for 32 regions in the world (including the Amazon – AMZ) are presented in the last evaluation re-

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[10] Relative probability is over 66%.

[11] Scenario A1B (see section V – Scenarios)

port of the IPCC (IPCC, 2007a)[12], based on the coupled general atmosphere-ocean general circulation model-AOGCM.

The IPCC also projects, in some of its models, an increase of occurrences of extreme events, such as drought in the Amazon and in Europe resulting from the increase in temperature and the decrease in precipitations in the summer. Some studies by the Institute of Amazon Research (Ipam) show that with global warming and more frequent droughts, forests in the Amazonian region will lose much of their humidity, thus becoming much more vulnerable to fires. There will also be a significant increase in the mortality of trees, followed by an increase in carbon emissions into the atmosphere. In addition to the association to climate change, since the 1970s some periods of longer and more intense droughts have in fact been observed in an increasing number of places in the world (Cox et al., 2004; Schaphoff et al., 2006; Scholze et al., 2006). The occurrence of this kind of event can affect the net productivity of forest ecosystems and cause carbon emissions as a result of the mortality of trees and reduction of resilience (see, for example, Betts et al., 2000; Peng and Apps, 2000; Semazzi and Song, 2001; Bergengren et al., 2001; Leemans et al., 2002; Körner, 2003; Cox et al., 2004; Canadell et al., 2004; Heath et al., 2005; Ciais et al., 2005). It is worth mentioning, however, that these effects are still not properly understood and vary from place to place (Reichstein et al., 2002; Betts et al., 2004). In higher and colder areas, for example, drought can accompany a greater growth of trees, due to the increase in the growth period and better photosynthetic activity (Jolly et al., 2005).

Besides the potential fluctuations in the mortality of trees, the increase in inflammability of vegetation is also attributed to drought. For instance, the results of some studies about the short and long term impacts on vegetation resulting from the European heat waves of 2003, point to a reduction of approximately 30% in primary gross vegetation productivity, turning it into a net carbon source, of about 0.5 Pg[13]C a year (Ciais et al., 2005). However, it was observed that the impacts on the vegetation were different depending on altitude (Jolly et al., 2005): some forest formations were able to recover their original state in the year following the disturbance (Gobron et al., 2005), whereas others presented complex delayed impacts (Fischer, 2005). The heat waves were also held responsible for the record occurrence of extensive forest fires in many European countries; the area of destroyed forest throughout the continent is estimated to be around 6.500 km^2 (De Bono et al., 2004). Portugal alone had an area affected by forest fires four times larger than the average observed from 1980 to 2004 (Trigo et al., 2005; Trigo et al., 2006).

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12 Scenario A1B (see section V – Scenarios)
See Figure 2.6 a (for average temperature) and b (for precipitation) in the contribution of Working Group II of the IPCC, Chapter 2, Section 2.4.6, pp. 150 and 151

13 1 petagram = 1015 grams

In Brazil, the drought in the North of the country caused by the El Niño phenomenon between 1997 and 1998 was responsible for a huge forest fire in the state of Roraima which affected a significant part of its primary forest. According to Cochrane (2003), fires are becoming more common and have strong negative effects on the vegetation of the Amazon. Although the IPCC forecasts little change in the scope of El Niño in the next a hundred years, the Panel indicates the possibility of an intensification of the extreme droughts and floods which happen during the occurrence of this phenomenon.

The repetition of events of this nature over a long period may result in alterations in the type of vegetation in the biome of the forest leading to the formation of bushes that are highly inflammable and thus more vulnerable to burning than other types of less inflammable vegetation, such as forests (Nunes et al, 2005). The emission of carbon dioxide resulting from the mortality of vegetation and loss of carbon associated with its original stock, and the emissions of other greenhouse effect gases by burning the biomass of vegetation, such as methane and nitrous oxide, can contribute to accelerating climate change (Cox et al., 2000). However, it is important to mention that the burning of biomass also promotes an increase in the quantity of aerosols in the atmosphere, and that globally these lead to negative radiative forcing.

The changes in the intensity and frequency of extreme events are expected to cause significant impacts in forest formations, capable of causing mass mortality of trees and thus affecting the distribution of species in the ecosystems (Parmesan et al., 2000). The IPCC forecasts that agriculture, forests and ecosystems will be negatively affected by the increase in heat waves, events of strong precipitation and drought or increase in intensity of tropical cyclones. It is projected that the decrease in frequency of cold days and cold nights will increase agricultural productivity in colder places, but will also increase the occurrence of insects.

Finally, it is important to point out that even in the alterations already observed in forest systems in some parts of the world, especially relating to a more frequent occurrence of forest fires and diseases, it is difficult to identify which of these effects what would be attributable to climatic or to non-climatic forces.

3.3. How can we predict the impact of climate change in the forests?

Even though it is understood that some systems, sectors and regions are particularly vulnerable to climate change, including forests (especially boreal ones), there is great difficulty in qualifying or quantifying the impact of such change. This is because of uncertainties associated with future emissions of greenhouse effect gases, which are intrinsically associated to the extension of climate change. The climatic models used to estimate future changes in some climatic variables, such as average surface temperature and precipitation, are based on scenarios of emissions that serve as the basis for some projections about climate. The IPCC uses several scenarios based on demographic, social, economic, technological and environmental developments, for which there does not always exist available or reliable data.

Some studies have tried to simulate the response of vegetation to different climatic conditions, but the results are not always consistent. Normally, they project significant changes in the spatial distribution of vegetation and differentiated impacts in different forest communities (Brzeziecki et al., 1995).

Kirschbaum and Fischlin (1996) showed that even an increase in the average surface temperature of around 1ºC could be enough to cause changes in growth and the regeneration capacity of many forest species. In 1994, Miles et al. (2004) projected the annual impacts caused by an increase in concentration of carbon dioxide of 1%, above the current and potential distribution of 69 forest species typical of the Amazon region. The results indicate that the species which are more widely distributed and with a high tolerance to environmental variations, were less sensitive to changes in the atmospheric concentration of CO_2. However, it is clear that climate change, the occurrence of extreme climatic events or other processes may alter the composition of species in an ecosystem.

Although there is a degree of uncertainty concerning the future global climatic scenario, especially in Brazil, due to the differences found in the results of several models used to project the climate of the 21st century, all the scenarios point to a warming in the Amazon, although of different magnitudes. Warming is greatest in the tropical region, around 2ºC and up to 3ºC in Northern Amazonia, in scenario A2 of the Intergovernmental Panel on Climate Change (Marengo, 2006).

The results of historical and paleoecological studies on the effect of climate changes observed in forests in the past cannot be used to project future climate changes in forest ecosystems. This is mainly because forest area, age composition and species are today different, and have been greatly affected by human activities. In addition, and possibly more important, is the fact that average surface temperature is increasing at a rate never before seen. The projection of the response of forests to altered patterns of temperature, precipitation, solar radiation, wind, and other factors, requires more complex models than those currently used, which should include the complexities of forests and of the climatic system, and which should involve more appropriate spatial and temporal scales. An advance is being made in the direction of integrated evaluations which represent complex interactions in several spatial and temporal scales, processes and activities, but the results of these models are still considered to be preliminary.

Models of the Land System[14], which include components of the climate system (atmosphere, oceans, cryosphere, the land system and the biosphere) and its interactions are being developed to evaluate the potentially dangerous impacts of climate change, through the analysis of risks and vulnerability of the systems (Rial et al., 2004). The Global Climate Models[15] are also advancing towards a more complete representation of the climatic system.

The result of simulations in models which integrate the atmosphere and biosphere through a complete carbon cycle points to potential large-scale death of the Amazonian forest, diminishing its role as a sink and reservoir for carbon and at the same time contributing to increasing the concentration of carbon dioxide in the atmosphere (Friedlingstein et al., 2006; Denman et al., 2007). In the mid-1990s some climatic models were already projecting substantial changes in the composition of forests, large-scale dieback, and loss of forest coverage in response to the increase in temperature associated with an increase in the concentration of greenhouse effect gases in the atmosphere.

After the third evaluation report of the IPCC, the event of large-scale death had already been projected by Dynamic Global Vegetation Models[16], to the end of this century and beyond. This phenomenon would affect forests in tropical, mountainous and boreal areas, resulting in loss of basic services.

According to Marengo (2006), "extreme climatic events, such as droughts caused by global warming and deforestation, may divide the Amazon in two and transform an area of 600,000 km^2" into savanna. Hutyra et al. (2005), mentioned by Marengo (2006), prepared "a map of the areas most sensitive to droughts, using precipitation records of the last 100 years". The authors discovered that one stretch of the map corresponds to 11% of the area of the forest, which goes from Tocantins to Guiana and crosses the region of Santarém (Pará) which has precipitation more akin to that of

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[14] The Models of the Land System are models designed to estimate the spatial and temporal distribution of the main flows of carbon and nitrogen and the reservoirs in the land biosphere, on regional and global scales.

[15] Global Climate Models are a class of General Circulation Models used to make forecast predictions, to understand the weather and project climate change. They are called Global Climate Models of because of their understanding of climate and projection of climate change.

[16] Dynamic Global Vegetation Models are models based on processes which include the coupling of biogeochemical flows with the dynamic of the vegetation (productivity, dynamic competitiveness of vegetation, growth, disturbances, mortality and others).

the savanna. This is consistent with the future scenarios generated by the Hadley Center model, which projects a savanna climate for the Amazon from 2050 on. This dry Amazon has vegetation with higher rates of evapotranspiration and its soils tend to be dryer during the months of drought than soils of very humid regions, and this makes it more vulnerable to forest fires, the main agent of turning forests into savanna. Previously, Oyama and Nobre (2003) had estimated that deforestation and warming could convert up to 60% of the Amazon into savanna, conclusions derived from the CPTEC[17] model, with a dynamic vegetation structure.

It is important to mention that some types of forests can benefit from climate change, especially those currently affected by limitations of their minimum requirements of temperature and precipitation. Forests can also improve their net productivity as a result of fertilization by CO_2 (although the magnitude of this effect is still uncertain for several types of systems), of the increase in average temperature in cold climates, with simultaneous increase in precipitation to compensate for the deficit of water evaporation, and of the increase in precipitation where the availability of water is limited.

In tropical forests, which have the biggest carbon reserves in their biomass, the increase in atmospheric concentration of carbon dioxide since the Industrial Era may have favored the dynamic of growth (Phillips et al., 2002; Laurance et al., 2004; Wright et al., 2004). However in the future, a more dynamic forest may, as a last resort, store less carbon instead of more, if changes in the composition of species occur (Laurance et al., 2004; Malhi et al., 2006), especially as a result of an exceptional response of the tropical vines to carbon dioxide, which may cause tree mortality and population changes (Körner, 2004).

In areas of unbroken Amazonian forest, the direct effects of fertilization by carbon dioxide may have caused a substantial increase in the density of vines in the last two decades (Phillips et al., 2004). Estimates of the primary net global production from vegetation rates derived from satellite data indicate an increase of 6% from 1982 to 1999, with great increases in tropical ecosystems. Satellite data used in a study by Zhou et al., (2001) confirm that vegetation activity in the Northern Hemisphere increased by 12% in Eurasia and 8% in North America, in the period 1981-1999. So in this sense, the tendency for longer seasons of growth is consistent with the increased greenness of the vegetation. Fang and Dingbo (2003) attribute the increase in the primary net productivity in forests in China to the increased growth season, in the whole country.

In Southern Europe a tendency in the reduction of biomass productivity was detected in relation to the decrease in precipitation, especially after the severe drought of 2003. In North America, the loss of an important part of forest, detected by satellite data, is associated with hotter and longer summers.

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[17] Center for Weather Forecasting and Climatic Studies of the National Institute of Space Research (Inpe).

Fragmented forests are more vulnerable to periodic damage from the droughts caused by El Niño than intact ones. Among the damage, a high rate of mortality of trees is recorded, changes in the phenology of plants and other ecological changes, especially on the edges of the forest. According to Laurance and Williamson (2001), forest fragments are especially vulnerable to drought, as their edges are dryer and more apt to suffer from fires and are normally near pastures, which are frequently burnt to renew their grass.

The IPCC projects, for the middle of this century, with great confidence, that the increase in temperature and the associated decrease in the amount of water in the soil will lead to the gradual substitution of tropical forest for savanna in the Eastern part of the Amazon, while in drier areas (like the semi-arid region), climate change is expected to lead to the salination and desertification of agricultural land.[18]

It is highly probable[19] that natural disturbances such as fire, insects and diseases will be altered by climate change, not only by their frequency, but also in their intensity, impacting on forests and the forestry sector. However, it is difficult to estimate precisely the impact of climate change in these disturbances.

Many existing forests and the greater part of those recently established can experience climatic conditions that differ from the current conditions. Unfortunately, for forests with low levels of management or no management at all, especially tropical forests, there are fewer options for planned adaptation than there are for more intensely managed forest, increasing the uncertainties about the vulnerability of those forests to climate change.

3.4. Adaptation of forests to climate change

Even though forests, as a class, have proved to be resistant to climate changes in the past, the fragmentation and degradation of forests today makes them vulnerable. The adaptation of species to climate change may occur through evolution or migration to more appropriate places, the latter being, very probably, the most common response in the past. Among the land use practices and management systems with the greatest possibility for maintaining biodiversity and the ecological functions of forests during climate change are: protection of primary forests, suppression of frag-

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[18] See the contribution of Working Group II of the IPCC in the Fourth Evaluation Report, in Chapter 13, sections 13.2, 13.4 and 13.7.

[19] Percentage probability of more then 90%.

mentation and representation of different forest types along environmental gradients in reserves, the practice of low-intensity forest exploitation, the maintenance of a varied gene bank, and the identification and protection of functional groups and important species.

The productive forest sector is already investing in increasing varieties, forest protection, regeneration of forests, silviculture management, and general forest operations (Spittlehouse and Stewart, 2003).

Forests are impacted by the increase in the concentration of CO_2 in the air, by changes in the temperature system and variations in the annual rainfall patterns. These changes may alter the basic biological processes in trees and the soil, in time influencing growth and commercial productivity. There are, however, gaps in time between the occurrence of atmospheric changes and the biological responses of forest systems which need to be better understood to understand the effect of climate change in forests.

Both climatic and non-climatic forces affect systems, making it a challenge to analyze the role of climate change in the changes observed. Non-climatic forces include urbanization and pollution, which may influence systems in a direct or indirect manner, through its effects on albedo and on the level of humidity in the soil. Socio-economic processes, including changes in land use (for instance, conversion of forest into agricultural land, or agricultural land into urban areas) and modification of land cover (for example, through degradation and restoration processes) also affect the systems.

A study evaluating the global impacts of climate change and the climatic variability in forests and forest products indicates that climate change may affect the productivity of forests, with an impact on the market as a consequence, and also on the supply of wood for other uses, such as biomass energy generation (Perez-Garcia et al., 2002). Alig et al. (2002) project that the net impact of climate changes in the American forest sector may be small, due to the low susceptibility of the American wood market to climate change. This happens because of the great stock of forests, technological changes in the wood industry and the ability to adapt (Shugart et al., 2003). Economic surveys on damage from climate change for different sectors show many regional inequalities in vulnerability to impacts of climate change (Tol, 2002a, b; Mendelsohn and Williams, 2004; Nordhaus, 2006).

Some studies conducted in Australia indicate that climate change may have significant negative impacts on its forestry industry, from the lower growth of trees due to little water, increase in temperature, increase of damage caused by fires and wind, and increased pressure of plagues and diseases. Frequent or extensive impacts on planted forests may reduce considerably the sustainable supply of wood to the processing industry. Climate change may also affect species that can be cultivated productively in different regions, impacting on financial income.

3.5. Scenarios

The Storylines[20] and global scenarios of the Special Report on Emission Scenarios[21]

The Special Report about Emission Scenarios presents four 'storylines', called A1, A2, B1 and B2, which describe the relations between driving forces of the emission of greenhouse effect gases and aerosols and their development during the 21st century, for large regions and also globally. Each storyline represents different demographic, social, economical, technological and environmental developments which diverge irreversibly and result in different levels of greenhouse effect gas emissions. The storylines assume that no specific climate policy is implemented, creating a baseline to which the narratives with specific adaptation and mitigation actions can be compared.

The storylines constitute the basis for the development of quantitative scenarios using different numeric models that were presented in the third evaluation report of the IPCC. The emission scenarios were converted into projections of atmospheric concentration of greenhouse effect gases and aerosols, radiative forcing of climate, effects on regional climate and climatic effects on global sea levels (IPCC, 2001).

In storyline A1, the world is directed to the market, the economy has a faster per capita growth; population peaks in 2050, declining afterwards, governance is regulated by strong regional interactions and income convergence; for technology, three groups of scenarios were developed: A1FI: fossil-intensive; A1T: sources of non-fossil energy;

- A1B: balance between all sources.

In storyline A2, the world is differentiated, the economy is oriented regionally and has the lowest per capita growth; population is continually growing; governance is self-supported in preserving local identities; technology is lower and technological development is more fragmented.

In storyline B1, the world is convergent; the economy is based on services and information and has less growth than in storyline A1; population is the same as in storyline A1; governance is

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[20] Storylines are narratives of how the future can evolve. They describe the main tendencies of social-political-economic driving forces of change and the relationship between them. Although storylines can constitute a scenario in themselves, they normally involve quantitative projections of future change. (IPCC, 2007a).

[21] The following text is an adapted translation of the one in Box 2.2 and its Figure 2.5, based on Nakićenović et al. (2000) (Synthesis of the characteristics of the four storylines of the Special Report of Emissions Scenarios), in section 2.4.6 of Chapter 2 of the Evaluation Report of Working Group II of the IPCC (IPCC, 2007a).

based on global solutions to economic, social and environmental sustainability; and technology is clean and efficient in resources.

In storyline B2, the world is based on local solutions; the economy has an intermediate growth level, the population is continually growing, but at a lower rate than in storyline A2; governance is based on local and regional solutions to environmental protection and social equity; technology develops more rapidly than in storyline A2, but less rapidly and in a more diverse way than in A1 and B1.

One of the limitations of the different models used to project the potential impacts of climate change is the representation in the models of changes in land use. Some models include the effect of climate change on land cover in the future, while others do not. In some studies, climate change is indicated as having a negligible effect on the change in land use when compared to socio-economic factors (Schröter et al., 2005). Technologies, especially those which affect productivity, will also determine the way the future will develop.

Preliminary versions of biochemical global models have indicated that land ecosystems would act as carbon a net carbon sink for many decades and possibly throughout the 21st century, due to benefits of fertilization by carbon dioxide, the occurrence of longer growth seasons and higher precipitation levels. Nonetheless, as the benefits of fertilization stabilize and the effect of the temperature on respiration and transpiration increase, this will lead to a reverse in the capacity for carbon removal from the atmosphere, potentially resulting in net losses of carbon in global ecosystems (e.g. Cramer et al., 2001).

One of the difficulties associated with modeling the impacts of climate change in forests is that the effects of climate change will probably differ between existing trees and those grown in the future (whether naturally or planted). Native forests are adapted to the local climate and to the variability of that specific climate. Climate changes will affect these trees through a change in the growth rate, mortality of trees and the production of seeds for the next generation of forests. For existing trees, other impacts of climate change may include the increase of risk of forest fires and mortality together with an increase in plagues and diseases. Our understanding of the relationship between existing trees and the climate is the basis for modeling of their future impact on climate. On the other hand, trees planted in the future will grow in a different environment, their responses to climate change may be surprising in terms of growth in volume, productivity and quality. Six dynamic models of global vegetation used to project the possible responses of tropical ecosystems and those in the Southern Hemisphere to the increase in the atmospheric concentration of CO_2 and to climate change in the net productivity, indicate great uncertainties.

3.6. The future and the needs

According to the IPCC (2007a)[22], "many studies about impact, adaptation and vulnerability to climate change need to include future changes of use and land cover. This is especially relevant to regional studies related to agriculture and water resources (Barlage et al., 2002; Klöcking et al., 2003), forests (Bhadwal and Singh, 2002) and ecosystems (Bennett et al., 2003; Cumming et al., 2005), but there is also a great influence in the regional patterns of demography and economical activity (Geurs and van Eck, 2003), and the problems caused by environmental degradation (Yang et al., 2003) and pollution (Bathurst et al., 2005). Scenarios of use and land cover were also used to analyze feedback to the climatic system (DeFries et al., 2002; Leemans et al., 2002; Maynard and Royer 2004) and sources and sinks of greenhouse effect gases (El-Fadel et al., 2002; Fearnside, 2000; Sands and Leimbach, 2003)".

It is necessary to improve the knowledge of the role of disturbance systems, referring to frequency and intensity of events such as drought, fire, insect epidemics, floods, wind storms because they interact with responses of the ecosystems to climate change and pollution (see, for example, Osmond et al., 2004; Opdam and Wascher, 2004).

There is also a need improve the projections of precipitation at a regional level and study its potential effects on the water system, emphasizing interactions between vegetation and atmosphere, including the effects of fertilization by CO2 on seasonal tropical forests and savannas (see, for example, Jasienski et al., 1998; Karnosky, 2003).

3.7. Preliminary recommendations

There is a series of recommendations that may be implemented in forest areas. Some of these recommendations may be put into the National (Action) Plan on Climate Change, currently in process of elaboration, and that has as its structural foundations the identification of mitigation actions, adaptation measures, research and development, training, dissemination and education.

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[22] See section 2.4.6.5 (Land use scenarios) in Chapter 2 (New Assessment Methods and the Characterization of Future Conditions).

As there is a synergy between deforestation and climate change, the former intensifying the impacts of the latter, actions to reduce deforestation will result in a reduction in the vulnerability of forests to climate change. Preventing forest fragmentation is a measure of anticipatory adaptation for native forests which is also associated with the reduction of deforestation. This reduction will bring not only benefits in terms of the prevention of climate change (mitigation), but also in terms of adaptation, reducing the vulnerability of forests to climate change.

There are important gaps in scientific knowledge about potential impacts of climate change on forests and on the productive forest sector as a whole, as well as in the identification of the vulnerabilities of these systems.

It is necessary to increase the quantity and quality of data and information necessary to study the impact, adaptation and vulnerability to climate change, and promote the use of methods and tools to allow a better regional and local evaluation of the vulnerabilities and potential impacts of climate change, especially on forest ecosystems. In the former, the Brazilian Research Group on Climate Change could become an important means of collecting data and information, since it proposed to carry out studies on the impacts of climate change in Brazil with emphasis in the vulnerabilities of the country to climate change and in the creation of alternative forms of adaptation to this change of the country's social, economic and environmental systems.

There must be a guarantee of the reliable dissemination of information about the impacts already observed and their locations, as well as projections of the expected impacts of climate change, in different emission scenarios, warning on irreversible impacts, estimating the different risks and identifying opportunities related to climate change.

Using knowledge about potential impacts, methods must be defined to identify and evaluate the measures and strategies of adaptation, including how to make forests more resistant to the impact of climate change. This can result in changes in the management and planning of planted forests, as well as in their composition. It is important to mention that reforestation with native species will not necessarily ensure that these forests will adapt to climate change. Currently, in Europe, ideas about genetic conservation and biodiversity policies vary. In Iceland, it is considered that all species present since 1948 are eligible for reforestation programs that aim to create climate-resistant forests. In the United Kingdom, only those species with a pollen record indicating they are more than 5,000 years old are considered native, and only in those regions where they were originally located. This can result in policies that are at first sight incoherent, not supporting reforestation of a species that is not native in a region which is potentially receptive to this species, since it may not adapt and continue to develop in its native region because of climate change.

There is a need for increasing knowledge about which species would be more appropriate to live in conditions of an increase in temperature and different of rainfall rates. It is important to mention that although it is possible to project a small or insignificant change in the annual amount of rain, there is a risk that the rainfall distribution will change, resulting in periods of really intense rain, followed by longer periods of drought.

Finally, it is important to work towards the development of mitigation scenarios which include policies and explicit measures to reduce emissions by deforestation and emissions by forest degradation, including the economic and technological aspects associated with the reduction of emissions.

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4. Vulnerabilities, impacts and adaptations to climate change in the agricultural sector and agricultural soils

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4.1. Introduction

According to the Intergovernmental Panel on Climate Change - IPCC (2001a), by the year 2100 the average global temperature will increase between 1.6°C and 5.8°C, representing warming rates from 0.1-0.4°C per decade. In Brazil, the highest warming rates will be seen in the Amazon rainforest and the lowest in the states of the Southeast region, on the Atlantic Rainforest coast (Morengo, 2006).

According to Morengo (2006), a warming trend has been observed in Brazil since the beginning of the 20th century, and it has been especially detected in winter, when the minimum temperature shows a tendency to rise greater than that of the maximum temperature. According to Morengo, an indicator of this warming would be a tendency to experiencing a greater frequency of warm days in winter and also, to a lesser extent, more frequent warmer days in summer and winter. In terms of rainfall, the trend is more uncertain due to the shortage of research in this area, although an increase in extremes of rainfall has been observed in the South and Southeast regions, as well as in Amazonia.

Agriculture is an activity that depends greatly on climatic factors, alterations in which may affect productivity and crop management, as well as social, economic and political factors, and therefore it will be influenced by global climate changes. This influence is specific to each crop and region. The adaptability of agricultural establishments to climate changes may vary, putting them in vulnerable positions according to different climate scenarios. The threat global climate changes represent to agriculture is mainly translated into a decrease in productivity and a reduction in the number of suitable areas for farming.

According to long-term predictions based on the global climatic models from the IPCC (IPCC, 2001a), tropical and subtropical regions, or regions at low latitudes, will be more affected by climate change than other regions (IPCC, 2001b; FAO, 2003; Ramankutty et al., 2002; Jones & Thornton, 2003; Mendelsohn et al., 2004c). The report also states that developing countries may be more vulnerable to climate alterations due to the predominance of agriculture in their economies, lack of financial resources for adaptation measures and their high exposure to extreme events (Parry et al., 2001; Fischer et al., 2005), as well as to inadequate provision of markets, among other factors. According to the IPCC (2001b, 2007), the ability of production systems in Latin America, Africa and Asia to adapt is low and their vulnerability is high, especially among low-income producers, who depend on more traditional agricultural systems or on land less suitable for agriculture.

The IPCC (2001b, 2007) points out a great probability of degradation of natural resources such as soil and water occurring as a result of temperature and rainfall changes, with negative consequences for agriculture. It also projects a reduction in the productivity of many crops, even when the direct effects of doubled concentration of CO_2 and of the implementation of moderate adaptation measures at farm level are considered. Despite the high variability in the projections of productivity, a certain pattern is consistent in indicating a reduction in rice production after 2010, and the increase of soybean production when the effects of CO_2 increases are considered (IPCC, 2007)

The increase in CO_2 may have positive effects on some plants, and may also provide a more efficient use of water. However, in scenarios of growing temperature increase, this effect may be neutralized by the impacts of climatic variability.

Some uncertainties remain as challenges to the composition of future scenarios, such as the size and the persistence of the effects of the increasing concentrations of CO_2 on agricultural production under realistic conditions of production; potential changes in loss of produce due to plant and animal diseases, spatial variability in responses to climate change, the effects of changes on climate variability and of extreme events on agriculture.

This paper discusses the impacts climate change may have on Brazilian agriculture and the subsequent risks to this area, as well as some adaptation strategies to face the problem.

4.2. Effects of different atmospheric concentrations of CO_2 on plants

Studies show that the concentration of atmospheric CO_2 increased from 280 ppm in the pre-industrial period to 379 ppm by 2005. Climate coupling and carbon cycle (C4MIP) models project increases in the concentration of CO_2 of between 730-1020 ppm, around the year 2100 (IPCC, 2007). The effect of this increase on plants has been the subject of studies, especially in terms of the impact on agriculture and food supply.

Recent research shows that the effects of CO_2 on plant growth and productivity will depend on the photosynthetic pathway of the species, the growth stage, and the system for managing water and applying fertilizer (Jablonski et al. 2002; Kimball et al., 2002; and other authors quoted in IPCC, 2007).

One of the characteristics of plant species which determines their productive potential is the photosynthetic pathway. Arboreal and bush species, the main plant components of important biomes on Earth, use the C3 photosynthetic pathway (see Box 1). In the same way, major agricultural crops, including some species from the gramineae family such as rice and wheat, also use this pathway, while several forage gramineae, including brachiaria, and those found on small plantations, such as corn, sorghum and sugarcane, use the C4 pathway. The latter is characterized by a higher efficiency in CO_2 fixation, notably through morphological and physiological modifications of the photosynthetic system, which causes different performances of plants in different environmental conditions (Table 1). The higher the intensity of light the more efficiently C4 type plants perform photosynthesis, and therefore they do not show saturation in assimilating CO_2 in relatively low conditions of lighting, as happens with C3 type plants. If sunlight is not a limiting factor, the production of C4 plants may be 2 or 3 times greater than that of C3 plants.

Box 1 - C3 and C4 plants

There are three types of photosynthetic assimilation of CO_2 by chlorophyll plants. According to their type, plants may be classified as C3, C4 and CAM plants. C3 and C4 refer to the number of carbon atoms in the first product of CO_2 fixation. In C3 plants the first product of the biochemical chain is 3-phosphoglyceric acid (3-PGA), a 3 carbon molecule. The C3 photosynthetic pathway involves a carboxylation process, which consists in the addition of a CO_2 molecule to a ribulose-1.5-bisphosphate, by means of the Rubisco enzyme (ribulose-1.5-bisphosphate carboxylase-oxygenase), a simplification of the so-called Calvin cycle.

The photosynthetic system of C4 plants produces a 4 carbon molecule, oxalacetic acid. These plants have a differentiated structure characterized by a layer of cells which wrap around the sap-conducting vessels like a sheath (Kranz anatomy), in which we find the Rubisco enzyme. Carboxylation is carried out in the other cells of the leaf through the addition of the CO_2 molecule to a phosphoenolpyruvate molecule (PEP), by means of the phosphoenolpyruvate carboxylase enzyme (PEPCase), forming oxalacetic acid, which is immediately transformed into malate and aspartate. In the chloroplasts (organelles containing chlorophyll, the substance which transforms light energy into chemical energy) of the sheath, aspartate and malate are turned into CO_2 and pyruvate. CO_2 is captured by the Rubisco enzyme, following the Calvin cycle.

C3 plants are limited by CO_2, that is, even with an abundance of light, the rate of CO_2 supply to the chloroplast is very slow. C4 plants overcome this limitation because they use available CO_2 more efficiently, with consequently higher rates of liquid production at high levels of light. Levels of lighting and temperature are environmental factors that limit photosynthesis for C4 plants.

Considering an average of several species under stress conditions, studies show that there would be an increase of 10-20% in the productivity of C3 plants and of 0-10% in C4 plants with a CO_2 concentration of 500 ppm, in relation to the current atmospheric concentrations (Ainsworth et al., 2004; Gifford, 2004; Long et al., 2004, quoted in IPCC, 2007). Good photosynthetic response is generally obtained at higher levels of temperature and radiation in C4 plants rather than in C3 species (Table 1). Stress due to high temperatures causes a set of morphoanatomical., physiological and biochemical changes in C3 plants (Wahid et al., 2007) which affects their development and may in some cases result in drastic reductions in productivity.

Table 7-1: Average photosynthetic response to radiation and temperature for four groups of crops

Characteristics	Crop adaptability group			
	I	II	III	IV
Photosynthetic pathway	C_3	C_3	C_4	C_4
Photosynthetic rate in saturation conditions of optimum lighting and temperature, in mg CO_2 dm^{-2} h^{-1}	20-30	40-50	70-100	70-100
Optimum temperature for maximum photosynthesis in °C	15-20	25-30	30-35	20-30
Radiation intensity in maximum photosynthesis	0.2-0.6	0.3-0.8	>1.0	>1.0
Crops	Wheat Potato Beans (temperate and high -altitude tropical cultivation)	Beans (tropical cultivation) Soybean Rice Cotton Sweet potato Cassava	Millet Sorghum (tropical cultivation) Corn (tropical cultivation) Sugarcane	Sorghum (temperate and tropical high -altitude cultivation) Corn (temperate and tropical high -altitude cultivation)

With current atmospheric CO_2 concentrations, C3 and C4 plants do not achieve saturation of the photosynthetic system, and this is the most common factor for the limitation of photosynthetic rates (Larcher, 2000). Considering the less efficient use of CO_2 made by C3 plants, in which photosynthetic system saturation would only occur with CO_2 concentrations of around 1000 ppmv, one would expect a significant increase in primary production of these plants as a response to the increase of CO_2 in the atmosphere. The primary production of tropical forests would be a direct effect, since other factors do not show a negative effect on plants (Karnosky, 2003). Studies under controlled conditions, including temperature and humidity, show an average increase of 30% in productivity of several C3 crops submitted to an atmosphere with doubled concentration of CO_2. Under less controlled conditions in the field, there were minor gains in productivity (10 to 28%). C4 plants show practically no advantage coming from the higher concentration of CO_2 (Fuhrer, 2003).

The larger accumulation of biomass by plants which benefit from higher concentrations of CO_2 in the atmosphere is followed by more efficient use of nitrogen, without necessarily producing crops richer in protein (Fuhrer, 2003). In the long term, productivity is expected to diminish due to the decrease of N stocks in the soil, which could be compensated for by soil fertilization. This could be a negative factor for agriculture in developing countries due to the lower than required doses of nitrogen fertilizers used on crops. In this respect, crop rotation, with the cultivation of leguminous plants that can fix atmospheric $N_{2,}$ may contribute to a greater presence of N in the soil. Soybean crops, which occupy wide areas of Brazil as a summer crop, besides their relevance as a source of oil and protein, may decrease the risk of damage in future scenarios of N shortage as a component of crop rotation which is capable of fixing enough nitrogen from the air for high productivity and leaving a nitrogen surplus for the next crop in the form of stubble.

It is obvious that a rise in CO_2levels may result in higher photosynthetic rates in C3 species, with direct consequences for productivity. However in scenarios of increasing global temperatures, this positive effect of CO_2 enrichment would be counteracted by negative effects resulting from high temperatures. Figure 4-1, which shows data compiled by Fuhrer (2003), indicates clearly the effects of temperature changes on wheat productivity, neutralizing the positive effects of a CO_2-enriched atmosphere.

In terms of adaptability to temperature and day length, there are marked differences between crops which use the C4 pathway for carbon assimilation (photosynthetic pathway) and those which use the C3 pathway. Good photosynthetic response is normally obtained with higher levels of temperature and radiation for C4 plants than those of C3 species (Table 1). Stress due to high temperatures causes a set of morphoanatomic, physiological and biochemical changes in C3 plants (Wahid et al., 2007), which affects their development and may in some cases result in drastic reductions in productivity.

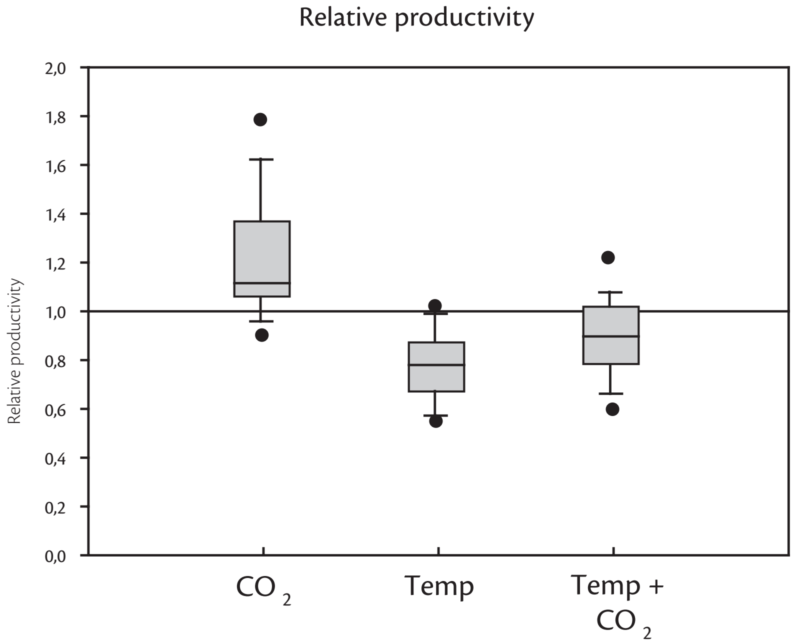

Figure 4-1: Effects of high concentration of CO2 and high temperatures, and effects of the combination of both factors on relative productivity of wheat; productivity in altered conditions in relation to normal environmental conditions of the studies.

Source: Fuhrer (2003).

According to climate scenario data generated by general circulation models, in 2050 soybean crops in Brazil will benefit from the higher concentration of CO_2 in the atmosphere, with an increase of productivity of about 20%. Wheat and corn productivity will be reduced as a consequence of temperature effects on crop cycles (Siqueira et al., 2001). However it is important to point out that effects of plague and diseases and climate risks were not considered in the model, which could drastically modify productivity predictions for crops.

Nowak et al. (2004) and Ainsworth and Long (2005) observed an increase of 10% in the production of air biomass in pastures composed of C3 plants. In tropical pastures there is a predominance of C4 plants which, according to studies revised by Porter (1993) (quoted in Howden et al., 1999), present a smaller increase in the production of dry matter (28%) compared to C3 plants (71%) under doubled concentrations of CO_2 in the atmosphere. Gains would be associated rather with more efficient use of water than to necessarily higher rates of CO_2 assimilation. More efficient use of water is due to smaller stomatal conductance which reduces humidity loss, while increased levels of atmospheric CO_2 maintain internal concentrations of CO_2, and thus also maintain the process of photosynthesis. We must also consider the combined effect of increasing concentrations of CO_2 and temperature oscillations, which may have a much more adverse effect in tropical areas than in temperate areas, as a consequence of larger evaporation and evapotranspiration, added to direct (temperature, precipitation) and indirect (plagues and diseases) effects on plants.

Nowadays it is agreed that the effects of high concentration of CO_2 observed in experimental sites may be overestimating the real situation at farm level, because limiting factors such as plagues and diseases, weeds, competition for water and nutrients, among other factors, are not well understood on a large-scale, and are not sufficiently used in the most sophisticated models available (IPCC, 2007).

4.3. Vulnerabilities of pasture areas and animal production systems

There is still great uncertainty about the effects of global changes on animal production systems. The prediction is that animal production in Latin America, predominantly characterized by the pasture system, will be negatively affected by greater variability in precipitation. Seasonal patterns of water availability and low nutrient availability in the soil are factors limiting the pasture areas of most of the region, and the nutritional value of tropical pastures, which is low already, may decrease even more as a consequence of the increase in the C:N (carbon:nitrogen) relationship (Zhao et al., 2005).

Among the most important factors for animal production systems is temperature increase and the CO_2 fertilizing effect. According to an FAO study (2003), agricultural livestock in temperate regions, especially in developed countries, will be favored, while in developing countries it will suffer losses due to heat stress on stock.

In terms of a direct effect on animals, temperature is the main factor. Variation in the rainfall regime may affect animals by drying water tanks and restricting water supply for consumption. Heat stress has a negative effect on the production of milk by cows, as well as on the fertility of pigs (Berman, 1991; Hahn & Mader, 1997; Hahn, 1999, quoted in Zhao et al. 2005).

Brazil, the greatest meat exporter in the world, has a beef stock mainly composed of zebu breeds, which is an advantage in relation to thermotolerance, given a future scenario of higher temperature. Zebu or Indian cattle (Bos indicus) have some advantages over the European (Bos taurus) in terms of thermotolerance, since zebu animals have greater capacity for regulating body temperature in thermal stress conditions, and high temperatures have less effect on their body cells in comparison to European cattle. In addition, zebu cattle's hide has special properties which increase heat loss and reduce the absorption of solar radiation (Hansen, 2004). Chicken breeding, in which Brazil is the second-largest producer, may also be affected by climate changes. Adult animals develop best when exposed to temperatures ranging from 18°C to 20°C, and are susceptible to high temperatures, with high mortality rates when the ambient temperature exceeds 38°C. Heat stress is responsible for great losses in chicken yield; a decrease in body weight is observed, followed by an increase in mortality rates (Fabrício, 1994). Thermotolerance is being investigated, but no great advance has yet been made. Acclimatization by exposing newborn chicks (up to 5 days old) to the stress of non-lethal heat (Arjona et al., 1988), or breeding birds with genes that result in fewer feathers, and therefore higher heat loss (Cahaner et al., 1993), are attempts at achieving better results from these birds in heat stress conditions. A plausible solution may be investments in facilities which ameliorate the effects of high temperatures.

Besides direct climate factors, other factors which affect agricultural livestock are the impact of changes on food availability and crop prices, impacts on pasture areas and forage crops, and the occurrence of plant and animal disease (Zhao et al., 2005).

4.4. Vulnerability of agricultural soil

Potential effects of climate changes on organic soil matter are still not well understood. It is however agreed that a significant alteration in carbon stocks in this sector will have an important effect on the composition of atmospheric gases, and will consequently affect the planet's weather. Climate change may induce losses of organic soil matter, interfering in the input and output of nutrients, and influencing the productivity of agricultural systems.

The amount of carbon present in the soil is the net outcome of the deposition and decomposition of organic residues when the former is part of the primary production of the surrounding vegetation. It is estimated that, in the first 30cm of depth, original stocks of carbon under native vegetation were around 37 Pg of C, and the largest stocks were found in Brazil's Southern region (Figure 4-2).

The inevitable removal of part of the native vegetation to obtain agricultural land has meant a reduction of carbon stocks in the soil, the level of which depended on the intensity of this agricultural use, as shown in Table 2, which illustrates the effects of soil use on important biomes around the country. Carbon loss in the soil is partly explained by a smaller production of residues in cultivated areas in comparison to areas with remaining native vegetation, and partly due to soil management, which has long been carried out on a conventional basis, with plows and harrows.

The increased adoption of production systems based on direct planting, and minimal cultivation, with crop rotation using plant species to promote soil overage and high residue production, with the emphasis here on integrating plantation and stock breeding, has not only reduced loss but created carbon accumulation in the soil, contributing to mitigating the greenhouse effect on the planet (Boddey et al., 2006; Cerri et al., 2007).

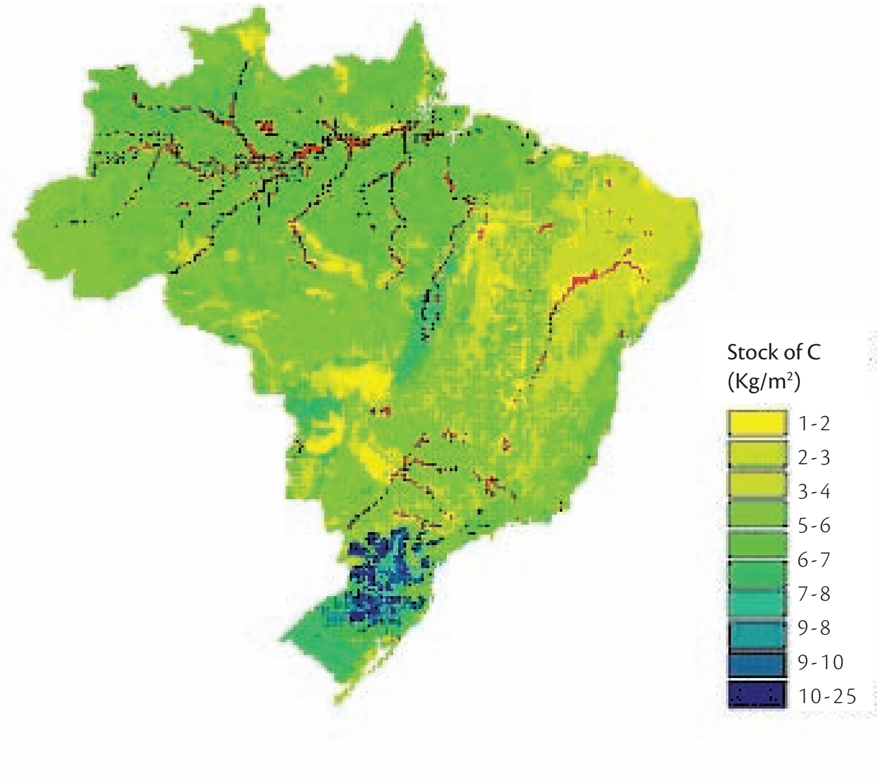

Figure 4-2: Carbon stocks (kg m^{-2}) in Brazilian territory (www.mct.gov.br)

Table 7-2: Effect of soil use on carbon stocks down to 1m deep, in subtropical forest and Cerrado regions

Soil use	C stocks (kg/m^2) for different soil layers (cm)	
	0-30	0-100
(subtropical) Forests	13.04	28.99
Cultivated (e.g. Forests)	6.56	13.58
Cerrado	9.35	19.46
Pasture (e.g. Cerrado)	7.52	13.61
Cultivated (e.g. Cerrado)	6.33	16.11

Changes in rainfall and temperature regimes will directly affect plant production, with consequent alterations in the balance between the deposition and decomposition of residues (Greenland et al., 1992). Increase of average soil temperature as a result of increased air temperature will have direct effects on the metabolism of organisms responsible for the decomposition of organic soil matter. As discussed by Davidson & Janssens (2006), organic matter decomposition is accelerated by an increase in temperature but this effect varies according to the organic matter component, thus the fraction which is protected by soil aggregates would not suffer from temperature effects. However if soil partitioning occurs due to direct impact of raindrops or to soil mechanization, organic matter will be unprotected and susceptible to mineralization, which will be more intense in a high-temperature scenario. In this case, a direct plantation system, which presupposes continual soil protection by preserving stubble, would play an important role in alleviating the effects of climate change on carbon loss from the soil.

A possible change in increase rainfall along with temperature rise, leads to uncertainties concerning the consequences of climate change for soil carbon stocks. More intense rains may break down aggregates and expose organic soil matter, where humid soil favors micro-organisms and their access to organic matter. On the other hand, in drier conditions, decomposition is reduced. In addition, it is more difficult to achieve soil humidity after long periods of drought by reason of an effect that repels water. This effect also occurs in areas which undergo frequent fires (Davidson & Janssens, 2006), which may happen in a scenario of higher temperatures, especially in forest regions.

These possibilities add to the uncertainties about the impact climate change may have on carbon stocks in the soil.

In relation to the growing concentrations of CO_2 in the atmosphere, recent research shows carbon stocks in the organic matter of the soil may rise and there may even be a saturation of this stock in conditions of high atmospheric concentrations of CO_2 (IPCC, 2007).

There are still many uncertainties about how extreme events (e.g. high temperatures, floods, etc.) and other atmospheric pollutants (e.g. tropospheric ozone) may affect soil carbon, especially in tropical soils, which reinforces the need for more research in this area in Brazil.

In an attempt at finding possible ways of reducing agricultural soil vulnerability to climate change, the IPCC (2007) draws attention the importance of identifying synergies between strategies of adaptation and mitigation in agricultural systems, bringing together questions about carbon capture, emission of greenhouse gases, change in land use and sustainable development of production systems within coherent networks of climate policy.

4.5. Effects of climate change on forests

Burning of forests and the intense use of their soil for agriculture largely contribute to the rise of the greenhouse-effect gases in the atmosphere, with Brazil responsible for more than 80% of total emissions caused by human agencies (Teixeira et al., 2006).

Forest ecosystems may be deeply affected by changes in concentration of CO_2 in the atmosphere and by alterations in climate variables. Global circulation models point to significant temperature rises in areas under natural vegetation, including the Amazon rainforest (Figure 4-3). In this case, biomass production and diversity may be influenced in a negative or positive way.

The great increase in concentration of CO_2 in the atmosphere projected for the coming decades must have a positive effect on tree growth, the extent of which will be influenced by plant species, soil fertility and the effect of other pollutants in the air (Karnosky et al., 2003). Oren et al. (2001) proved the fertilizing effect of CO_2-enriched atmospheres on *Pinus taeda* species, but experiments have shown that in low-fertility soils, no fertilizing effect has been observed. Since most forests occupy low fertility-soils, where nitrogen is an important limiting factor for tree growth (Vitousek & Howarth, 1991), we may not expect a significant compensatory effect from the excess of CO_2 in the atmosphere due to carbon capture in the forest biomass. An increase of 500ppm in the concentration of CO_2 in the air biomass has been observed for trees, within a range of 0-30%, where young trees have shown the highest values, and natural adult forests have shown few or no values at all (Nowak et al., 2004; Ainsworth and Long, 2005, quoted in IPCC, 2007).

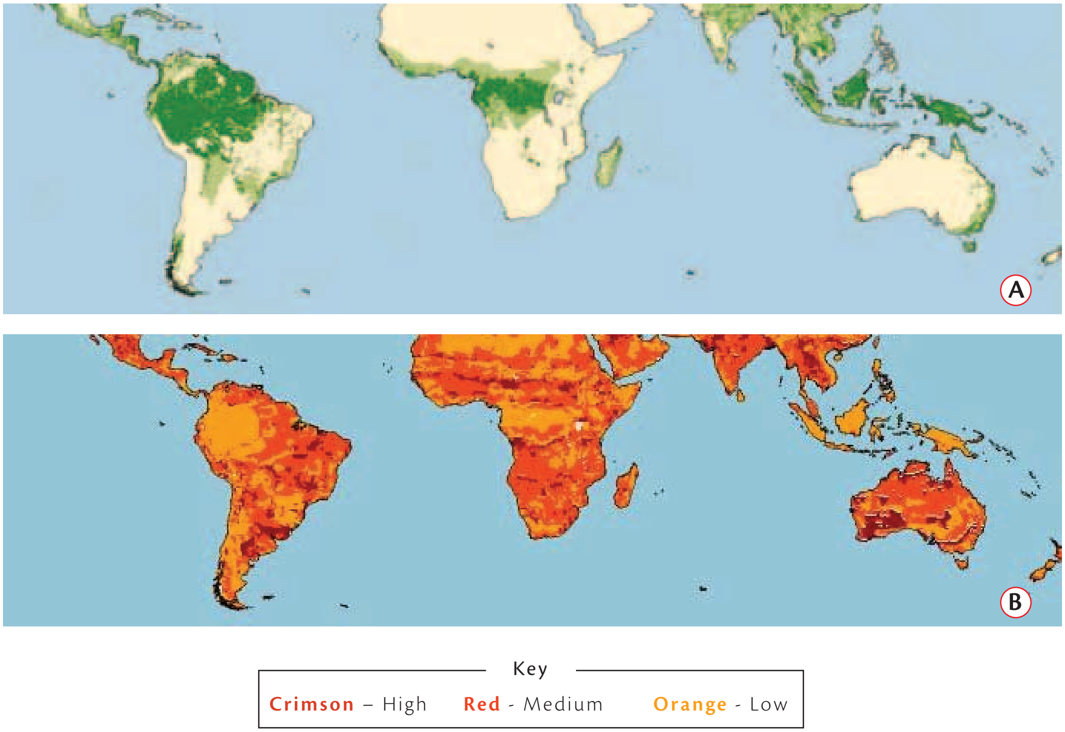

Figure 4-3: (A) Areas under tropical forests throughout the world, in green; (B) vulnerability according to climate changes.

Source: WWF - www.panda.gov.br

Temperature increase has a direct effect on the photosynthetic mechanism and in extreme conditions it may lead to a system collapse (Larcher, 2000). Water availability is a key factor in this process, and some regions such as the Amazon rainforest may suffer from water stress, becoming very vulnerable, although there are still great uncertainties concerning this.

The availability of nitrogen and other nutrients in the soil may rise due to accelerated decomposition of organic matter because of temperature increase (Melillo et al., 2002), and become more available for plant development, a situation which would allow an increase of carbon stocks in the system in the form of biomass. The presence of pollutants such as O_3 in the troposphere, combined with higher concentrations of CO_2, may decrease plants' defenses and increase their susceptibility to diseases, and the result would be a reduction in plant production (Percy et al., 2002). However some plagues and diseases themselves may be negatively affected, enabling better development of the forest (Zhao et al., 2005).

The Amazon rainforest has received special attention concerning the effects of climate change. The region holds the largest amount of tropical forest remaining in the world, the importance of which is in its role in the hydrological and climatic regulation of wide areas of South America, besides holding a large carbon stock and great biodiversity (Fearnside, 1999). Due to its importance, there is great concern about the global impact that the gradual disappearance of the Amazon rainforest would cause. This concern rises from the high deforestation rates observed over the years, which are the result of new roads that facilitate access to natural resources, and the creation of pastures, usually accompanied by fires (Figure 4-4).

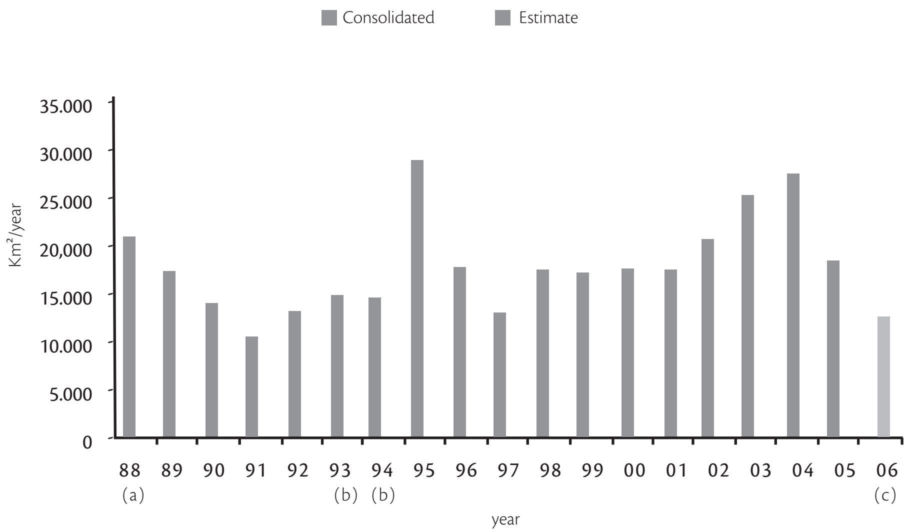
Rate of annual deforestation in Legal Amazonia Year

Figure 4-4: Deforestation next to roads opened within the Amazon Rainforest (A). The expectation of natural resources in the forest and the use of the land for agricultural activities are responsible for higher deforestation rates (B).

Source: www.inpe.br, INPE announces estimates of deforestation in Legal Amazon from August 2005 – August 2006, on 26/10/2006).

Deforestation leads to disastrous impacts on the environment, and fragments of forest remaining become even more vulnerable to climatic events. Laurance & Williamson (2001) show that forest fragments are more susceptible than intact forests to damage caused by long periods of drought caused by the El Niño phenomenon, which leads to physiological damage and even to the death of trees on the edges of the forest. These areas are drier, the risk of fire is higher and they are probably going to play a more important role in the permanence of plant covering than climate change (Zhao et al., 2005). The transformation of forest areas into pasture has immediate effect on temperature, evapotranspiration and precipitation. A study based on global circulation models confirms these effects, with increased drought periods, which would limit the development of humid tropical forests that are adapted to short periods of drought or even no drought at all (Nobre et al., 1991).

The predominance of drier environments has a negative effect on big forest trees, which cannot live under dry circumstances, and are then replaced by resistant species, which may give rise to the savannization of the Amazon rainforest.

Results presented by research studies are still filled with uncertainties about the impact of climate change on the survival and productivity of forests, especially tropical forests. However it seems reasonable to assume that the Amazon region may suffer from higher temperatures, and from periodic El Niño events, increasing the risk of fires. Forest areas in Brazil are certainly becoming more and more vulnerable due to deforestation and fires.

Finally, forests play an important role in regulating humidity and air temperature, on local, regional and global scales. Amazon forest evapotranspiration, for instance, is responsible for rains that pass over the Andes and arrive in the Mid-South region of Brazil (Fearnside, 2006), and this region is responsible for most of the nation's agricultural production. Thus changes in forest areas may result in great impacts on the country's agriculture.

4.6. Significant extreme events for agriculture

The frequency and magnitude of many climatic events increase as a result of even small temperature rises, and they will be higher given higher temperatures. Extreme events are floods, lack of soil humidity, tropical cyclones, storms, high temperatures and fires. Extreme events often have large-scale impacts locally and may significantly affect whole regions and specific sectors. Agriculture tends to be more vulnerable when exposed to extreme events related to water and temperature since this sector largely depends on natural resources. The growing of crops and quality of harvests may be relatively more susceptible to brief extreme events such as higher temperatures, severe frosts, hailstorms, and persistent droughts, situations which farmers fear the most.

The amount of damage caused by an extreme event depends on the development stage the crop has reached at the time of the incident. Cereals are a good example: if they are exposed to high temperatures before flowering, there will be a reduction in the number of grains that grow, leading to reduced grain production.

In order to measure the risk of extreme events and their consequences for crops, studies must consider crop-modeling activities. Large-scale models often mask local extreme events. Hence the importance of developing specific extreme event models for each crop.

According to Marengo (2006), global climate models have not shown a satisfactory simulation of current extreme events related to rainfall and statements declaring that extreme occurrences may be more intense and more frequent are based on observations made in the last 50 years and not necessarily on the projections of the models.

Observations made in Rio Grande do Sul, for instance, show that flood events and long droughts are respectively related to the El Niño phenomenon (warming of Pacific ocean waters) and to La Niña (cooling of Pacific waters). Harvest losses are observed during these events. According to the statistics available for the last two decades, four out of each ten harvests have been affected by drought events. Even though a forecasting system operates based on monitoring Pacific waters, much damage is still observed in production areas. Rainfall in the three summer months in 2004/2005 was less than 200mm in most of the state, the lowest in 53 years (Berlato and Cordeiro, 2005). According to these authors, this heavy drought led to a shortfall of about 20 million tons in the harvest in Brazil.

In Rio Grande do Sul alone, losses were more than 3.5 billion *reais* (US $1.7 billion). Harvest shortfall affects mostly poorer populations, which lose scarce resources invested in supporting their families and suffer food shortages, as is observed during the dry season in the Northeast region.

4.7. Projected impacts and risks for agriculture in Brazil

We do not yet have a reasonable idea of climate change consequences for Brazilian agriculture in general, although they are extremely important by reason of this sector's economic contribution to the country, with a GDP of approximately 6.4% (average GDP from 2000 to 2005, taking into account Gross Added Value of Agriculture and Stockbreeding to Basic Prices, according to the IBGE). Brazil is an important exporter of agricultural products, such as sugar, chicken, beef, pork, coffee, tobacco, soybean flour, soybeans, soybean oil and cotton, as well as cellulose and fruit. This agricultural situation may suffer changes due to climatic conditions in the areas recommended for each crop.

Based on observed evidence and tendencies in Brazil, as well as on studies which have considered climatic projections derived from climatic models from the IPCC, Marengo points out the fact that perennial crops, such as oranges, tend to seek out regions with gentler maximum temperatures, and hence they shift to the South. High temperatures in the summer will force this movement towards areas with favorable weather, which may lead to a reduction in the cultivated area, as is the case with rice, beans and soybeans.

In Brazil, the most important studies are those made by Siqueira et al. (1994, 2001), Alves & Evenson (1996), Assad et al. (2007), Pinto et al. (2004), Zullu Jr. et al. (2006), the main conclusions of which are shown below.

4.7.1. Simulation based on global circulation models and agricultural production models in Brazil

The projection of future agricultural productions under different scenarios of climate change, based on simulation models which include components of the soil-plant-climate system, has appeared as an important tool for evaluating technological strategies and environmental impacts.

Applying General Circulation Models (GCMs), such as GISS, GFDL and UKMO, and agricultural production models, Siqueira et al. (1994, 2001) have presented projections about the potential effects of global climate change on Brazilian agriculture, taking 13 different locations in the country as reference points and analyzing wheat, corn and soybean crops. The impact on crop production would be relatively large, with projected reductions in wheat and corn production. On the other hand, national production of soybeans would increase.

According to Siqueira et al. (1994, 2001), for the cultivation of wheat, the models projected a reduction in productivity of around 30%, accompanied by a shortening of plant growth cycles of between 14% and 15%, and the worst projected effects would take place in the Mid-South region (a transitional climatic zone between tropical and temperate climates). Projections for the cultivation of corn in the country were not favorable, according to these authors, with reductions in productivity estimated at 14% and 33% (an average of 16%), the most affected were Mid-South and Northern regions, with shortening of plant growth cycles of between 33% and 21% respectively.

Projections for soybean cultivation were positive, with a projected increase in productivity of between 5% and 34% (an average of 21%), where the effects on cycle length very from region to region, with the worst impacts on the Center-South and Southern regions, but not significant on a national scale (Siqueira et al., 2001).

The Northeast region would be especially vulnerable to a decrease in corn production and the Central and Mid-South regions would be vulnerable to reductions in wheat production. The Southern region would be vulnerable to wheat and corn reductions and the Northern region would be susceptible to reduced corn harvests

Applying the GISS transient atmospheric balance model, Siqueira et al. (1994, 2001) simulated scenarios with gradual alterations of CO_2 in plants to evaluate possible impacts on agricultural production. Projections pointed to a decline in wheat and corn production between 1990 and 2060. The most significant reductions in wheat and corn production appeared in the Mid-South region, while projections for soybean production were stable, and less marked for the Northeast region.

According to these authors, the main limitations of this study rest in the fact that the simulation devices applied were not enabled for all the regions analyzed and that technology and land use were taken as constant factors, even knowing that they might change in the future. They also pointed out the need for evaluating the real implications of physiological effects of CO_2 on the development of crop productivity.

4.7.2. Risks in climatic zoning of crops

Recent studies show that, according to scenarios of temperature increase, risks of production loss in several crops may occur, assuming they remain in the same areas where they are today, which are regarded as appropriate areas for agriculture. Risk scenarios in climatic zoning show a reduction in the favorable area for the cultivation of crops that are important for the country, with coffee growing the most harmed, followed by soybean production (Figure 4-5 and Table 4-3).There are uncertainties concerning these estimates, mainly because of the lack of information about all the variables involved, but they are useful for developing adaptation strategies for agriculture, and to serve as a basis for planning public policies for this sector.

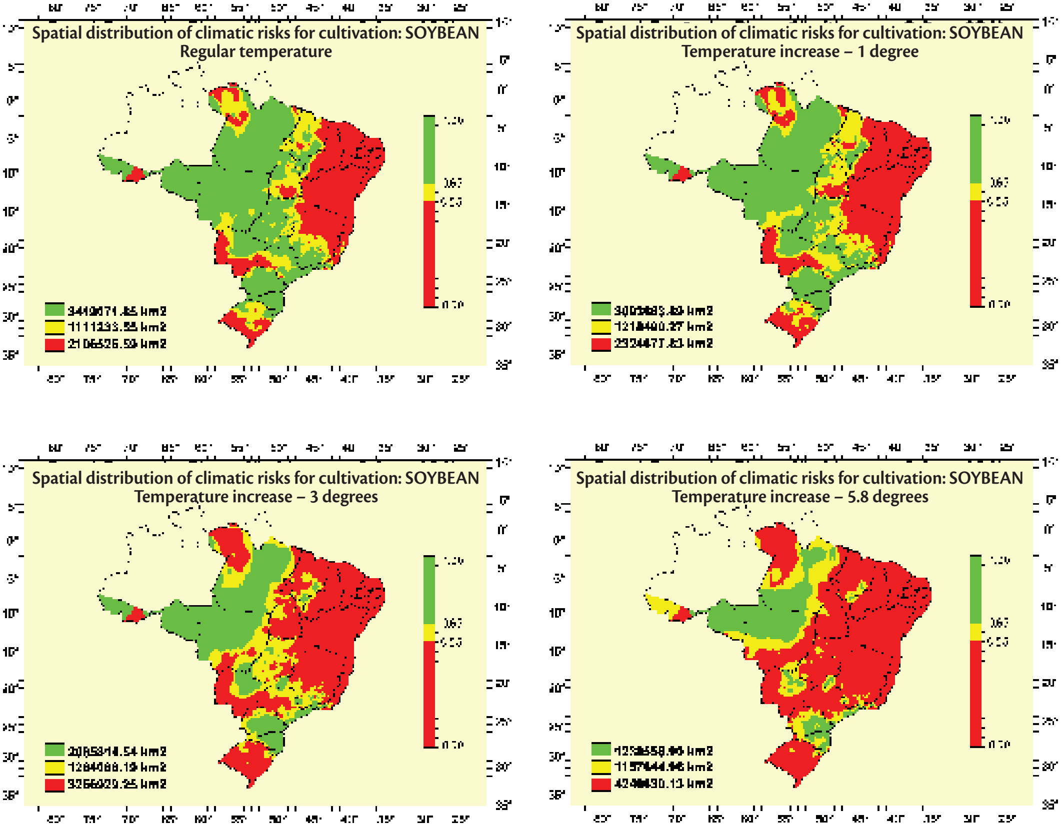

Figure 4-5: Impact of the variation of average air temperature on areas appropriate for soybean cultivation in Brazil. The maps show the distribution of favorable areas for the cultivation of soybeans, from green to red.

Table 4-3 – Future decrease of planted areas projected for an optimistic scenario of average global temperature rise of 1oC, and for a pessimistic scenario with a rise of 5.8oC, where current potential area is the reference.

Table 7-3: Future reduction in the planted area of certain crops expected in an optimistic scenario of +1°C in average global temperature, and for a pessimistic scenario of +5.8°C, taking as a reference current potentially usable area.

Crop	Current potential area (km^2)	Area reduction (%)	
		Optimistic scenario 33.8°F (1°C)	Pessimistic scenario 42.44°F (5.8°C)
Rice	4,755,204	4	41
Beans	5,141,047	3	23
Soybean	3,419,072	10	64
Corn	5,169,034	2	14
Coffee	904,971	23	92

Adapted from Assad et al. (2007)

Potential impacts of the increase in average air temperature of 1°C, 3°C and 5.8°C and of an increase of 15% in rainfall in the agroclimatic zoning of coffee (Coffea arabica L.) were simulated and evaluated by Assad et al. (2004) for Goiás, Minas Gerais, São Paulo and Paraná. Climatic risks for coffee growing in these states were defined based on annual water deficiency values, average annual temperature, and frost possibilities, resulting in a risk-zoning map. Evapotranspiration and water balance values in the simulation were re-calculated based on temperature maps (1°C, 3°C, 5.8°C). The authors showed a potential reduction of 95% in areas suitable for coffee cultivation in Goiás, Minas Gerais and São Paulo, and of 75% in Paraná, under a temperature increase scenario of 5.8°C. Zullu Jr. et al. (2006) also evaluated the impact on corn production, applying this methodology. According to their projections, crop production would decrease in sandy soil faster than in clay soil as temperatures increased. With a temperature increase of 5.8°C, there would be a severe reduction in the suitability for corn production, regardless of soil texture. They also argue that increased rainfall would not be enough to soften the impacts related to a rise in average temperatures.

4.7.3. The Ricardian model

Using another methodological approach, Alves & Evenson (1996) and Sanghi et al. (1997) apply the Ricardian model (Mendelsohn, Nordhaus and Shaw, 1994) to estimate the impact of global climate change on Brazilian agriculture. The Ricardian model consists in evaluating the influence of variables such as production, work, fertilizers, constructions, roads, scientific research, technology choice, rural extension, and climatic variables (temperature, rain, solar radiation, etc.) and soil variables (type of soil, declivity, texture, etc.) on land productivity, and consequently on its price. The Ricardian model analyzes land value according to different climatic values, combining these values with climatic variables (temperature and precipitation) and other factors. It is a cross-sectional approximation, based on the hypothesis formulated by David Ricardo, in which land value indicates the current value of expected productivity of the land in the future. The results are presented as the difference between the land value in a future climatic scenario, and the current land value. Based on this analysis, it would be possible to estimate the impacts of landowners' adaptations to climate change on the production and productivity of agricultural establishments. According to the authors, the net impact of climate change for Brazilian agriculture would be negative, especially for the Mid-West region, where the predominant vegetation is the *Cerrado*, while the Southern region would benefit moderately from global warming.

Following these research projects, a study has been recently carried out in seven South American countries (Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela), with the aim of evaluating the impact of climate change on agriculture, as well as the vulnerabilities and possible directions for adaptation in each country. This study (Climate and Rural Poverty: Incorporating Climate into Rural Development Strategies) is part of a bigger project from the Yale School of Forestry and Environmental Studies, financed by the World Bank and applied to Southern Cone and Andean countries. In this study, impacts of climate variability and climate change on natural resources and on rural poverty in Brazilian regions were identified. The changes landowners are already applying to adapt to the weather and the new adaptations which might be applied in the future, were also evaluated. The results have shown that temperature and precipitation changes will negatively affect land values for 9-31% of small farmers and 47-80% of commercial producers (Mendelsohn et al., 2007).

4.7.4. Effects of climate change on pathogens

Climate changes are associated to the sensitivity of plants to humidity and their responses to pathogens. Climate change may lead to diseases emerging through gradual alterations in climate (through alterations of invertebrate vectors or increasing temperature and water stresses on plants) and a higher occurrence of unusual climate events (a tendency to dry weather favors insect vectors and viruses, while humid weather favors fungal and bacterial pathogens) (Anderson et al., 2004).

In a study on black sigatoka disease in banana trees using distribution maps of the disease and scenarios from the IPCC, Ghini et al. (2007) showed a reduction in the favorable area for the disease in Brazil, especially in A2 and B2[1] scenarios. The research considered the premise that the development of the disease is favored by temperatures between 20°C and 30°C, and relative humidity above 70%, so that regions where the average temperature is less than 20°C, or over 30°C, or where average relative humidity is less than 70%, were considered as unfavorable areas for the disease to flourish.

According to Fernandes et al. (2004), the risk of occurrence of *Fusarium* in wheat crops is very likely to rise as a consequence of climate change in southern Brazil and Uruguay.

Few measurement experiments have been conducted in the field in Brazil to evaluate the effects of climate change on agriculture, and these are very important to validate simulation models used to estimate impacts on agricultural soil, crops and livestock activities.

4.8. Adaptations of agriculture to climate change

Plant species have a wide range of physiological adaptability which provides a considerable capacity to create a buffer effect against the variability associated with climate change. On the other hand, it is necessary to increase our knowledge about the potentialities and limitations of production systems in relation to climate change, taking into account the determining factors of agro-climatic sustainability and flexibility in tolerating change. The main factors concerning plants would be the photosynthetic pathways, tolerance to high temperature stress and drought periods, as well as the photoperiod, which could be important if plantations need to migrate to different latitudes. Soil type, considering its characteristics of humidity storage, drainage and erosion risks, as well as management, must also be considered

The FAO (2003) has identified some actions for adaptation to climate change for the agricultural sector, for instance:

- formulation of support mechanisms for producers to help them adapt to climate change.

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[1] The A2 scenario presents high rates of greenhouse gas emissions, that is, it maintains the current standard of emissions. It describes a very heterogeneous world with a high growth of human population. Economic growth is regionally oriented. B2 is a scenario of lower emissions, with more optimistic characteristics than the A2 scenario. It describes a world which emphasizes local solutions to economic, social and environmental sustainability. It presents moderate population growth and medium levels of economic growth. It is oriented towards environmental protection and social equity, but focused on local and regional levels (IPCC, 2001c)

- maintenance of a wide genetic base for crops and development of varieties of crops and animal breeds more resistant to drought;
- improvement of resilience of agricultural ecosystems through the promotion of practices which create and maintain biological diversity;
- improvement of efficiency of water use and restocking underground water supplies through conservational agriculture;
- supporting pasture systems and other systems of animal production with activities concentrating on the production of food supplements, veterinary services, and water supply, among other measures.

We present below adaptation strategies for agricultural systems in Brazil, bearing in mind the current stage of knowledge.

4.8.1. Agroclimatic zoning

Agroclimatic zoning is achieved by data compilation concerning weather, which may be obtained from surveys on a regional scale, with information about the temperature and water needed for good development of a crop. The information originated allows the estimation of production risks for each crop, and helps to give guidance for better use of the land.

The use of this tool is very important for identifying better areas for each type of crop, allowing greater productivity, as has happened with the cultivation of rice on highlands in Mato Grosso, which is nowadays the second biggest producer of rice in Brazil. This work has been conducted in several *Cerrado* regions by Embrapa Arroz e Feijão (Rice and Beans - www.cnpaf.embrapa.br). Agroclimatic zoning will thus allow the identification of vulnerable areas, as well as areas which will be more suitable for each crop according to the rainfall and temperature systems.

4.8.2. Plant improvement

Temperature and rainfall regimes are the main climatic variables which will impact on global agriculture due to climate change. Accordingly, plant improvement is a key process for the adaptation of crops to stress conditions which might occur much more severely in future scenarios.

Stress caused by high temperatures, be it transitory or continuous, already affects some agricultural regions, Brazil included. It is believed that it will be possible to overcome thermal stress, by means of transference between individual thermotolerant species. High-temperature stress may occur in different phases of development of plants, from germination to the development of grains, which is encouraging research into ways of controlling this characteristic. In addition, some species, such as soy and other types of beans develop associations with soil bacteria which naturally feed the plant. These associations are also affected by high temperatures. Several studies are being conducted in order to select varieties with the potential for tolerating temperature effects but it is a slow process.

Some varieties which show tolerance to long droughts may carry genes which guarantee thermo-tolerance, as must be the case for some varieties of beans, especially those planted in the Northeast region. Gene mapping and the development of transference techniques are primary objectives for future research (Wahid et al 2007).

Concerning micro-organisms, studies involving rhizobium selection capable of colonizing root nodules and fixing nitrogen in high temperature conditions have already enabled the isolation of efficient strains for bean plants (Hungria et al., 2000).

Besides the negative effect of high temperature, drought is one of the environmental stresses that most affects crop productivity around the world. However simply improving crops for high productivity in conditions without water stress already permits higher productivity when crops experience gentle or moderate stress situations (Cattivelli et al., 2008). Plants have several genetic characteristics related to water stress, and traditional improvement by crossing compatible individuals is a way to obtain stress-tolerant crops. The *robusta* coffee plant, for instance, has genetic characteristics which make it more tolerant to drought periods and is part of a research study being carried out by Embrapa Genetic Resources for transferring this characteristic to the *arabica* strain of coffee through traditional improvement techniques (Cenargen, Agricultural Report dated 14/04/2007). On the other hand, with the advance of molecular techniques which allow the genetic sequencing of many plant species, genes related to characteristics of drought tolerance have been identified. The cowpea (*Vigna unguiculata*) in the Northeast region produces great quantities of an amino-acid called proline which provides the plant with tolerance to drought and heat, the genes responsible for which have been isolated and are now used in studies on the genetic modification of crops submitted to water stress such as soybeans, corn, sugarcane, etc. (ACT, 2007), which will probably have a positive effect on these species' thermotolerance.

Embrapa, in cooperation with the Japanese government, is testing a new variety of soybean which has received, through biotechnology, a gene which makes it more tolerant of to drier periods (Figure 4-6) extracted from the first species of plant to have its gene sequenced, called *Arabidopsis thaliana*. It is a herbaceous plant of the Brassicaceae family, to which mustard also belongs. It plays an important role in botanic genetic studies, similar to that of drosophila, in other genetic fields. Research studies to evaluate performance in the field and possible environmental impacts are still being carried out before releasing the project for commercial use.

Figure 4-6: Soybean with drought-tolerant genes. The four pots on the left contain the gene for tolerance, the other four correspond to the common soybean. This photograph was kindly provided by Dr. Alexandre Nepomuceno, member of the research staff at Embrapa Soja, Londrina, PR.

4.8.3. Management of crops and soils

While efforts are made to improve of plants capable of resisting abnormally high temperatures and drought, the management of production systems may contribute in a more immediate way to reducing the problem. Coffee growing, for instance, is very sensitive to temperature changes, and according to Assad et al. (2004), more than 90% of the areas used for growing coffee would be compromised by a rise of 6°C in average air temperature. A possibility for mitigating this process is the use of shade systems, as practiced in Costa Rica. Under the shade of trees, temperatures are lower, contributing to a reduction in risks of productivity loss resulting from high temperatures. This possibility has already been the topic of discussions concerning the future of crops in Brazil ("Debate sobre arborização e mudanças climáticas traz alerta a cafeicultores" a paper published on 21/11/2006 on the Portal do Agronegócio - www.portaldoagronegocio.com.br), and it is already being used experimentally by Embrapa in growing organic coffee (Figure 4-7), which includes a greater variaty of species.

Figure 4-7: Shaded coffee plant in an organic system cultivated along with leguminosae species and banana plants. Embrapa Agrobiologia, Seropédica, RJ.

Afforestation is a strategy which may benefit crop production and pasture. Recently, Embrapa has invested in the development of silvopastoral and production systems which integrate crops-livestock-forest. The presence of trees in the production system creates favorable micro-climates for forage plants and animals which may be affected by heat waves caused by climate change.

Direct planting is a system which has great success in saving soil water (Figure 4-8). This system is applied in almost half the production area of crops in the country, and it is characterized by its lack of soil movement for planting, and therefore soil remains covered by harvest residue. Direct planting has replaced conventional soil preparation system as a way of interrupting water run-off, which took with it large quantities of soil, promoting erosion. According to data gathered by De Maria (1999), direct planting may decrease water run-off by 20% due to the slower run-off resulting from the presence of residues on the soil. Also, the presence of residues on the soil surface diminishes evaporation and leaves relatively more water for plants (Silva et al., 2005), raising the chances for the crops to survive through drought periods. In Brazil, it is estimated that this practice is applied in more than 20 million hectares, especially in the South and Central-Western regions (Cerri et al., 2007)

Figure 4-8: Direct planting on straw: reduces water loss by superficial run-off and preserves soil water due to less evaporation.

4.9. Preliminary recommendations for adaptation policies and strategies for the agricultural sector in terms of climate change

Due to the need to take decisions concerning possible climate changes by means of public policies, it is very important to improve prediction models at regional levels in order to deal with future climate events, taking into account uncertainties and associated probabilities of loss. Options for inaction, mitigation and adaptation derive from the expectations and magnitude of abnormal climate effects.

1) Elaborating and setting up sound R&D programs for evaluating impacts of climate change on agriculture and for proposing adaptation measures, bearing in mind the main agricultural and forage crops, and including predictions about extreme events with implications for agriculture. To achieve this objective, it is very important to promote and encourage technical training on the evaluation of risks caused by climate change, using different methodological approaches which can be applied to estimates of vulnerability.

   There is a shortage of studies in Brazil about the effects of increasing concentrations of CO_2 in the soil-plant system of agricultural ecosystems, combined with predicted temperature increase in water and nutrients. Field and laboratory research must be encouraged in order to generate knowledge about the real responses of each system to climate change, giving support to prediction models.

Other R&D actions include initiatives for implementing and improving socioeconomic, meteorological, environmental, agricultural and demographic databases to provide more consistent evaluation of climate change impacts on food security and rural properties in Brazil, seeking opportunities to reduce vulnerability to rural poverty which will lead to local actions concerning mitigation and adaptation measures in relation to climate change. Studies researching the synergy between mitigation and adaptation measures must be supported.

2) Rural extension courses to inform rural producers about the potential impacts of climate change, and to give them guidance about adaptation measures.
3) Development of services to give warning of extreme events and climatic variation.
4) Adopting incentives for preserving and expanding forest areas, forest corridors, integrated crop-forest systems, as well as stricter supervision of legal land use.
5) Development and application of management technologies for land use and plant improvement.
6) Incentive for mixed production systems (e.g. integrated crops-livestock-forest system)
7) Encouraging projects like the Clean Development Mechanism (CDM) with a view to instituting sustainable development and making a positive impact on local communities. According to Brazil's current emission profile, it is highly recommended that there should be discussion and application of new models of relationship between those interested in the CDM process: government agents, agricultural workers, landowners and private companies. The Federal government should stimulate projects concerning land use in a CDM context, defining clear policies which minimize risks and promote the engagement of every actor in the process. Wider implementation of an economic strategy, such as carbon credits or payment for environmental services, may be an interesting approach.

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5. Analysis of the vulnerability of brazilian biodiversity in the face of global climate changes

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Dora Canhos

5.1. Global climate changes and their impact on the natural ecosystems of South America

The fourth Report of the Intergovernmental Panel on Climate Change (R4 IPCC, 2007) describes the advances made in evaluating the impact of human and natural factors in climate change. The term 'climate change', used in the fourth report of the IPCC, refers to climate changes over time as a result of natural variability and human activity. These analyses are based on climate processes and predictions of future climate changes. The report not only incorporates the data from previous IPCC evaluations, it also contains developments from the last six years of research conducted by the Panel; it is therefore based on recent data covering many fields as well as on more sophisticated analyses, which allows for a better understanding of the processes and better simulation of models and a more robust analysis of the zones of uncertainty (ALLEY et al. 2007).

Today the indicators for global warming are undeniable, and they can be seen in observations of the rise in average global temperatures in the atmosphere and the oceans, and in the generalized melting of the polar caps, which is leading to a rise in the average sea level on a global scale. Observations of climate change on continental, regional and oceanic basin levels include temperature change, general changes in precipitation levels, in the quantity of ice in the Arctic regions, salt levels in the ocean, wind patterns and the increased incidence of extreme climatic events, which include droughts, strong precipitation, heat waves and a more frequent occurrence of stronger tropical cyclones.

Global warming is a direct result of the greenhouse effect. Among all the gases responsible for the greenhouse effect (carbon dioxide, methane gas and nitrous oxide), carbon dioxide is the most important factor in global warming. Because of its importance, climate scenarios are constructed based on future levels of the emission of this gas.

South America is a region that is, climatically speaking, highly heterogeneous, due to its great breadth of latitude, extending from the Northern Hemisphere's tropical region all the way to the high latitudes in the Southern Hemisphere. Furthermore, the region is strongly affected by extreme topographical characteristics such as the existence of the Andes (GRIMM and NATORI, 2006). The IPCC report on the South American and Caribbean region presents a large amount of evidence showing an increase in extreme climatic events and changes in the climate. The report predicts a decrease in diversity of plant and animal species together with changes in the composition of ecosystems and the distribution of biomes. It also predicts melting of tropical glacier areas in the near future (2020-2030) and an increase in desertification and aridity in other regions. These changes will have a drastic impact on individuals, populations, natural resources and economic activities and will cause further changes due to an increase of agricultural plagues and tropical diseases, as well as alterations in the distribution of human infectious diseases, and the rise of new ones.

The IPCC report for 2007 indicates a particularly severe impact in the Amazon Region, where susceptibility to forest fires will intensify due to an increase in droughts related to El Niño and changes in the use of the land (deforestation, selective cutting of timber and forest fragmentation).

Coastal mangrove areas in low-lying coastal areas will become very vulnerable to the rise in sea-level, the increase in temperatures and the more frequent and more intense occurrence of hurricanes.

Higher precipitation rates are predicted for the Southeast region of Brazil, Paraguay, Uruguay, the Argentinean Pampas and some parts of Bolivia; this will have a direct impact on land use, on agricultural societies and on the frequency and intensity of floods.

A decrease in precipitation rates is expected in the Southern region of Chile, Southeastern Argentina, southern Peru and Western Central America.

Studies using A2[1] scenarios for the period 2071-2100 show an increase in precipitation in the Southeast region of South America during all seasons of the year and a reduction in those rates in the Southern Andes during the period from fall to spring (GRIMM and NATORI, 2006).

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[1] Intergovernamental Panel on Climate Change [For a basic explanation about the different scenarios] 2000. Available at: <http://sedac.ciesin.columbia.edu/ddc/sres/index.html>.

5.2. Vulnerability of brazilian ecosystems in the face of global climate changes

Some articles based on climate models have recently been published based on climate models for South America (SALAZAR at al., 2007) and more specifically for the Amazon (NOBRE et al., 2007) and also analyses based on deforestation processes in tropical forests (GUILLISON et al., 2007) and analyses based on the use of SimAmazônia, an information system that allows the creation of models derived from environmental and economic data for the Amazon[2].

5.2.1. Analyses based on climate models

Climate models are based on the prediction of climate changes for the various regions analyzed and evaluate the consequences of those changes on vegetation (the biome) as a whole. The consequences predicted are based on the idea that the new climatic values would be incompatible with local vegetation. Even though other authors might say that nowadays it is still difficult to predict the impacts of global warming, since the models show a wide divergence in results, there is some agreement for some of the regions analyzed.

For example, an increase in temperature would result in an increase in soil water evaporation, which would increase the aridity of the *Caatinga* [a scrubland environment characterized by thorny bushes – trans] region. In the 15 scenarios projected for 2100, ten indicate the desertification or semi-desertification of the *Caatinga*, which indicates the probability of a desert being created that will occupy an area equivalent to half the total of semi-arid territory in Brazil.

Other consequences would be the probability that part of the Brazilian Amazon will become a savanna, also due to the reduction of water in the soil. Over 75% of the models indicate the likelihood that the Southeast region of the Amazon, mainly the forests in the state of Pará, will undergo a process of savannization. The projections indicate an 18% reduction of the areas covered by tropical forests by the end of this century, and a 30.4% increase in areas covered by savanna, according to the A2 scenario of the IPCC.

According to Marengo (2006), we have a broad view of the current nature of the climate and of some climatic alterations for the country during the 21st century. This work emphasizes that maps of future climate scenarios (A2 and B2), referring to the different IPCC models, show that results differ between models, even with the same concentrations of gas, especially in relation to precipitation. Therefore

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[2] Universidade Federal de Minas Gerais. Simamazônia. Available at: <http://www.csr.ufmg.br/simamazonia/>.

future climate predictions still have difficulty in predicting rain patterns. On the subject of temperature, all models show a systematic increase. Furthermore, the report indicates that the Amazon, the Northeast and the South of Brazil are regions where the models present the greatest variation.

The doubts about climate changes are mostly caused by uncertainties about future scenarios for the emission of greenhouse effect gases throughout this century. Depending on the quantity of gases emitted by 2100, the average global surface temperature might rise from 1.5ºC to 5.5ºC. Another source of uncertainty is the difficulty in predicting rainfall scenarios, which makes it difficult to make full use of them in impact studies where rainfall is a determining factor. Furthermore, other factors that are not yet measured by these scenarios might have an impact on rain patterns, for example large-scale deforestation. This means that any conclusion about the consequences of climate changes on biodiversity, especially in species whose distribution patterns are intimately related to the availability of water and to climatic seasonality, must be assessed with care.

A very important aspect of this study is the regionalization of climate predictions, which is fundamental in order to increase the quality of the analysis on a more finely-tuned level.

Among the results obtained, three regions are highlighted. For the Amazon, five models have pointed to less rain than at present, which suggests that the dry season in the future might be longer than it currently is in the A2 and B2 scenarios. In the Northeast the situation is even more extreme; the different models suggest results that are very different in precipitation levels although two models predict that for both scenarios (A2 and B2) there will be less rain during the rainy season and that the dry season will last longer. Finally, in the River Plate Basin the models are very different, with two of them simulating a longer dry season and a postponement of the rainy season for a period of up to two months (MARENGO 2006).

5.2.2. Analyses based on socioeconomic models

According to (GUILLISON et al. 2007) if the deforestation rate of the last years remains constant, the destruction of the tropical forests should release an additional quantity of 87-130 billion tons of carbon by the year 2100. This volume is equivalent to more than 10 years of emissions caused by the use of fossil fuel. During the 1990s the deforestation of tropical forests released a total of about 1.5 billion of tons of carbon per year (or 20% of emissions of greenhouse effect gases caused by human agencies). According to the IPCC, a reduction of at least 50% in deforestation rates must occur by the year 2050 (and this rate must be maintained until 2100) so that a reduction of more than 10% in the quantity of carbon dioxide can be achieved, thus helping to maintain the CO_2 levels in the atmosphere at 450 parts per million, the limit above which, according to the IPCC, global warming will increase to over 2ºC and cause problems on a global scale.

Based on environmental and economic data, the SimAmazônia system is capable of creating detailed and complex digital models to predict the behavior or the environmental evolution of a specific region and it is being used to create new public policies for the Amazon region. The SimAmazônia database uses information from sources such as the census conducted by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE), the Program for Calculating the Deforestation of the Amazon (Programa de Cálculo do Desflorestamento da Amazônia - Prodes) and the National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais - Inpe), and maps of physical and transport aspects, showing connecting roads in the region. Analyses made with SimAmazônia are encouraging the formulation of new public policies for the Amazonian region aimed at improving environmental services and consequently combating deforestation and increased carbon emissions into the atmosphere. The results show ways for Brazil to begin to sell carbon to developed countries that are willing to pay for its non-emission.

In ideal conditions, according to SimAmazônia data, by 2050 the region could be selling around 17 billion tons of carbon which would have otherwise have been released into the atmosphere. This would be equivalent to saving four years of global pollution emissions and would offer the opportunity for the Amazon to enter that year with 4.5 million km² of forest still intact. According to Soares, “this scenario shows how much more advantageous it would be to preserve the forest instead of turning it into low-income pasture.” The ‘business-as-usual’ scenario shows that the biggest tropical forest on the planet could be reduced to just over half of its original area due to the expansion of agriculture and cattle-raising, timber extraction and the construction and paving of roads. Of the 5.4 million km² currently in existence in the nine Amazonian countries, only 3.2 million km² would be left. The destruction and fragmentation of the forests would jeopardize the existence of hundreds of animal species included in the simulation. Over 40% of the areas where they live would disappear, especially in the Eastern Amazon, the area that is the most liable to suffering the creation of new roads and deforestation. Among the primates, at least 35 species would lose from 60 to 100% of their habitats. This scenario further indicates that eight of the twelve biggest hydrographic basins might lose over half their forest covering by 2050.

The ‘Governance’ scenario (in which the simulation predicts the slowing down of deforestation rates due to a progressive implementation of public policies[3]) indicates ways that might reduce by half the destruction caused by the expansion of the agricultural frontier. This simulation projects a

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[3] Programa de grande escala da biosfera - Atmosfera na Amazônia. Available at: <http://lba.cptec.inpe.br/lba/site/?p=oportunidade&t=0&s=5&lg=&op=1247>

slowing down of deforestation over time through a progressive establishment of protected areas. If the entire forest were granted government protection against invasion and depredation, at most 50% of private forests would be deforested.

The study shows that fiscal and financial incentives created to encourage owners to keep forest reserves in private areas are essential for the 'governance' scenario to succeed, in addition to investments in order to maintain intact areas protected by law.

Another important study on development and conservation in the Amazon Region comes from the Advances in Applied Biodiversity Science series (KILLEEN, 2007), where scenarios involving advances in the agricultural frontier, deforestation, climate changes, forest fires, biofuels, mining, hydroelectric energy, among others, are discussed in relation to social, economic and environmental factors.

5.3. Vulnerability of priority conservation areas in Brazil

In Brazil the main effort for the definition of priority biodiversity conservation areas is a result of the project entitled "Priority Actions for the Conservation of the Biodiversity of Brazilian Biomes"[4] (Ações Prioritarios para a Conservação da Biodiversidade dos Biomas Brasileiros). This project was carried out during the 1990s, was coordinated by the Ministry of the Environment, developed in collaboration with Conservation International, Funatura and the Biodiversitas Foundation (Fundação Biodiversitas) and was staffed by specialists from the country's main institutions working in this area. During this project workshops were held to discuss and define conservation priorities for the *Cerrado* [savanna – trans.] and Pantanal, the Coastal and Sea Area, the Amazon Forest, the Atlantic rainforest and Southern Grasslands, and the *Caatinga* regions. The initiative involved the participation of about 1,000 specialists in ecology, botany, zoology and related areas who discussed and defined the conservation priorities of the main Brazilian biomes. Base maps of the regions to be analyzed were prepared to be used as a platform for the inclusion of data such as natural area distribution, existing conservation areas, physical and political subdivisions, economic and demographic statistics and data on the flora and fauna compiled by consultants. The map that resulted from the themed workshops focused on the different Brazilian biomes is shown in Figure 5-1.

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[4] Brasil. Ministério do Meio Ambiente [**PROBIO**]. Available at: <http://www.mma.gov.br/sitio/index.php?ido=conteudo.monta&idEstrutura=14>. Accessed: 19 Nov. 2009.

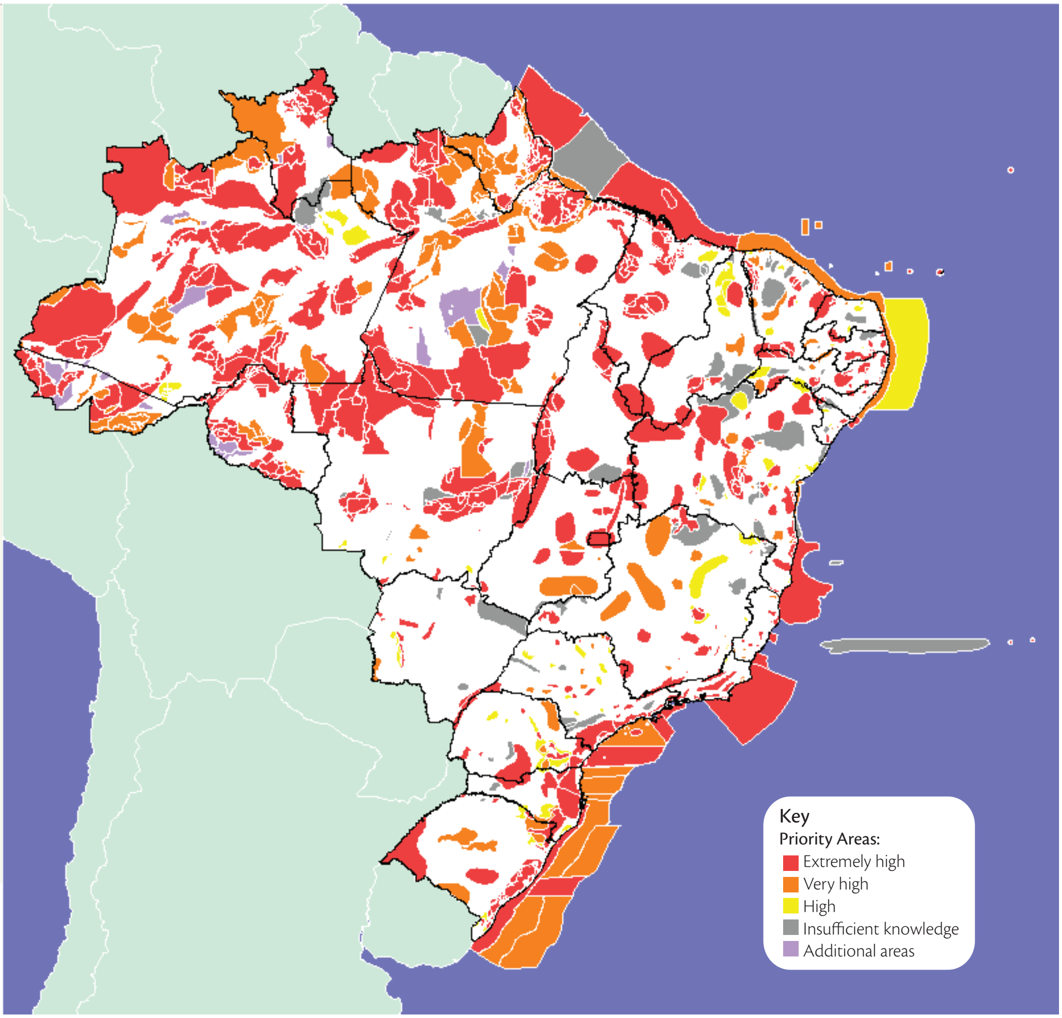

Figure 5-1: Synthesis map of the conservation priorities for the main Brazilian biomes.

The method used was able to identify priority conservation areas, being based on a complete evaluation of biological information and of conditioning factors of human activity and taking into account the data and analysis methodologies available at the time of the project (1995-2000). The efforts to define priorities were based more on the knowledge and evaluation of specialists rather than on the use of priority data analysis tools concerning the country's biodiversity. Since the initiative did not consider future scenarios such as the impact of and vulnerability to climate changes, it is important that the priority areas be re-evaluated by more advanced and more appropriate methodologies, and if possible that they use data on biodiversity that incorporates climate change factors and not only the knowledge of specialists. The procedure to be adopted and the analyses of the scenarios are the factors that will depend on the knowledge of specialists.

On a more local scale, the 2007 Workshop "Directives for the Conservation and Restoration of Biodiversity in the State of São Paulo" (Diretrizes para Conservação e Restauração da Biodiversidade no Estado de São Paulo) was a recent and very important effort to indicate priority areas for conservation, to evaluate areas for environmental restoration and to indicate gaps in our knowledge. The project involved researchers, research institutes, NGOs and state government bodies; data provided from the speciesLink[5] and Sinbiota[6] networks and from landscape metrics were used.

5.4. Analyses of biodiversity vulnerability in the face of global climate changes

Studies on ecological niche modeling associated with the predictions of climate changes indicate a significant risk of extinctions and alterations in the distribution of many species (HUNTLEY et al., 1995; MAGANA et al., 1997; SALA et al., 2000; PETERSON et al., 2001; BERRY; 2002; PETERSON et al., 2002; OBERHAUSER and PETERSON, 2003; SIQUEIRA and PETERSON, 2003; MARTÍNEZ-MEYER et al., 2004; THOMAS et al., 2004; THUILLER et al.; 2005; ARAÚJO et al., 2006; HARRISON et al., 2006; PEARSON et al., 2006, and THUILLER et al., 2006), some studies even indicate that biodiversity is already showing alterations due to climate change (PARMESAN and YOHE, 2003; ROOT et al., 2005; WALTHER et al., 2005, and LAVERGNE et al., 2006).

Thomas et al. (2004) have predicted average extinction rates of more than 20% for the 1,103 species that were analyzed (including mammals, birds, amphibians, reptiles, plants, butterflies and other invertebrates). This study, based on three climate scenarios, indicates extinction rates ranging from 15% in the best scenario (minimum alterations), to 24% for the intermediate scenario and 35% for the worst-case scenario (maximum alterations).

The study by Harrison et al. (2006) shows an impact analysis of climate changes on 47 European species (including plants, insects, birds and mammals) and shows that different species have different responses to those changes. Some species have gained more area while others have lost it. Other studies on European biodiversity have confirmed the possibility of area gain (ARAÚJO et al., 2006).

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[5] Specieslink. Available at: <http://splink.cria.org.br/>

[6] Programa de Pesquisa em caraterização, conservação de uso sustentável da biodiversidade do Estado de São Paulo. SinBiota. Available at.<http://sinbiota.cria.org.br/>. Accessed: 20, Nov. 2009.

In this study 42 amphibian and 66 reptile species were analyzed. The predictions used four different scenarios for 2050 (A1, A2, B1 and B2). The results obtained show that in the average of the projection values used in each of the scenarios, 69% of the amphibians and 65% of the reptiles gained area. This increase of potential living area for some animals is directly related to the fact that these animals use the temperature of the environment to adjust their body temperatures. These species would be the most affected by a decrease in temperature as opposed to an increase, as long as those animals did not encounter any problems with dispersion. However, these results are not confirmed due to the current evidence of a decline in those animal groups in Europe (ARAÚJO et al., 2006). In fact, the authors show that if the species are considered incapable of dispersion, then an area reduction is expected for all the species analyzed. Therefore the development of models that add ecological aspects to the existing environmental models will bring a large benefit to the analyses of the consequences of climate changes on biodiversity.

There have been very few and very restricted studies made about the impacts on Brazilian biodiversity. Some examples would include studies about the impacts on arboreal species in the *Cerrado* (SIQUEIRA and PETERSON, 2003), the Atlantic Rainforest (COLOMBO, 2007), the results of which show an average reduction of 25% in area for all the 38 species analyzed (the most optimistic scenario) and of 50% (the most pessimistic scenario) following a move to the South of the current distribution of these species. The study of the impact of climate change on the distribution of the vectors of leishmaniosis in Brazil shows the dramatic increase in the potential distribution of *Lutzomyia whitmani* in the Southeast of Brazil (PETERSON and SHAW, 2003). Another study involving 49 species of birds (looking at the absence of dispersion) showed the potential extinction of 20% of the species analyzed (ANCIÂES and PETERSON, 2006). These studies show the dramatic impact on and vulnerability of the species analyzed when faced with global climate changes, emphasizing the need to increase impact studies on species of different taxonomic groups to provide a better foundation for establishing the impacts of climate changes on biodiversity in Brazil.

5.4.1. Data infrastructure for modeling the potential distribution of species

Recent breakthroughs associated with the implementation of global, regional and local initiatives are the catalyst for coordinated projects in the digitalization and public release of data about the environment, climate and biodiversity on the Internet. The shared infrastructure of online data resulting from these efforts is increasing dynamic access to data and information, but still has not reached the degree of precision necessary for impact studies about climate changes and for the modeling of biological species on a more exact scale.

5.4.1.1. Abiotic data

Currently, the data Distribution Center of the IPCC[7] offers a great number of models and future climate scenarios. Over 20 models for 8 different scenarios are available, with data concerning humidity, precipitation, air pressure, air temperature (maximum and minimum), wind and others.

The IPCC data have a resolution of 2º and 3º (pixels from 200 to 300 km). This resolution, used for global analyses, is not adequate for an impact evaluation of climate changes on biodiversity on regional and local scales. In this context, an important initiative is that of the Worldclim[8], which offers a CCM3 (Climate Change Model 3) climate simulation model that predicts a doubling of CO_2 levels in the atmosphere by 2100 (GOVIDASAMY et al., 2003). These data have an original resolution of approximately 50x50 km, to which spatial interpolation techniques were applied in order to reduce the scale to a resolution of approximately 1x1 km. This resolution makes it possible to make predictions on regional and even local scales. However, the scenario used by Worldclim is very 'optimistic' when compared to the IPCC's scenarios. That being so, the analyses resulting from Worldclim data are 'conservative' when compared to other future scenarios, which are much more pessimistic about the quantity of carbon dioxide that will be released in the atmosphere by 2100. Therefore it is still necessary for more climate data to be made available, using other models and scenarios with better resolution so that broader and more realistic studies about the possible impacts on biodiversity on regional and local scales can be conducted and compared.

When analyzing the potential distribution of species (animal and plants), mainly on regional and local scales, other data become important in order to evaluate the current distribution patterns of species, such as data on soils (including granulometry, richness, pH, and available water supply). These data are fundamental when modeling vegetable species whose distribution is directly related to the type of soil in which they are growing. When these data do exist they are not available in measures adequate for more precise analyses. Furthermore, in terms of modeling tools currently available, these data should ideally be in a continuous format, that is, not categorized into classes (types of soil), which is the most usual format.

Therefore, in relation to access to abiotic data in order to conduct impact studies on climate change in biodiversity, much has to be done for these analyses to be conducted in greater numbers and with greater quality so that they may offer reliable help in taking decisions for the conservation of species. It is necessary to invest in the availability of even more data, on more precise scales, so that

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[7] Intergovernamental Panel on Climate Change. [***Data Distribution Centre***]. available at: <http://www.ipcc-data.org/>

[8] HIJMANS, Robert J.; CAMERON, Susan; PARRA, Juan. [***wordclim***]. Available at: <http://www.worldclim.org/future.htm>

the biodiversity researcher has access to adequate material for conducting research on the impacts of global climate changes, focusing on the species.

5.4.1.2. Infrastructure for biological data

Analyses of the vulnerability of biological species to climate changes and the planning of impact mitigation strategies need easy and dynamic access to a great amount of primary data about biodiversity, which include their validated scientific names, places where the species appear (latitude/longitude) and other complementary data. Developing an information system that provides dynamic access to quality primary data requires a structure involving many national and international institutions interested in sharing primary data about species (scientific names, synonyms and taxonomic terms) and specimens (vouchers deposited in herbariums and zoological collections).

Valid scientific names are the link for integrating information associated with taxonomical terms and complementary information about samples deposited in scientific collections. The Catalogue of Life (CoL)[9], created in partnership with Species 2000[10] and the Integrated Taxonomic Information System (ITIS)[11] is an index of valid names of known species. This international initiative currently contains over a million valid names of microorganisms, fungi, plants and animals on the Internet. The checklist of the Catalogue of Life 2007 contains information from 47 taxonomic databanks drawn up with the help of contributions from over 3,000 specialists. However, big gaps in the geographic and taxonomic knowledge about neotropical fauna and flora still exist, especially in the Amazon Basin, a region that occupies a total area of over 6 million km^2. Adequate strategic planning does not yet exist in Brazil for creating a Brazil Catalogue of Life, and the biodiversity of many areas being deforested has not even been collected and studied. Therefore, we are currently undergoing a process of accelerated loss of biodiversity that is still unknown.

The samples deposited in biological collections and their taxonomic terminologies are a result of scientific expeditions and the consolidated efforts of biologists and naturalists to describe and document the planet's biodiversity over the last 250 years. It is a collection containing two or three billion samples stored in scientific conditions and distributed around the world, an unparalleled and peerless collection of records on the spatial distribution of the biological diversity of our planet. The Brazilian scientific collection contains around 30 million samples, a small fraction (between 1-2%) of

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[9] INTEGRATED TAXONOMIC INFORMATION SYSTEM. Catalogue of life. Available at: <http://www.catalogueoflife.org/>.

[10] _______[Species 2000]. Available at: <http://www.sp2000.org/> Accessed: 20 nov 2009.

[11] _______[site]. Available at: <http://www.itis.gov/>

the total held in great international museums and herbariums. This information is fundamental to the construction of past and future scenarios of biological diversity in Brazil.

The Global Biodiversity Information Facility (GBIF)[12], officially established in 2001, is an international program that aims at consolidating free access to information on biodiversity through the Internet. The implementation of this infrastructure, which is an initiative open to the participation of countries and international organizations interested in sharing data about biodiversity, is helping to develop and adopt standards and protocols that allow for the interoperability of information systems. The result of this undertaking is an integrating web environment of shared infrastructure of tools for the analysis, synthesis and spatial visualization of biodiversity. The six years since the implementation of the GBIF have shown it to be the most important information center on biodiversity. Founded in February 2004, and with 9 million records, the GBIF portal[13] currently (January 2008) contains information from 950 databanks, making available about 140 million records and an array of documents about procedures of data cleaning and correction, and computational tools. Local and regional initiatives developed by using the standards and protocols of the GBIF are having a positive influence on the culture of sharing fundamental data for environmental administration, simplifying the creation of a global knowledge database on biodiversity.

In Brazil, the Virtual Institute on Biodiversity (Instituto Virtual da Biodiversidade) associated with the Fapesp Biota Program (Programa Biota - Fapesp)[14] incorporates the advances achieved by the implementation of the GBIF. The initiative contains data from about 60 different research projects (fauna, flora and microbiota) and involves over 500 researchers. The data integration of the Biota program is based on two interoperable information systems, the SinBiota[15] and the specieslink[16] networks, developed by the adoption of internationally accepted standards and protocols. SinBiota is the centralized information system that integrates sampling data and information associated with the Biota program. Use of a standard file for data recording developed by the scientific community, and the geocodification (latitude and longitude) of the sampling are compulsory for any project affiliated to the program. The digital cartographical base of the state of São Paulo, with its associated environmental layers (hydrographic basins, vegetation covering, roads, municipal divisions and conservation areas) that make up the Biota Atlas, is a fundamental component of this information system.

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[12] GLOBAL BIODIVERSITY INFORMATION FACILITY. [*site*]. Available at: <http://www.gbif.org/>

[13] ______. [*Data portal*]. Available at: <http://data.gbif.org>.

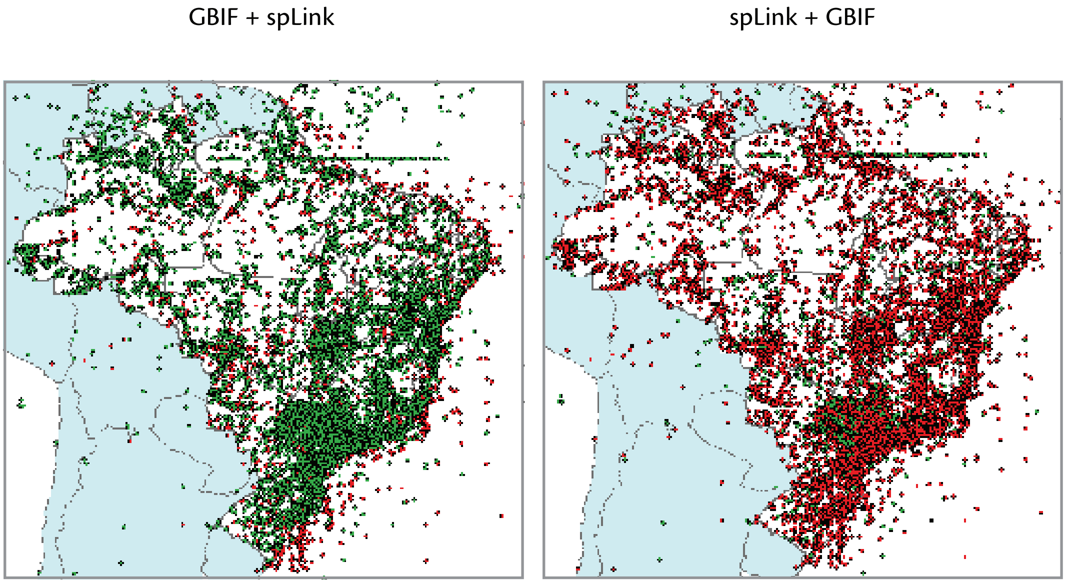
[14] PROGRAMA DE PESQUISA EM CARACTERIZAÇÃO, CONSERVAÇÃO E USO DA BIODIVERSIDADE DO ESTADO DE SÃO PAULO. [*site*]. Available at: <http://www.biota.org.br>. Accessed: 20 Nov. 2009.

[15] ______. [Atlas]. Available at: <http://sinbiota.cria.org.br/atlas>Accessed 20 Nov. 2009.

[16] Specieslink. Available at: <http://splink.cria.org.br>.

The speciesLink network is an information system aimed at achieving a dynamic integration of primary data on species stored in separate biological collections. It uses current advances in communication protocols and databank management, free open-source software and data-mirroring techniques in regional nodes connected through the Internet. The system also has support tools for the correction and visualization of data and information about the collections associated with the network. The speciesLink network, implemented with support from Fapesp during its initial stages (2001-2005), has been increased thanks to the support of various financial sources, including the JRS Biodiversity Foundation, MCT and GBIF. At the moment, the network contains about 2.3 million records from over 100 collections and sub-collections that are distributed among and integrated with other networks, including the Taxonline network (PR) PPBio Western Amazon (PPBio Amazônia Ocidental – Inpa/AM) and the Capixaba Network (ES). It also contains data from collections in Rio Grande do Sul, São Paulo, Rio de Janeiro, Bahia, Paraíba and Pernambuco. The system has mechanisms for filtering sensitive data, and the information provider has control over which data or record will or will not be available.

Figure 5-2 compares data from Brazil that are available on the GBIF and *species*Link networks.



GBIF + spLink

spLink + GBIF

SpeciesLink_BR: 1,736,554 (764.149)
Different Names: 11,998

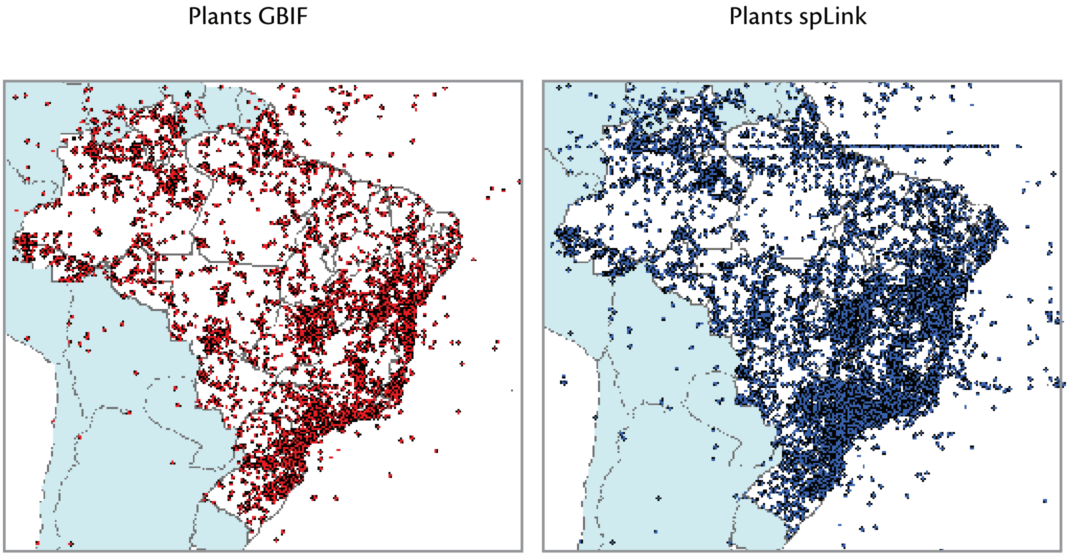
GBIF_BR: 387,922 (145,247)
Species: 60,924

Figure 5-2: Representation of the georeferenced data of the GBIF and *species*Link networks (November, 2007).

The figure on the left shows the superposition of Data from the *species*Link network (green dots) over the georeferenced records of the GBIF network (red dots), indicating geographical gaps in the records of both networks, and the superimposing of sampling spots, most likely a result of depositing duplicates of the same material in two collections.

For plants, we have the following representation of the points for both networks (Figure 5-3).

Figure 5-3: Comparison of the georeferenced data of plants in the GBIF and *species*Link networks (November, 2007)



Plants GBIF

Plants spLink

The figures show a greater amount of data about plants in the *species*Link network, several geographical gaps (in white) in both networks and some mistakes, with some points being registered as occurring in Brazil but with registration mistakes in the geographical coordinates.

Making the same comparison with data on animals we have:

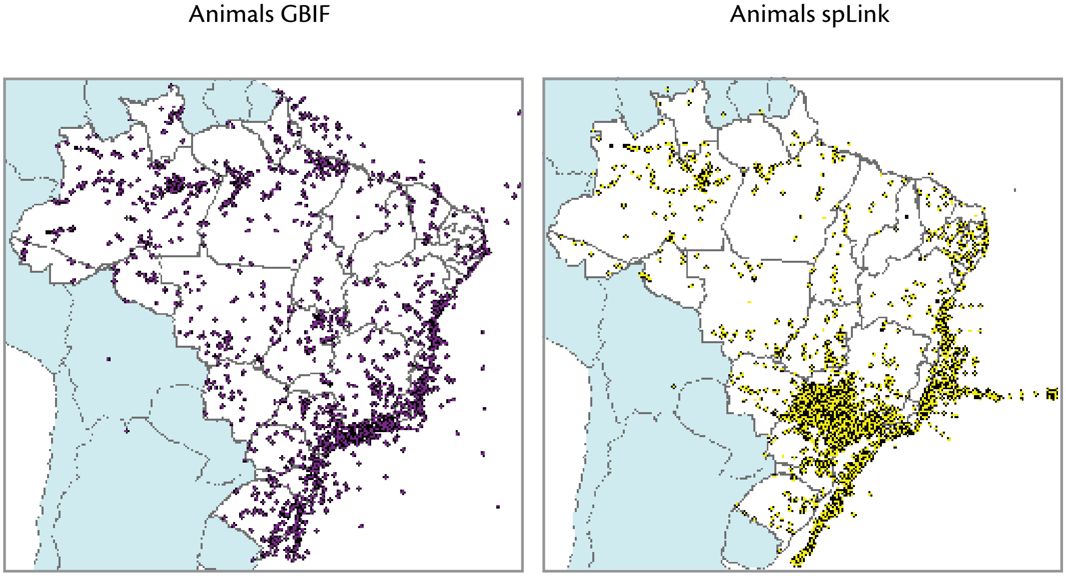


Figure 5-4: Comparison of georeferenced data of animals in the GBIF and *species*Link networks (November, 2007)

As the *species*Link network provides data from the Revizee/Score South project to the OBIS (Ocean Biodiversity Information System) network, and the OBIS network provides data to the GBIF network, much superimposing of points can be seen on the Brazilian coastline. We may also observe a large concentration of points in the State of São Paulo due to the sampling and observations conducted within the Biota/Fapest program. As well as the data from these two programs, Revizee and Biota, the GBIF network provides more animal georeferenced data than the *species*Link network.

As a final analysis, if we take into consideration only the Amazon region (Figure 5-5) we can see many gaps in geographical information. Certainly if we analyze the taxonomic data we will also find many gaps in taxonomic information.

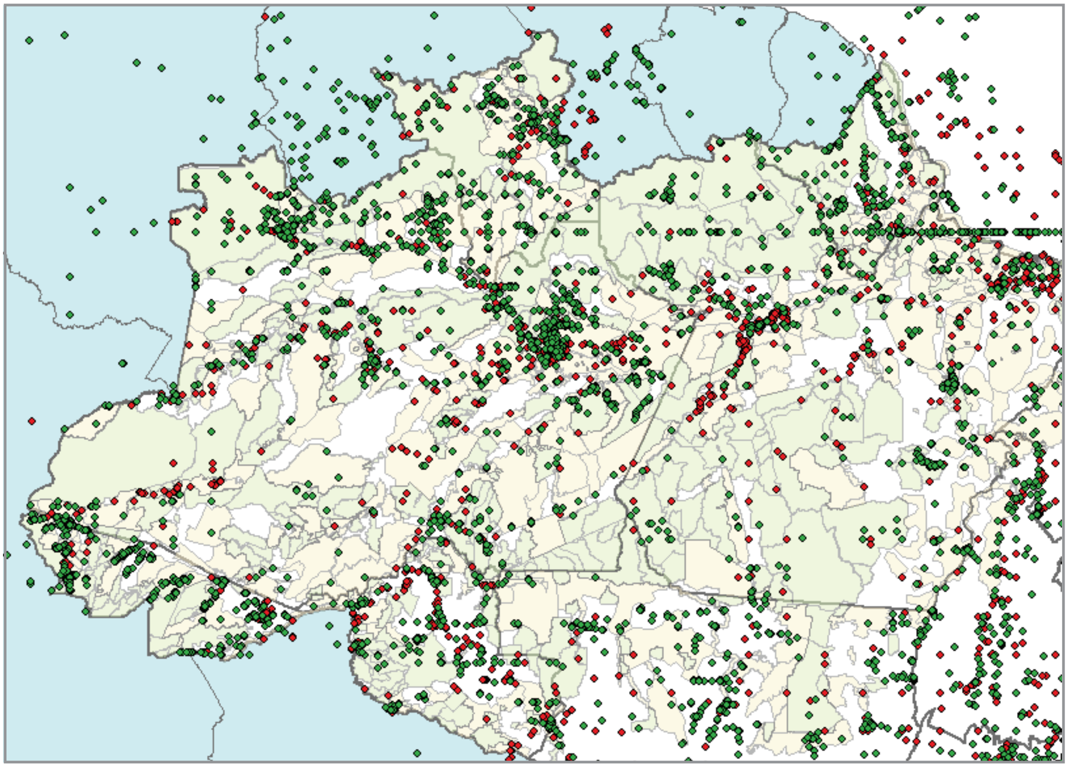


Figure 5-5: Georeferenced data of the GBIF and *species*Link networks for the Amazon Region (November, 2007)

The aim of the 2007-2010 Action Plan (MCT 2007) of the Ministry of Science and Technology (MCT) is the implementation of two thirds of the goals defined by the document "Directives and strategies for the modernization of biological collections and the consolidation of integrated information systems on biodiversity" (Diretrizes e estratégicas para a modernização de coleções biológicas e a consolidação de sistemas integrados de informação sobre biodiversidade) (PEIXOTO 2006). This means that there will be support for the establishment of a freely and openly accessible integrated information system on biodiversity. There is no doubt that this is a great political step forward that will surely help the country to learn, monitor and act in relation to its biodiversity in a much more relevant way.

Despite the advances that have happened due to the implementation of the GBIF and of the Biota-Fapesp Program, and of the PPBio, online access to primary data of the occurrence of species that are relevant for the modeling of the ecological niche of Brazilian biomes is still at an initial stage and is unorganized.

Although efforts have been made to create an inventory of the country's biodiversity, there are still many gaps in our taxonomic and ecological knowledge. Because Brazil is a highly diversified country of continental size it is necessary to find ways for field research to be directed and cover any gaps in geographical and taxonomic knowledge, with the aim of identifying priority diversity areas for the conservation of species. That being so, the use of computational tools in dealing with these gaps becomes imperative.

The use of modeling techniques of the geographical distribution of species is particularly suitable when making decisions based on a limited amount of available information, as is the case of the main Brazilian biomes. However, it is important to point out that the efficiency of these techniques is highly dependent on the quality of the biological and environmental data available.

5.4.2. Analytical tools for modeling the potential distribution of species

One of the possible applications of the projections of different future climate scenarios is in the modeling of the potential geographical distribution of species. This modeling is useful to evaluate the impact of those changes in the distribution pattern of biodiversity (PETERSON 2001, PETERSON and VIEGLAIS 2001, ANDERSON et al. 2003, and ANDERSON et al. 2003).

These methods seek to define the environmental limitations of the species within the measures for which the model is created, based on information of the occurrence of species projected in a geographical space, and in the use of algorithms that allow the identification of areas with similar environmental characteristics, indicating the potential of the species to maintain viable populations (PETERSON and VIEGLAIS 2001).

To conduct this type of analysis, it is necessary to have environmental data on suitable levels (current and future climatic maps), biotic data (records of occurrence and distribution of species) and algorithms that are used in the modeling of the current and future potential geographical distribution of the species (Figure 5-6).

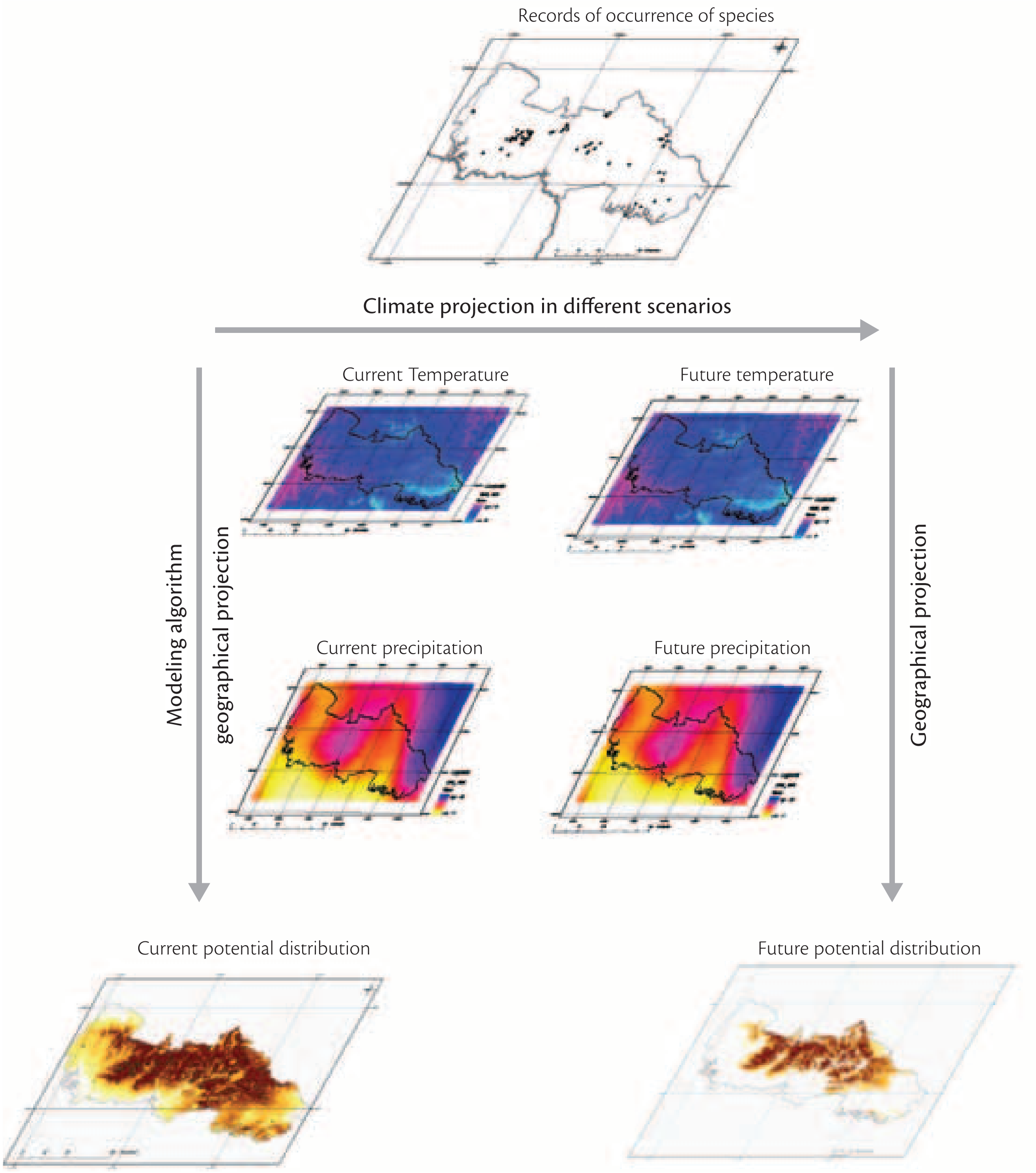


Figure 5-6: Modeling of potential distribution of species based on current climate data and in future scenarios.

There are about 12 software packages available for modeling potential distribution of species based on the concept of ecological niche, and those most used are Desktop Garp,[17] MaxEnt,[18] Floramap[19] and Biomod[20]. Most of these programs only have one modeling algorithm and usually require the conversion of environmental data (projection system, datum, resolution, etc.) from different sources. Many of these problems are being solved with the development of the openModeller[21]computational modeling environment, a partnership between the Reference Center in Environmental Information (Centro de Referência em Informação Ambiental – Cria), the Polytechnic School of the University of São Paulo and the National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais - Inpe), that receives support from Fapesp. This environment has many different algorithms available and it integrates data in different formats using a GDAL[22] library which simplifies the automation of various steps in the modeling process (SUTTON et al., 2007, SANTANA et al. accepted for publication).

Current modeling tools are based solely on the influence of the physical environment on the distribution of species and do not consider the influence of geographical and/or ecological barriers that may be involved in the process. This approach brings with it many uncertainties and problems in the results of modeling the impact of climate changes on biodiversity (Pearson and Dawson 2003, Thuiller et al., 2004, Araújo et al., 2005). A more robust analysis of the consequences of global climate changes in biodiversity requires the inclusion of aspects that involve the dynamics of populations (migrations), land use (processes of modification and fragmentation of habitats) and biotic interactions in the modeling process (Thuiller et al., in press). The latter authors have defined migration as the result of four processes: rates of fertility, dispersion, recruitment and population growth. The inclusion of these factors in the modeling process is important since climate changes affect species with low migration and locomotion capacity much more. It is important to consider the impact of the modification and fragmentations of habitats in the reduction, or even the prevention, of the dispersion of propagating elements in several species. In the view of these authorities, the models should incorporate measures, even if in a simple way, of migration rates, concepts of meta-population to respond to questions of recruitment and landscape metrics to deal with questions concerning the use of land and the fragmentation of habitats.

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[17] DESKTOPGARP. University of Kansas. Available at: <http://nhm.ku.edu/desktopgarp>. Accessed: 20 Nov. 2009

[18] MAXENT Software for species habitat modeling. Available at: <http://www.cs.princeton.edu/~schapire/maxent>. Accessed: 20 Nov. 2009.

[19] INTERNATIONAL CENTER FOR TROPICAL AGRICULTURE. *Marksin and Floramap*. Available at: <http://gisweb.ciat.cgiar.org/SIG/marksim_floramap.htm>. Accessed: 20 Nov. 2009.

[20] THUILLER, Wilfried. Biomod: optinizing predictions of species distribuitions. [Global Change Biology], v.9, p.1353-1362, 2009. Available at: <http://www.will.chez-alice.fr/pdf/ThuillerGCB2003.pdf>

[21] OPENMODELLER. Site. Available at: <http://openmodeller.sourceforge.net/>

[22] DOXYGEN. Geospatial data abstraction library. Available at: <http://www.gdal.org/>. Accessed: 20 Nov. 2009

Thus it is necessary for analysis tools to be constantly evolving, implementing and testing new techniques in the modeling process. In this context, the openModeller computational environment is especially recommended as it is free, open source software involving modular architecture and collaborative development. These characteristics simplify the implementation process of new algorithms and a simpler pre- and post-analysis process, making this software a suitable environment for the experimentation processes in the modeling biodiversity (SANTANA et al. accepted for publication).

5.4.3. The vulnerability of Brazilian biodiversity in the face of global climate changes and the improper use of land

The last ten years (1998-2007) can already be considered the hottest since the planet's temperature started to be measured in 1850. During this period an average area of 20,000 km^2 of the vegetation cover of Brazil's 'Legal Amazonia' was lost each year. The environmental devastation and the increasing fragmentation of habitats and ecosystems are not simply a factor that increases the impact of climate changes, but a factor that multiplies it when we consider the stress associated with them. It is difficult to estimate the vulnerability of biological species because of both insufficient knowledge about the taxonomic levels and the lack of consistent and complete biogeographical data. Currently, very few modeling studies exist about ecological niches that focus on Brazilian biomes. Another noteworthy factor is that Brazilian economic ecological zoning is still only at the planning stage. According to the note published by the Institute of Studies for Commerce and International Negotiations (Instituto de Estudos de Comércio e Negociações Internacionais – Icone)[23], the most recent official numbers we have about the area given over to pasture are from 1996. Brazil, as the third largest agricultural country and the ninth largest possessor of planted forests in the world, cannot allow itself to not have a readily-available databank on land use and the ongoing changes that result from structural changes in the market of agricultural commodities, as well as the impacts resulting from climate change. The lack of defined rules and of adequate monitoring of land and coastal area usage associated with the impact of ongoing climate change will result in even greater losses of the yet-unknown biodiversity in Brazil.

According to Hoegh-Guldberg, Mumby et al. (2997), coral reefs around the Earth may become extinct from 2050 onward if the concentration of CO_2 in the atmosphere reaches over 500 ppm (parts per million), as the IPCC predicts will happen. The concentration of this gas in the atmosphere is currently 380 ppm, and if it reaches 500 ppm the pH and the concentration of aragonite (the min-

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[23] INSTITUTO DE ESTUDOS DO COMÉRCIO E NEGOCIAÇÕES INTERNACIONAIS. [*Icone*]. Available at: <http://www.iconebrasil.org.br/pt/>. Accessed: 20 Nov. 2009.

eral used by corals to create their calcarial skeletons) in the oceans will drop in such a way that it will become impossible for most coral species to survive. The Brazilian coastline, which is 8,000 km long, is currently undergoing many changes due to a real estate boom, especially in the Northeast region. The area near Abrolhos is being threatened by crab-breeding in the south of the State of Bahia. Despite the efforts of the Revizee project[24], the biodiversity of the Brazilian coastline is still little-known and information is not concentrated or readily available.

On land, the 'disconnection of habitats' is considered to be one of the main reasons for the decline in amphibian populations. According to Becker, Fonseca et al. (2997) the greater distances from the forests in which they live from the bodies of water where they reproduce is even now threatening the existence of several species. The study evaluates the impact of the fragmentation of the Atlantic rainforest, 93% of which has been destroyed, but it also warns that the problem might be happening around the world because of the destruction of 'waterside forests'. In the interior of the state of São Paulo, as well as the fact that a substantial amount of the remaining Atlantic rainforest is separated from water sources by sugarcane plantations or pastures, 76% of the 'waterside forest' has been destroyed.

The Brazilian Amazon will remain at the center of the global discussion about weather, natural resources and biodiversity due to its important mechanisms for the balance and regulation of the climate in the South American continent and the oceans. The deforestation of the Amazon region is once more increasing in 2007, after three years of slowdown, thanks to an increase in the cattle-raising area and the intensification of soy planting. If the current global emission of greenhouse effect gases is maintained, from 2050 onwards some forests in the center of the Amazon region may give way to vegetation typical of the *Cerrado*. According to data from PrevFogo[25] (Prevention of Forest Fires in Conservation Areas – Prevenção de Incêndios Florestais em Unidades de Conservação) the number of forest fires grew by 30% in 2007 in comparison to 2006. At least 65% of the deforestation detected by the Imazon[26] (Institute of Man and the Environment of the Amazon – Instituto do Homem e do Meio Ambiente da Amazônia) in Pará occurred in conservation areas and in indian territories in the 'Terra do Meio' (Middle Land) and on the BR-163 road. The loss of forest in conservation areas has been significant, affecting over 20% of the total environmental preservation areas. Therefore, there is no point in taking the measure of declaring reserves without assigning equipment and personnel to them.

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[24] BRASIL. Ministério do Meio Ambiente. *Projeto Revizee*. Available at: <http://www.mma.gov.br/port/sqa/projeto/revizee/capa/> Accessed: 20 Nov. 2009

[25] BRASIL. Tribuanal de Contas da União. Available at: <http://www2.tcu.gov.br/pls/portal/docs/PAGE/TCU/CONTROLE_EXTERNO/FISCALIZACAO/AVALICAO_PROGRAMAS_GOVERNO/RELATORIOS/PREVFOGO_IMPACTO.PDF>

[26] INSTITUTO DO HOMEM E MEIO AMBIENTE DA AMAZÔNIA. Available at:<http://www.imazon.org.br/home/index.asp>. Accessed: 20 Nov. 2009.

The advance of the rural frontier no longer seems to be deterred by forbidding land development in protected areas. It can only be controlled with a wide-ranging agroecological zoning of the Amazon, as long as this is in fact implemented by law.

Originally the *Cerrado* vegetation covered over 20% of the Brazilian territory, occupying around 2 million km^2, occupying a good part of the 11 states in the central area of the country (RATTER et al., 1997). In the last 30 years, the vegetation covering of the *Cerrado* has been rapidly transformed as a result of the expansion in agriculture and cattle-raising. According to some indicators, over 65% of the original *Cerrado* area has already been highly modified, since the biome currently has around 40% of its area compromised and this indicator may rise even more through the improper expansion of agriculture and cattle-raising. This situation is one of great concern because the *Cerrado*, besides being very rich in numbers of species, is also very rich in endemic species. It is estimated that the *Cerrado* contains around 10,000 species of plants and that 44% of those are endemic to this biome (Myers et al. 2000). Despite this ecological wealth, less than 3% of the original area of the *Cerrado* is protected by conservation units (Ministry of the Environment, 1998) and there is no specific legislation to effectively protect its remaining areas. The *Cerrado* is being progressively occupied by monocultures such as soy and sugarcane as well as by cattle-raising, and the CO_2 emitted by the *Cerrado* is being underestimated. Calculations conducted by researchers at UnB (the University of Brasilia) show that emissions of carbon in this biome is very significant. A study conducted by the Society, Population and Nature Institute (Instituto Sociedade, População e Natureza – ISPN[27]) shows an increasing tendency for sugarcane crops to be used in the production of ethanol and all this is happening in the second most threatened biome of the country. In the near future 47 new ethanol factories will be built in the states of Goiás, Mato Grosso and Minas Gerais, in *Cerrado* areas. Today, sugarcane already occupies lands that were considered priority areas for preservation and sustainable use by the MMA. Sugarcane plantations in the *Cerrado* show the difficulty the government has in implementing a protection system in areas the government itself has defined as priority ones.

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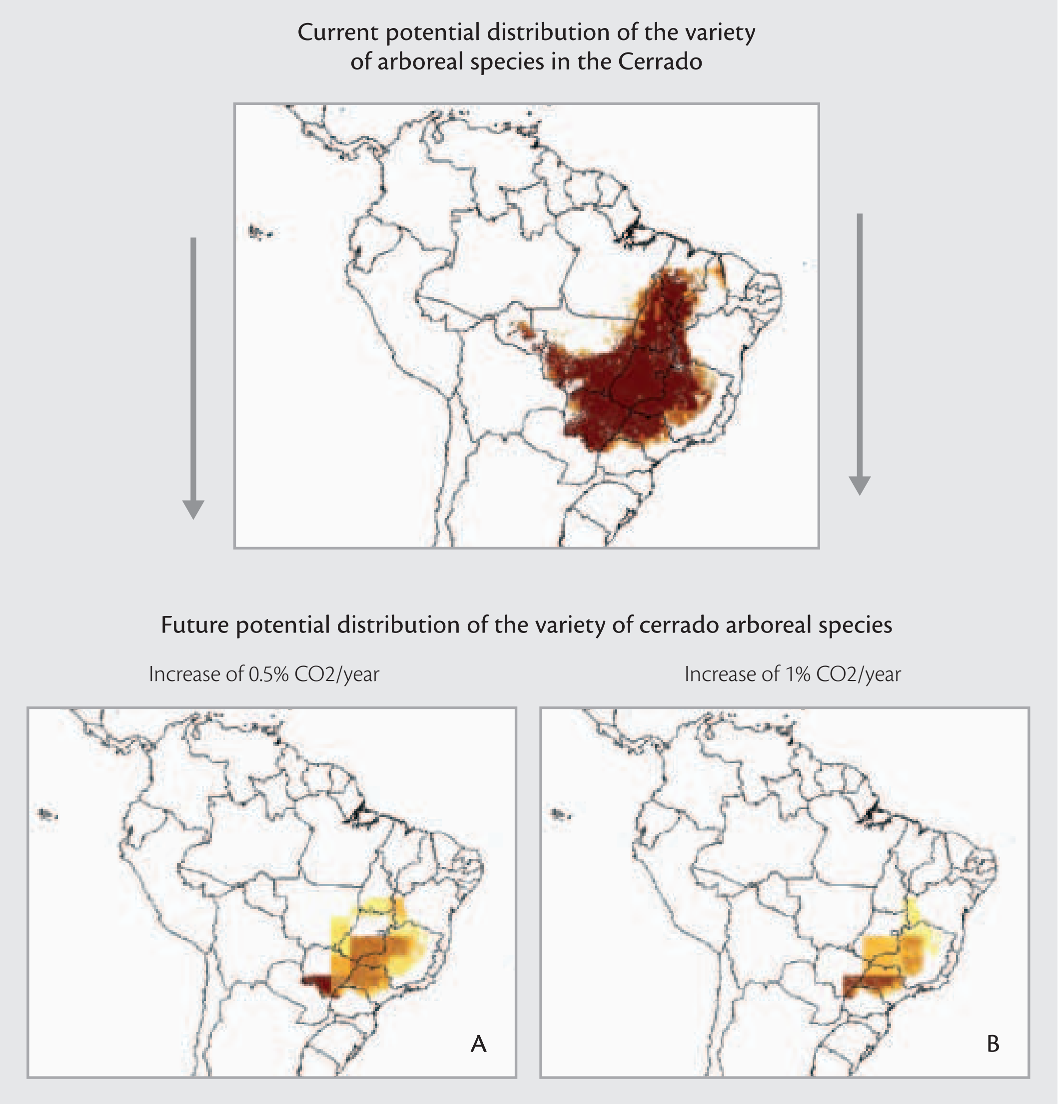
[27] CANAVIAIS Comprometem áreas importantes do Cerrado. Socioambiental, 03 Dez. 2007. Available at: <http://www.socioambiental.org/nsa/detalhe?id=2577>. Accessed: 20 Nov. 2007

5.4.4. Case study of the vulnerability of plants in the Brazilian *Cerrado*

The vulnerability of arboreal species in the Brazilian *Cerrado* to the impact of climate change was evaluated by Siqueira and Peterson (2003), using predictive modeling methodologies to generate geographical distribution maps based on the concept of an ecological species niche (PETERSON 2001, PETERSON and VIEGLAIS 2001, ANDERSON et al. 2002, ANDERSON et al. 2003). Based on occurrence records of 162 selected arboreal species, using data from the Technical Cooperation, Conservation and Handling of the Biodiversity of the Cerrado Biome Project (Projeto de Cooperação Técnica, Conservação e Manejo da Biodiversidade do Bioma Cerrado – Embrapa Cerrados, UnB, Ibama/DFID and RBGE/United Kingdom), some projections for the future potential areas of occurrence of those species were made, using two IPCC climate scenarios (2001). In both scenarios the study shows a loss of area greater than 50% for all species analyzed. It shows that between 18 and 56 species will not have habitable areas in the *Cerrado* region in 2050, and between 91 and 123 species will have their habitable area reduced by 90%, with a removal of the core area of the *Cerrado* from the Mid-west to the South/South-west region (Figure 5-7).



Current potential distribution of the variety of arboreal species in the Cerrado

Future potential distribution of the variety of cerrado arboreal species

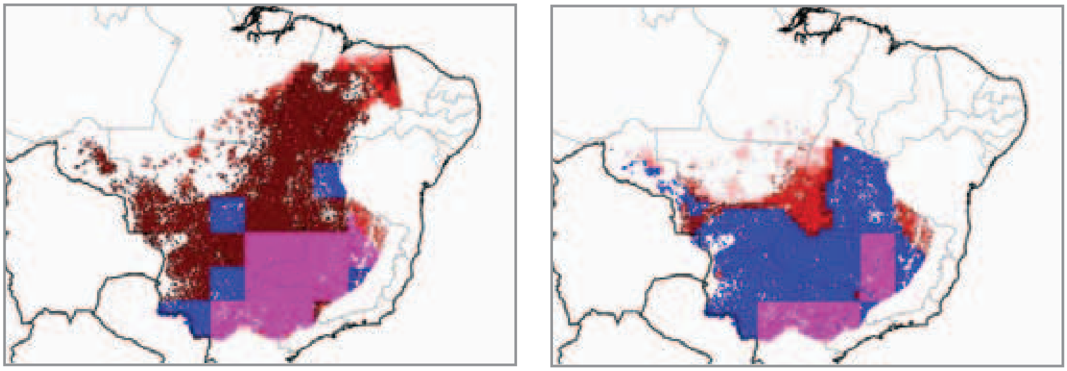
Increase of 0.5% CO2/year

Increase of 1% CO2/year

Figure 5-7: Current and future potential distribution for two climate scenarios.

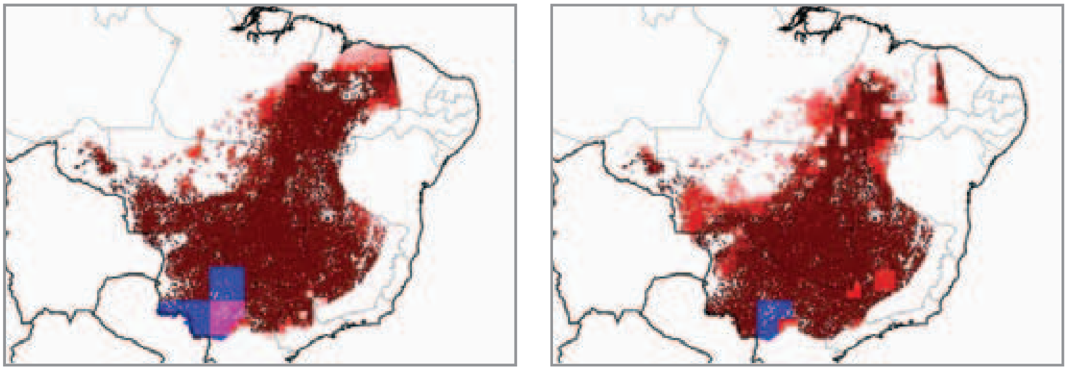
Source: Siqueira & Peterson (2003).

Figure 5-8 shows the difference in response to climate change of four arboreal *Cerrado* species, indicating a great reduction of area and the possibility of extinction of the *Rapanea guianensis*, and a smaller change in the distribution of *Qualea grandiflora*. This shows the need to carry out this type of analysis for each species, since different species have different ecological needs and different forms of adaptation to environmental changes.



Quaela grandiflora

Acosmiun subelegans



Quaela parviflora

Rapanea guianensis

Figure 5-8: Future distribution, based on two climate scenarios, of four Cerrado arboreal species. Blue represents the future potential area based on a more optimistic scenario (an increase of 0.5% of CO_2/year) and pink represent the future potential area for a more pessimistic scenario (an increase of 1% of CO_2/year).

Source: Siqueira and Peterson (2003).

Figure 5-9 shows the results of the potential distribution of *Qualea gradiflora* in the Siqueira and Peterson study (2003) and the results obtained by using new climate data generated in 2005. The resolution of the models generated with the 2005 data allows for more accurate analysis of the impacts of climate change in the distribution of species at a local level.

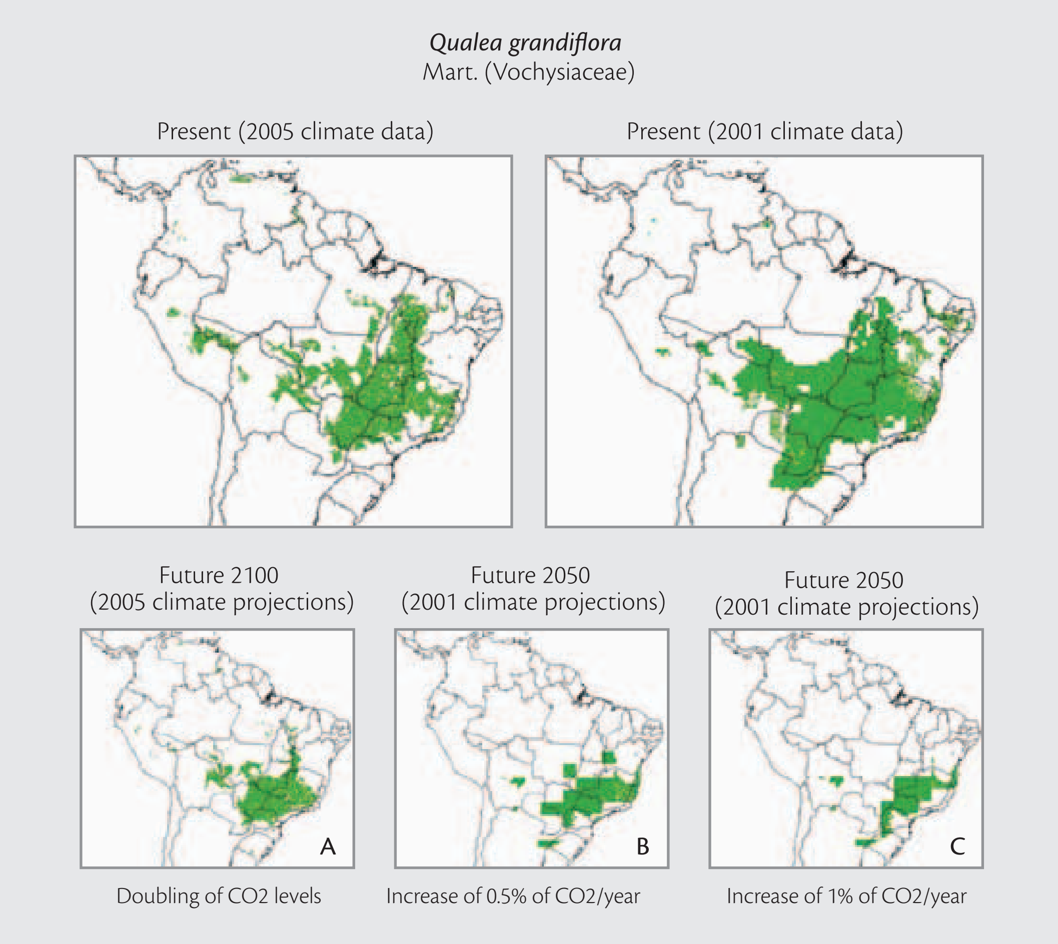


Figure 5-9: Modeling of the current and future potential distribution of *Qualea grandiflora* based on three different climate scenarios.

5.5. Conclusions

Natural systems can be especially vulnerable to climate changes due to a limited capacity for adaptation, and some of those may suffer significant and irreparable damage. The vulnerability of natural systems varies according to geographical location, time and the prevailing social, economic and environmental conditions. Ecosystems are subjected to many pressures such as change in the usage of the land, deposits of nutrients and pollutants, agricultural use, introduction of exotic species and natural climate variability.

Populations of threatened species will run an even greater risk of extinction due to the synergy of pressures acting against them, including changes in land use and the fragmentation of habitats. Unless they can adapt, some of the species defined as 'critically threatened' will be extinct in a few years, and species classified as 'threatened or vulnerable' will become much rarer during this century. The irreversible loss of species will bring adverse impacts on socioeconomic activities due to the change of environmental services such as pollination and natural pest control, and also on recreational activities, including ecotourism. Possible methods for adapting to the loss of species include the establishment of refuges, parks and natural reserves with ecological corridors to allow the migration of species, along with measures that stimulate breeding in captivity, establishing embryo and germoplasm banks, and measures for the transposition of species. However, these options are limited by their cost factor. Some specific conclusions about the impact and potential vulnerability of Brazilian ecosystems in the face of climate change scenarios are shown below:

1) The shared infrastructure of biological data is still at an initial stage and unorganized, and usually not available in digital form. The impossibility of dynamic access to data with the quality and precision required for the predictive modeling of species hinders the development of consistent impact and vulnerability scenarios for the main natural systems in Brazil.
2) Biodiversity informatics is a new area of scientific and technological development on a global level. Only in the last five years has rapid development of the sector begun to occur, with the implementation of the Global Biodiversity Information Facility (GBIF) and the adoption of standards and protocols that allow for the interoperability between information systems.
3) The existing projections of the impact of climatic changes in biodiversity are based on a few case studies that use a small amount of data associated with the selected biomes.
4) Organisms express the climatic-environmental characteristics of their ecological niche. Therefore, the distribution of species is directly affected by the impact of climate changes

in these ecological niches. It is important to define systemic approaches that will allow an evaluation over time of the impact climate changes will have on species, populations, communities, ecological niches and biomes.

5) The case study of the impact of climate change on arboreal species of the Brazilian Cerrado indicates a significant loss of biodiversity due to the average temperature increase of 2° Celsius over a 50-year period.

6) Preliminary Recommendations

   a) Support for the consolidation of shared and organized data infrastructure (biological and abiotic) to help develop consistent analyses of predictive modeling. This effort should be implemented in close collaboration with other global and regional initiatives.

   b) Support for the development of analysis tools that are integrated through a computational environment associated with the data infrastructure and that allows the development of impact and vulnerability scenarios through the use of different algorithms.

   c) Definition of indicators that allow the monitoring of the impact of climate changes on species, populations, communities and biomes (e.g., the decline of amphibian populations and of pollinators; changes in the phenological characteristics of plants).

   d) Definition of methodologies for the elaboration of impact, vulnerability and adaptation maps for the main Brazilian biomes. , taking into consideration various factors in the study and monitoring of the phenophases of vegetation species, dynamic seed germination, etc.

   e) Revision of the conservation priorities and the establishment of ecological corridors, taking into account the impact of climate change on biodiversity.

   f) Development of analysis, synthesis and data visualization systems that permit the monitoring of biodiversity loss and the adoption of preventive measures.

   g) Establishment of policies and strategies that result in the development of an integrated system for gathering and preserving data of public interest.

   h) Creation of a financial mechanism for the remuneration of the environmental services provided for the forests by conservation units, as a strategy to contain deforestation and mitigate climate change.

   i) Giving value to the environmental services provided by the conservation units with the creation of 'green markets'.

   j) Definition of indicator species susceptible to the impact of climate changes for each of the different Brazilian ecosystems

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6. Vulnerability, impacts and adaptation (VIA) to climate change in the semi-arid region of Brazil

Jose A. Marengo

6.1. Introduction

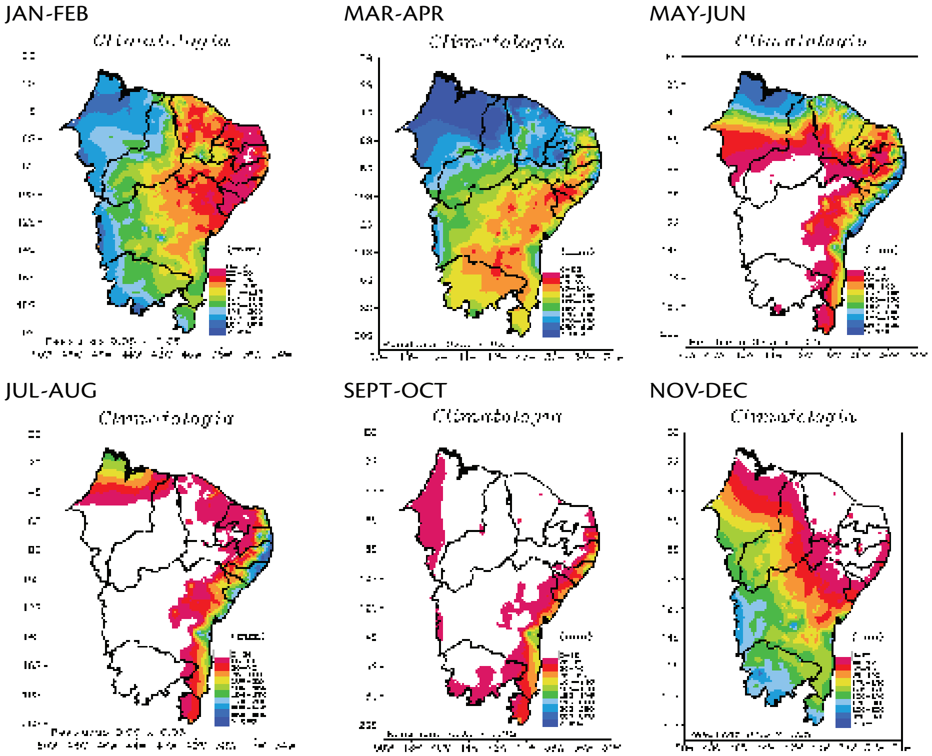
The Brazilian Northeast occupies 1.600.000 km² of the nation's territory and in 62% of this area contains the Drought Polygon, a semi-arid region of 940,000 km², which covers nine states of the Northeast and which faces a chronic problem of lack of water and rainfall levels of less than 800 mm a year. In the semi-arid region, which has 86% of the territory of the Northeast, there are approximately 30 million inhabitants, or about 15% of the national population. These numbers make this area the most populated dry region in the world. The irregularity of rainfall is a constant obstacle to the development of agricultural activities and the lack of efficient systems to store water - which are almost always controlled by a minority - intensifies the negative social impacts. To make things worse, strong cycles of drought customarily occur in the region in intervals varying from a few years to even decades. These cycles work together to permanently destroy the already fragile living conditions of small farmers and other poorer groups, and are often the excuse needed to leave the region.

It is known that rainfall in the semi-arid region of the Northeast is very varied in terms of space and time. Years of drought and abundant rain alternate in an unpredictable way and the droughts of 1710-11, 1723-27, 1736-57, 1744-45, 1777-78, 1808-09, 1824-25, 1835-37, 1844-45, 1877-79, 1982-83, 1997-98 were severe, just as were the lesser droughts in 2003 and 2005. The occurrence of rain alone does not guarantee that the subsistence plantations in drylands will be successful, and a *veranico* - a dry period during the rainy season - may have unfavorable impacts on the agriculture of the region. In the semi-arid region it is common to experience droughts during the rainy season which, depending on their intensity and duration, cause significant damage to subsistence crops (NAE 2005).

There is a natural tendency for the Northeast to be affected by large evaporation rates due to the great availability of solar energy and high temperatures. Increase in temperature associated to climate change caused by global warming, regardless of what happens in terms of rainfall, would already be enough to cause greater evaporation in lakes, dams and reservoirs and a higher evaporative demand from plants. This means that, unless there is an increase in the amount of rain, water will become a scarcer commodity, with serious consequences to the sustainability of the regional development.

6.2. The climate of the Northeast

The Northeast of Brazil presents a wide climatic variety that can be observed in the area stretching from the semi-arid climate in the countryside of this region, with accumulated precipitation of less than 500mm/year, to the rainy climate found mainly on the East coast, with annual accumulated precipitation of more than 1,500mm. The Northern coast of the region receives between 1,000 and 1,200mm/year. Figure 6-1 shows the bimonthly amounts of rain in the Northeast. The area which is most affected by the lack of rain is the Drought Polygon, an area of over 1 million km^2 where 27 million people live, scattered throughout eight states (only Maranhão is left out) and the North of Minas Gerais (NAE 2005, MARENGO e SILVA DIAS, 2007).



JAN-FEB

MAR-APR

MAY-JUN

JUL-AUG

SEPT-OCT

NOV-DEC

Figure 6-1: Bimonthly climatology of rain in Brazil (1970-90). The red spots represent a smaller volume of rain and the blue spots show a larger volume of rain, according to the color scale on the left of the map (in mm over three months).

Sources: NMRH-AL, SRH-BA, Funceme-CE, SEAG-ES, SEMARH/LMRS-PB, SECTMA/DMRH-PE, SIMGE-MG, SEAAB-PI, EMPARN-RN, Cepes-SE, CMCD/Inpe, INMET. Proclima: www.cptec.inpe.br/proclima.

This region has basically three rainfall regimes:

1) In the South-southwest of the Northeast Region, the main period of rainfall is from October to February. Rain is mainly caused by the passage of cold fronts coming from the South of the country. Moreover, rainfall occurs as isolated events and this normally occurs in the end of the afternoon and at the beginning of the night, due to the warmth of the day.
2) In the North of the Northeast Region, which covers the greatest part of the semi-arid zone, the period of heaviest rainfall occurs between February and May. This region is well-known for being the one where the most severe droughts occur. The most important system that causes rain in this sub-region is the Inter-tropical Convergence Zone (ITCZ).
3) In the East of the Northeast or Forest Zone, the main period of rainfall occurs between April and August and rain is caused mainly by the contrasts between the sea and land temperatures by means of sea breeze. Winds blowing towards the land carry humidity from the sea, which condenses and precipitates along the coast line and in the region of the Forest Zone.

Figure 6-2 shows the spatial distribution per month, in which average monthly precipitation reaches its maximum and also gives the histogram of the annual distribution of precipitation for five representative seasons. In most of the region the dry season occurs from September to December. The driest trimester is between August and October, along a line running from Northwest/Southwest, starting in the extreme West of the Northeast. In the South of the Northeast, the driest trimester changes to July/August/September and finally to June/July/August in the whole of the interior of the state of Bahia. The coast of Bahia presents great variety in rainfall regime: the driest trimester is January/February/March in the extreme South, precisely in the period of greatest accumulation of rain immediately to the South of that region. From Salvador to the North, the driest trimester occurs between August and October.

The percentage of days with water deficit (the ratio between the number of days with water deficit and the total number of days) for the period 1970- 1990 (Figure 6-3) can be used as a criterion to evaluate the climatic vulnerability of the semi-arid region. Figure 6-3 shows that an analysis based on water balance indicates that areas defined as semi-arid (a region delimited by the 80mm isohyet line) are consistent for the region in the period 1970-90, with a water deficit at least 60% of time, according to the water balance model. Some areas of the Mid-Jequitinhonha district have the same conditions, but they are not yet legally included in the semi arid region. So in this sense the analysis based on water balance, which incorporates factors not considered in the current delimitation of the semi-arid, has confirmed that this region is more frequently affected by droughts.

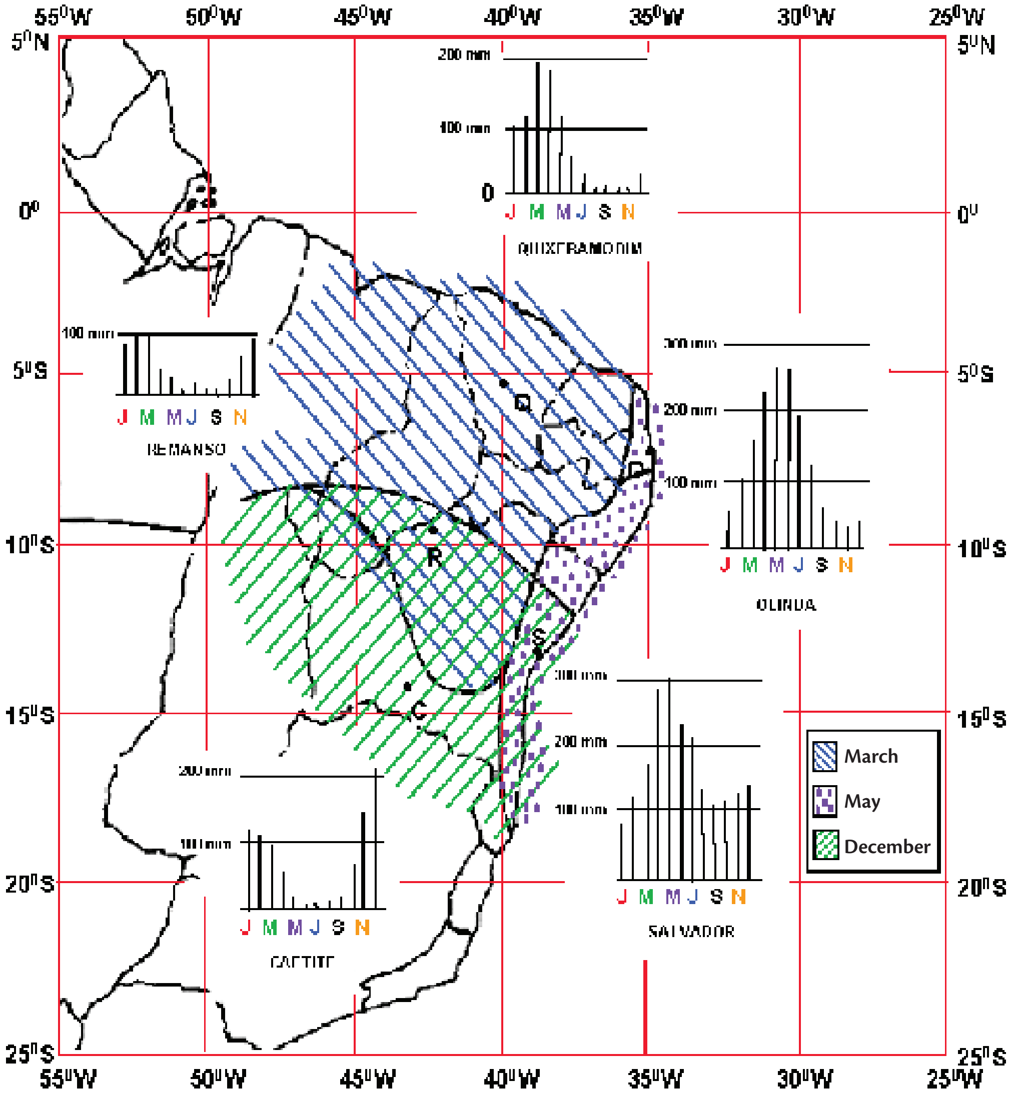


Figure 6-2: Spatial distribution of the month in which the average monthly precipitation reaches its maximum and histograms of the annual distribution of precipitation (vertical axis in mm) for five observation points, representing different rainfall regimes in the Northeast. The data used are for the period 1931-1960. The locations of the observation points are indicated by the letters Q (Quixeramobim), O (Olinda), S (Salvador), C (Caetité) and R (Remanso).

Source: CPTEC/Inpe.

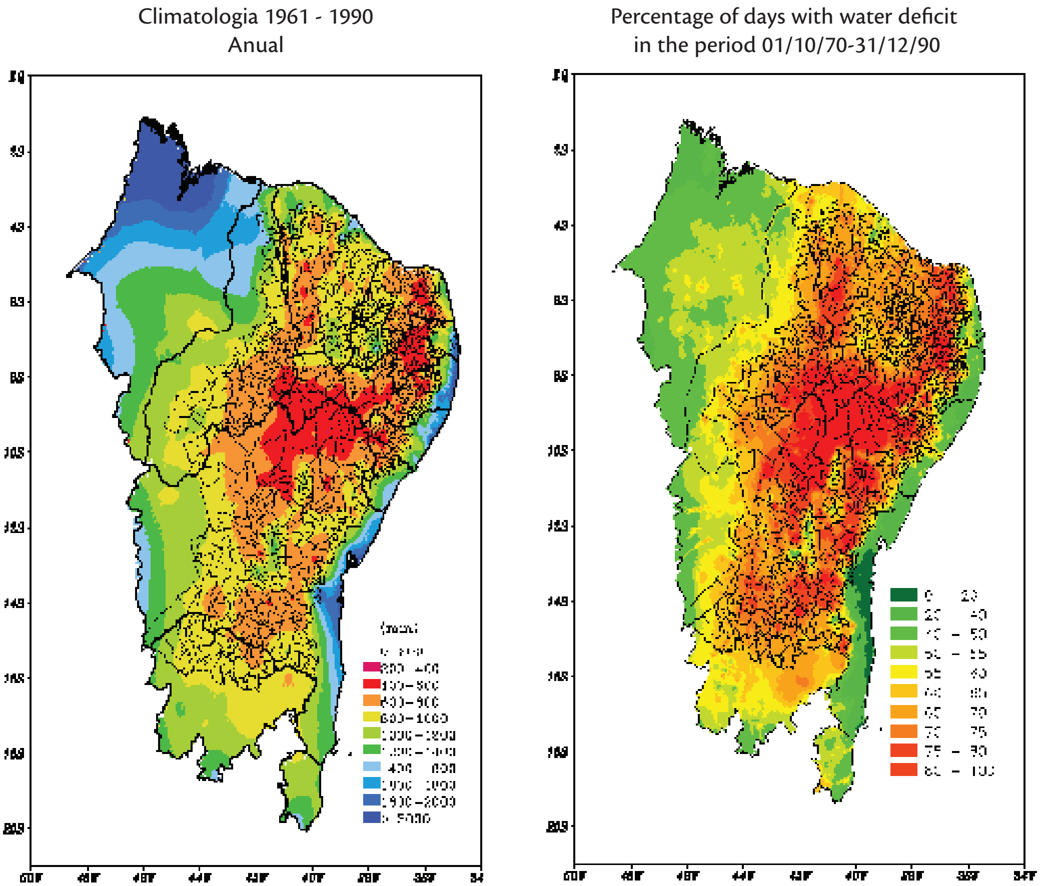


Figure 6-3: Map of annual rainfall 1961-90 and scale in colors in mm. Percentage of days with water deficit in the period 1970-90 and scale in % (bottom-right).

Source: Proclima-www.cptec.impe.br/proclima.

6.3. Climatic variability

The management of water resources in the semi-arid region depends considerably on the variability of the climate, especially the distribution of rain. Long-term climatic variability has been studied by the climate centers in Brazil and the Northeast region (MARENGO and SILVA DIAS 2007, MARENGO 2002, 200 a, b, SOUZA FILHO 2003). However, it is still necessary to study this variability in combination with the uncertainties associated with future climate change, whether due to natural variability or to human action, associated with an increase in the concentration of greenhouse effect gases in the atmosphere.

Climate change in Brazil threatens to intensify the already existing difficulties in gaining access to water. The combination of changes in the climate, in the form of lack of rain or little rain accompanied by high temperatures and high evaporation levels and competition for water resources, can lead to a potentially catastrophic crisis, with the poorer subsistence farmers in the semi-arid area of the Northeast being the most vulnerable. With a semi-arid region becoming more arid, and experiencing more frequent droughts, the basis of support for human activities will diminish, so it is probable there will be an increase in the removal of the population to cities or to areas where it is possible to develop irrigated agriculture. According to the IPCC (2007a), even if the reduction of gas emissions to 1990 levels is achieved – which would need a huge effort and one which is unlikely to happen – the temperature of the planet will increase by about 1°C until 2100, with projections of 4.5°C in the worst-case scenario of high emissions. Actually, the temperature has already increased by 0.7°C in the last 50 years all over Brazil and in the Northeast the increase at the top of the temperature scale has been from 1.5-2°C over the last 41 years (F. Lacerda-Laboratorio de Meteorologia-ITEP, Recife-Pernambuco).

In terms of the population, the most vulnerable are those with fewer resources and less ability to adapt. In 2005 a study developed by the Center for Strategic Affairs of the Presidency of the Republic (Núcleo de Assuntos Estratégicos - NAE 2005) suggested that the Northeast is the region most vulnerable to climate change. The semi-arid region of the Northeast which has a short, but crucial rainy season could, in a hotter and dryer climate in the future, become an arid region. This can affect subsistence agriculture of the region, the availability of water and the health of the population, forcing people to migrate, generating waves of 'environmental climate refugees', moving to the big cities or to other regions, increasing the social problems that already exist in big cities. This problem has already been observed in the great droughts of 1777-78, 1876, 1983 and 1998, among others.

This article represents an updating of what appears in NAE (2005), emphasizing the aspects associated with climate change in the Northeast region, aiming to analyze future climate scenarios in the region until the end of the 21st century. Analyses concerning the vulnerability of the Northeast region are presented and, when related to the impacts of climate change, they suggest areas that are potentially vulnerable to these effects, as well as possible actions for adaptation and mitigation. It is suggested that the reader should access the following bibliographical references to expand this review of the literature concerning climate and climatic variability in the Northeast: Magalhães et al., 1988; Xavier, 2001; Marengo, 2003 2007a; Marengo and Nobre, 2001; Silva Dias and Marengo, 2002; Nobre et al., 2006; IPCC, 2007 a, b; Marengo and Silva Dias, 2007.

6.4. Current vulnerability to extremes of climate variation in the semi-arid region of the Northeast

A change in climatic variability increases the vulnerability of an ecological system and uncertainties in the process of water administration. The term 'vulnerability' denotes a limit beyond which a person or system may be affected, while 'sustainability' means the capacity of a system to maintain itself in a specific situation, so vulnerability denotes the point where sustainability may be compromised. To conclude, in the current context, vulnerability and sustainability are related concepts where the fragile sustainability of a system is understood as being more vulnerable.

In general, the economy of the area of the semi-arid region is presented as a complex of extensive cattle-raising and low-cost agriculture, both which have produced satisfactory profits, supported by consortia of landowners based on corn, cotton, beans and manioc production. This kind of subsistence agriculture is very vulnerable to the phenomenon of droughts.

As an example of climatic extremes of great impact on the region, the great drought of 1998 and 1999 resulted in a decrease of 72% in the production of beans, corn, cotton, rice and manioc during the drought, according to the study of Joaquim Nabuco's Foundation (Fundaj) in a study involving 15 municipalities in five affected states. The rains during the summer of 2004 were considered to be above the normal amount, because there were episodes of heavy rainfall in Ceará state in January, 2004. In this period the rains were 500% above the normal level and caused sizeable economic losses in Ceará (NAE, 2005). More discussions on this point appear in Section 5.

6.5. Impacts of climatic extremes in the economic history of the semi-arid region

6.5.1. Drought

The main manifestation of climatic variability in the Northeast of Brazil is drought. The semi-arid region has in its past a history of droughts which affects dramatically its rural population. The region is an enclave with little precipitation which runs from the coast of Ceará and Rio Grande do Norte states to the middle section of the São Francisco river, with a vegetation of the *caatinga* variety [dry, scrubland vegetation characterized by thorny bushes – trans.]. Historically, the region has always been affected by severe droughts or severe floods. Reports of droughts in the region can be found since the 17th century, when the Portuguese arrived in the region. Kane (1989) referring to the Northeast, stated that in 29 years of El Niño occurrence over 137 years (1849-1985), only 12 were associated with droughts in the region.

In the semi-arid region of the Northeast this climatic variability, especially drought, is always synonymous with the suffering of rural populations in the interior of the region and has been an object of concern to society and government bodies for many years. The best proof of this preoccupation was the building of the first water reservoirs in the semi-arid region of the Northeast, which date from the end of the 19th century, during the Imperial period, such as the building of the Cedro Dam in Quixadá/CE. The many authors who enumerate the droughts of the 17th, 18th and 19th centuries base their analyses on the water records made by the writers of the time, or even on personal statements. It becomes difficult to achieve an objective classification of the dry years, except from events such as the great droughts like those of 1777 and 1877.

According to a study by Souza Filho (2003), the Semi-arid region of the Northeast in the 18th century showed a very small demographic density. This did not reduce the impact of droughts on the regional economy during that century. Brígido (2001) observes that 'the one of 1777, which lasted until 1778, resulted in the loss of seven-eighths of the cows in the Captaincy of Ceará'; and 'the drought of 175 was so severe it made the springs of Cariri dry up', probably impacting on the plantation of sugar-cane and the general multiple crops that were characteristic of the period.

These droughts are associated with the climatic characteristics of the region and the variability of the Pacific and Tropical Atlantic oceans (MARENGO and SILVA DIAS, 2007, NOBRE et al., 2006). Statistically, there are 18-20 years of drought in every 100 years. The most serious droughts, which occur when the rain is reduced to less than half of this level, appear in historical records since the beginning of the colonization in the 16th century.. So far, the 20th century has been one of the most arid, recording no less than 27 years of drought. The longest started in 1979 and 50% of cattle were killed by lack of water, undernourishment increased dramatically and thousands of people died of thirst and malnutrition.

The first economic process of the semi-arid region was cattle-breeding, which occupied the sertões [dry bush country - trans.] until the great drought of 1877, when seven-eighths of the herd that existed in the semi-arid region was decimated by the drought. At that time, the manufacture of leather was an important economic activity. The second most important economic activity was the association of livestock with cotton. In the period 1844-1877, rains were regular and cows were reproducing, increasing population densities significantly. The American Civil War allowed the cotton from the semi-arid region to gain access to the European market. And the soil, not yet degraded, raised the productivity of cotton. This situation developed until the drought of 1877, when the cotton industry and livestock were decimated. So in this sense, we may conclude that a view of the development of the semi-arid region of the Northeast cannot be separated from the issue of coexisting with climatic variability.

Since 1942 there have been no victims of drought except for isolated cases. Guerra (1981) says that 'there was been water in big reservoirs, where the greatest irrigations occurred. The policy of dam-construction began with the building of the Cedro reservoir, started in 1884 by Revy and was concluded in 1924 by Piquet Carneiro. Other constructions of the Cedro kind, which made irrigation possible, would only be built after the drought of 1930/32'. Reservoirs that have been created include: Estreito Ema, Feiticeiro, Choro, General Sampaio and Jaibara, in Ceará; Riacho dos Cavalos, Pilões, Santa Luzia, São Gonçalo, Condado and Soledade, in Paraíba; Lucrecia, Ithans and Inharé in Rio Grande do Norte; reservoir construction has also been started in Curemas (Paraíba) and Lima Campos (Ceará).

Analyzing the effects of droughts on production in the period 1973-1983, the Federal Senate Report (1997) estimates that, computing the total figures for the period provides impressive figures of 1.6 million of MT of cotton, 4 million MT of manioc; 3 million MT of corn and 952,000 MT of beans, without considering the other losses verified in other products. The 1983 El Niño affected 1,328 municipalities with a total population of 28,954,000 people. During the 1998 El Niño, after the disaster of the drought generated by climatic phenomenon, the Federal Government gave R$465 million out of a total 1.6 billon to help those affected by the drought (NAE 2005).

Figure 6-4 presents the variability of rainfall in the semi-arid region for the March-April-May rainy season, where the aforementioned droughts can be observed. The greatest droughts have been attributed to El Niño, like those of 1982 and 1998, and others have been attributed the warming of the North Tropical Atlantic Ocean. Tendencies for systematic increase or reduction of rainfall have not been observed, although rainfalls have decreased and become less regular in the past five years. In November 2007, when the Sobradinho dam had only 15% of the water it should have contained, 158 municipalities of Paraíba state were in a drought-related state of emergency. In that year rainfall was up to 2.5mm/day less than normal. Variations in rainfall in the Northeast present interdecade scale variations, with relatively humid periods in the 1970s and dryer ones in the 1940s.

Rainfall Anomaly: Northeast Region
(-33 to -34 long. -8 to -3 lat.) March/April/May

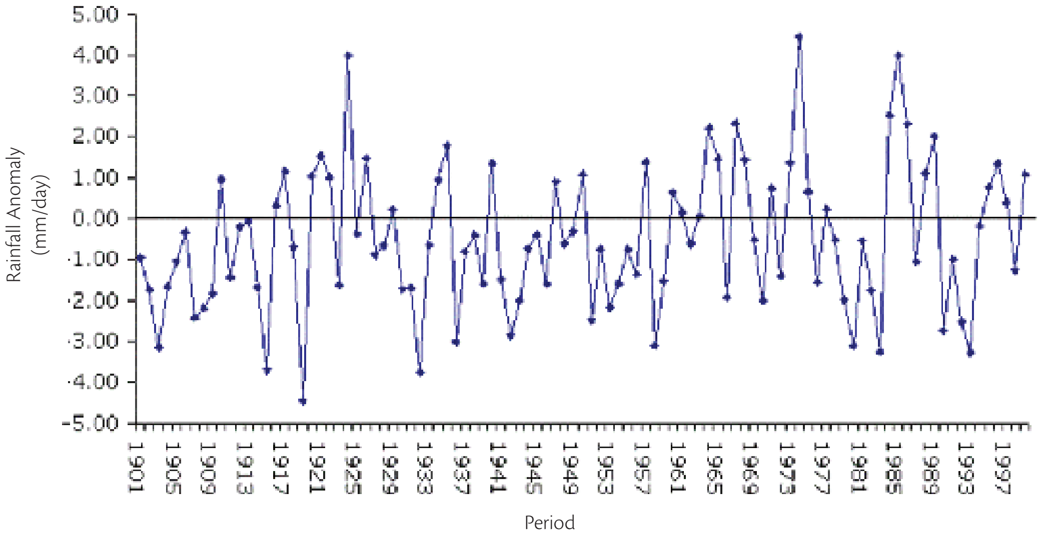


Figure 6-4: Rainfall anomalies (mm/day) in the semi-arid region of the Northeast during the rainy season in the months March-April-May (MAM) from 1901 to 2000, in relation to historical average.

6.5.2. Floods

The heavy rainfalls that occur in red in all regions in January 2004, generated the total accumulated of rainfall in some regions which, in this period, came to 500% above the historical average. In some localities, maximum precipitation was 300 mm above the climatological average for the month. In Picos (PI) there was 436 mm of rain, when the monthly average is 127 mm; in Barra (BA) there was 280 mm of rain (monthly average 12mm); in Quixeramobim (CE) there was 252mm of rain (monthly average 78mm). The water reserves in the Northeast, which at the beginning of January hold, on average, around 30% of maximum capacity, in the summer of 2004 were over 90% full by the end of the month, due to high levels of rainfall. According to the CPTEC, the causes of these heavy rainfalls were the transport of atmospheric humidity from the Tropical Atlantic and from the Amazon Basin to the Northeast, which is a rather unusual but not an impossible event.

According to the National Civil Defense Secretariat, the floods of January 2004 in the Northeast had the following impacts: 219 casualties, 1,404 hurt, 370,000 homeless, 1,219 municipalities affected

(42% of the municipalities of the Northeast were affected) and 115,984 houses destroyed or damaged. Even so, the rainfalls during the MAM 2004 rainy season were 2mm/day lower than normal.

6.6. Actions to monitor the climatic vulnerability of the semi-arid region

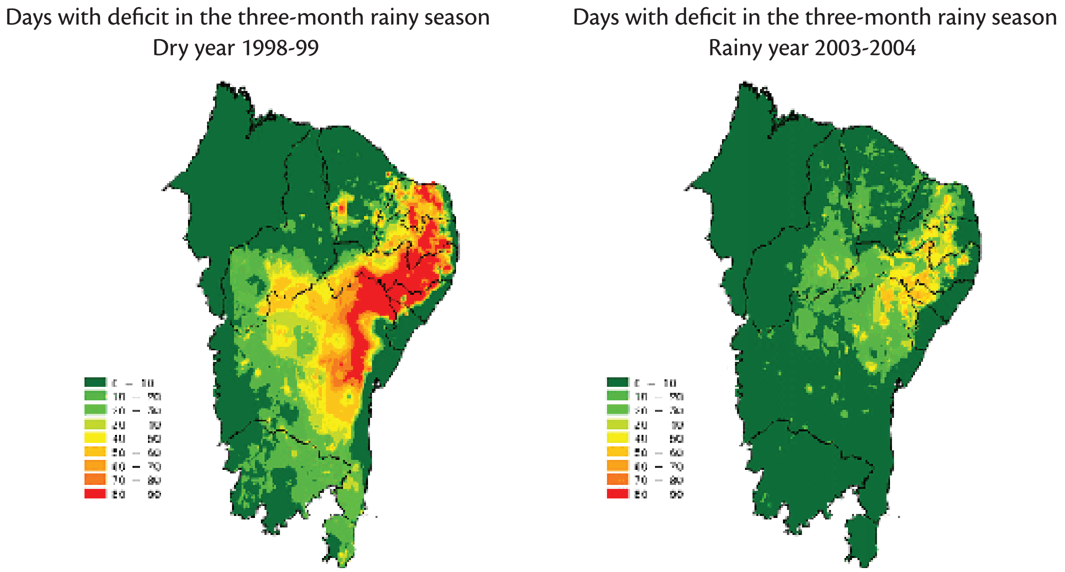
Since precipitation in the region is very variable in terms of time and space, the occurrence of rainfall alone does not guarantee that the subsistence cultures will flourish. An intense drought during the rainy season, or intense or excessive precipitation at the same time, may have quite negative impacts on the regional and national economy because the Federal Government has to take action to mitigate damage and minimize losses.

In this context, the Real-Time Climatic Monitoring Program in the Northeast Region (Proclima) is an initiative of Sudene and of the National Integration Ministry to monitor the rainy season in the Northeast. Proclima is carried out by CPTEC/Inpe and the states of the Northeast Region, Minas Gerais e Espírito Santo, through centers and state laboratories participating in the Ministry of Science and Technology's Weather, Climate and Water Resources Monitoring Program (PMTCRH). One of the products generated by Proclima is the record of the number of days with water deficit during the rainy season, which is a good reference for the behavior of pluviometric precipitation, in quantity and regularity, as well as for the possible impact on agricultural activities, thus making it an indicator of the vulnerability of agriculture to the lack of rain in this region.

Figures 6-5 a-b show the number of days with water deficit in the trimester of the three-month rainy season in Sudene's area of activity is for extreme years: dry (1998-99) and rainy (2003-2004). It is important to remember that the climatic regimes in the Northeast are different, which means that the beginning of the rainy season will be different in each micro-region. The analysis presented concentrates on the three-month rainy season in each of the sub-regions in the semi-arid region, which includes February, March, April and May. The green colors show areas potentially favorable for agricultural activities. The areas in yellow correspond to intermediate situations, where there was a decrease in productivity or partial loss of harvest. In general terms, we may observe the existence of a climatic situation in the semi-arid region that is not very suitable for agriculture.

A number of days (with a high water deficit) indicates insufficient rainfall or of occurrence of dry periods in critical periods for the development of culture (a phenomenon called 'green drought' in the semi-arid region) which may therefore be associated with a possible collapse of subsistence crops.

In the case of the dry year 1998-99 (an El Niño year), the areas in red indicate those that had a significant water deficit, in which agricultural activity was adversely affected. The areas in red fill great areas of the semi-arid region from the Northeast of the state of Bahia to Rio Grande do Norte. In the rainy year 2003-2004, the situation became noticeably better and the semi-arid region presented areas with 40-50 days with water deficit, compared to values of 80-90 days with deficit in the dry year. Preliminary analysis indicates that in the rainy season of 1998/1999 there were more severe effects from the south of the state of Rio Grande do Norte to the north of the state of Bahia.

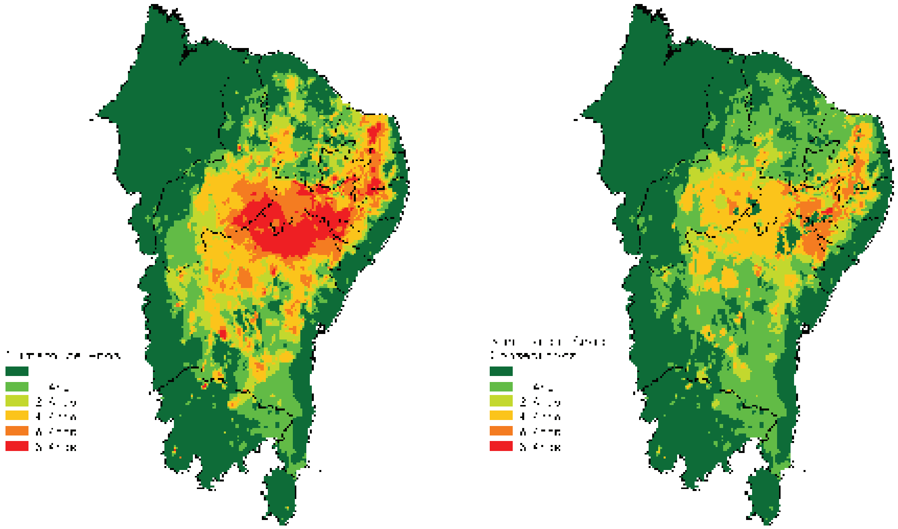

Days with deficit in the three-month rainy season
Dry year 1998-99

Days with deficit in the three-month rainy season
Rainy year 2003-2004

Figure 6-5: Dry days with water deficit in the Three-month Rainy Season in the Northeast: (a) dry year 1998-99, (b) rainy year 2003-2004

Source: Proclima-CPTEC/Inp

Figure 6-6 indicates areas which exhibited water deficits lasting more than 30 days in the period 1999-2007 (a) and with a deficit of more than 30 days in consecutive years. The areas in red presented severe water deficit in the last four rainy seasons, while green colors indicate areas in which there has not been severe water deficit in at least three of the last rainy seasons. Based on this analysis, it can be concluded that the areas in red are more vulnerable to the possibility a new drought in the 2007-08 rainy season. Therefore, the humidity of the soil is unfavorable in the region covering the North of Bahia state, the East of Piauí state, the center and the West of Pernambuco state and the centre of Paraíba state and Rio Grande do Norte state. These areas are most frequently affected by climatic events and serve as an initial indicator of regions potentially more vulnerable due to successive critical climatic events. It is worth mentioning that the current analysis is based only on climatic factors and does not consider the mitigation actions resulting from current public policies.



Areas with deficit lasting more than 30 days in three-month rainy season - period 1999-2007.

Areas with deficit lasting more than 30 days in the three-month rainy season in consecutive years - period 1999-2007.

Figure 6-6: Dry days with water deficit lasting more than 30 days in the Three-month Rainy Season in the Northeast, in the period 1999-2007 in: (a) non-consecutive years, (b) consecutive years

Source: Proclima-CPTEC/Inpe

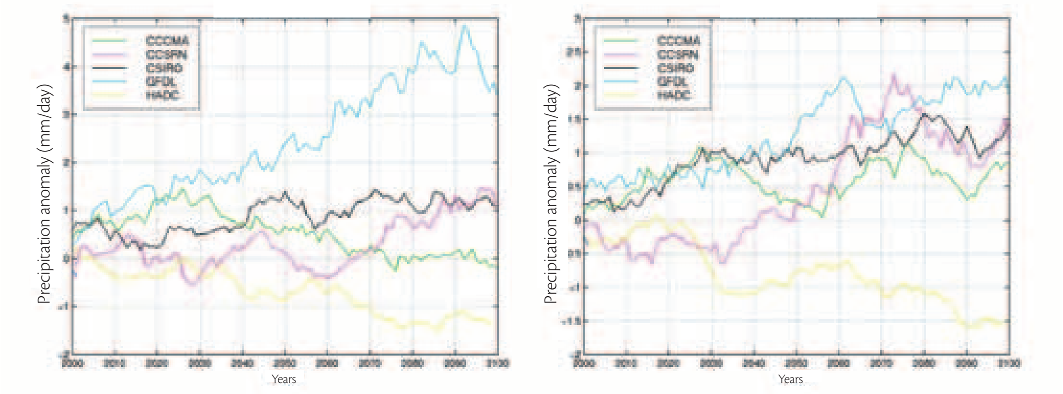
6.7. Vulnerability of the semi-arid region to future climate changes: possible risks and impacts of climate change

The projections of future climate in the Fourth Report of the IPCC AR4 (IPCC, 2007 a and b) and the Climate Report of Inpe (MARENGO et al., 2007 a and b; AMBRIZZI et al., 2007) have shown scenarios of drought and extreme rainfall events in large areas of the planet and of Brazil respectively. In Brazil, the most vulnerable region to climate change from the social point of view would be the semi-arid region (locally known as *sertão*).

Figure 6-7 presents rainfall anomalies generated by five global climatic models from the IPCC AR4 for the period 2000-2010 (MARENGO, 2007 a), in relation to the 1961-1990 average, for extreme climatic emissions scenarios: A2 (pessimistic high emission of greenhouse effect gases) and B2 (optimistic low emission of greenhouse effect gases). For the B2 scenario, the CSIRO (Australia), GFDL (EUA), CCMA (Canada) climatic models (from 2000) and the CCSR/NIES model (from 2060) show positive rainfall anomalies which reach 2 mm/day in GFDL for 2100. In A2 scenario, the CCSR/NIES model (Japan) presents positive anomalies that are less marked than those of the B2 scenario. In A2, the greatest difference between it and B2 is in the GFDL model, which presents positive tendencies for rainfall reaching 4 -5 mm/day in 2100, in comparison with 2 mm/day^{-1} in the B2 scenario. In both scenarios the HadCM3 model (United Kingdom) presents negative anomalies, reaching 1.5 mm/day in 2100.

Northeast Region

Northeast Region



Northeast A2

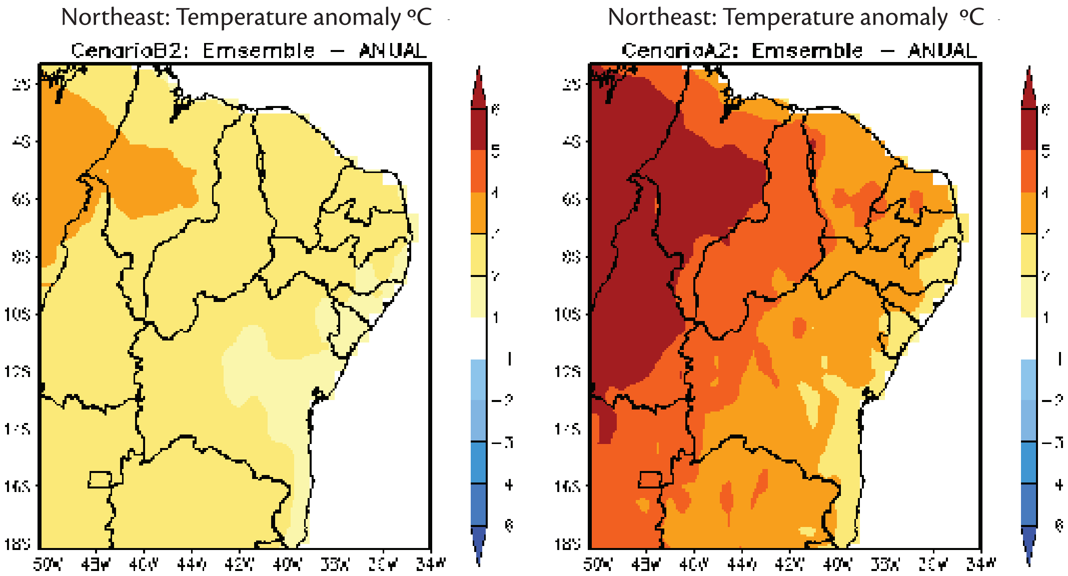
Northeast B2

Figure 6-7: Time Series of rain anomalies for the Northeast during FMAM in 2000-2100, generated by linked ocean-atmosphere IPCC-AR4 CCMA, CCSR/NIES, CSIRO, GFDL and HadCM3 models. The anomalies were calculated in relation to climatology of 1961-90 for each model. The series were softened using a mobile average of 11 years.

Source: Marengo 2007a.

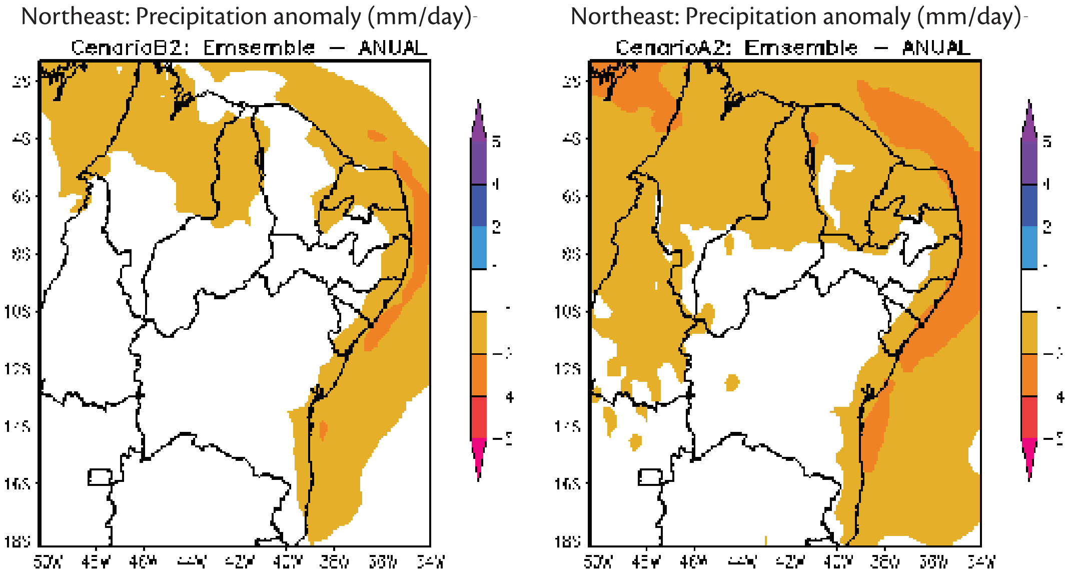
The Inpe Climate Report has shown climate change in Brazil until the end of the 21st century. The report describes regionalized climate scenarios for the future (2071-2100) derived from three regional climate models (Eta-CPTEC, HadRM3 and RegCM3, with spatial resolution of 50km latitude-longitude) skewed according to the global model of the United Kingdom Climatic Centre (Hadley Centre) HadAM3, for extreme scenarios of A2-pessimistic emissions and B2-optimistic emissions. More details may be found in Ambrizzi et al. (2007) and Marengo et al. (2007 a, b). Figures 3-8 and 3-9 show the seasonal projections of changes in temperature and rainfall for the Northeast during 2071-2100 in relation to the present (defined as 1961-90) for the two climate scenarios A2 and B2, and the average of the three regional models. According to the Inpe report, in the pessimistic climatic scenario, temperatures would increase from 2-4°C and rainfall would diminish between 15-20% (2-4 mm/day) in the Northeast until the end of the 21st century. In the optimistic scenario, warming would be something between 1-3°C and rainfall levels would be around 10-15% (1-2 mm/day) less than current annual levels.

In relation to extreme climate events, the most important impact would be the increase in the number of consecutive dry days (CDDs - indicators of the so-called *veranicos*), reaching an amount of up to 30 days/year in 2071-2100 in the A2 scenario (Figure 6-8) compared to 12 days/year in the current climate, as well as a reduction of days with intense extremes of rain, especially in the countryside of the Northeast, on the coast of Piauí and in the state of Bahia.



Northeast: Temperature anomaly °C

Northeast: Temperature anomaly °C



Northeast: Precipitation anomaly (mm/day)

Northeast: Precipitation anomaly (mm/day)

Figure 6-8: Annual rainfall anomalies for the Northeast (in mm/day) to the future (2071-2100), in relation to the current climate (1961-90). Anomalies represent the average of three regional models (resolution of 50km lat.-long.) for the emission scenarios of A2-high emissions and B2-low emissions. Red/Blue colors represent negative/positive rain anomalies, and a color scale appears on the right side of each panel

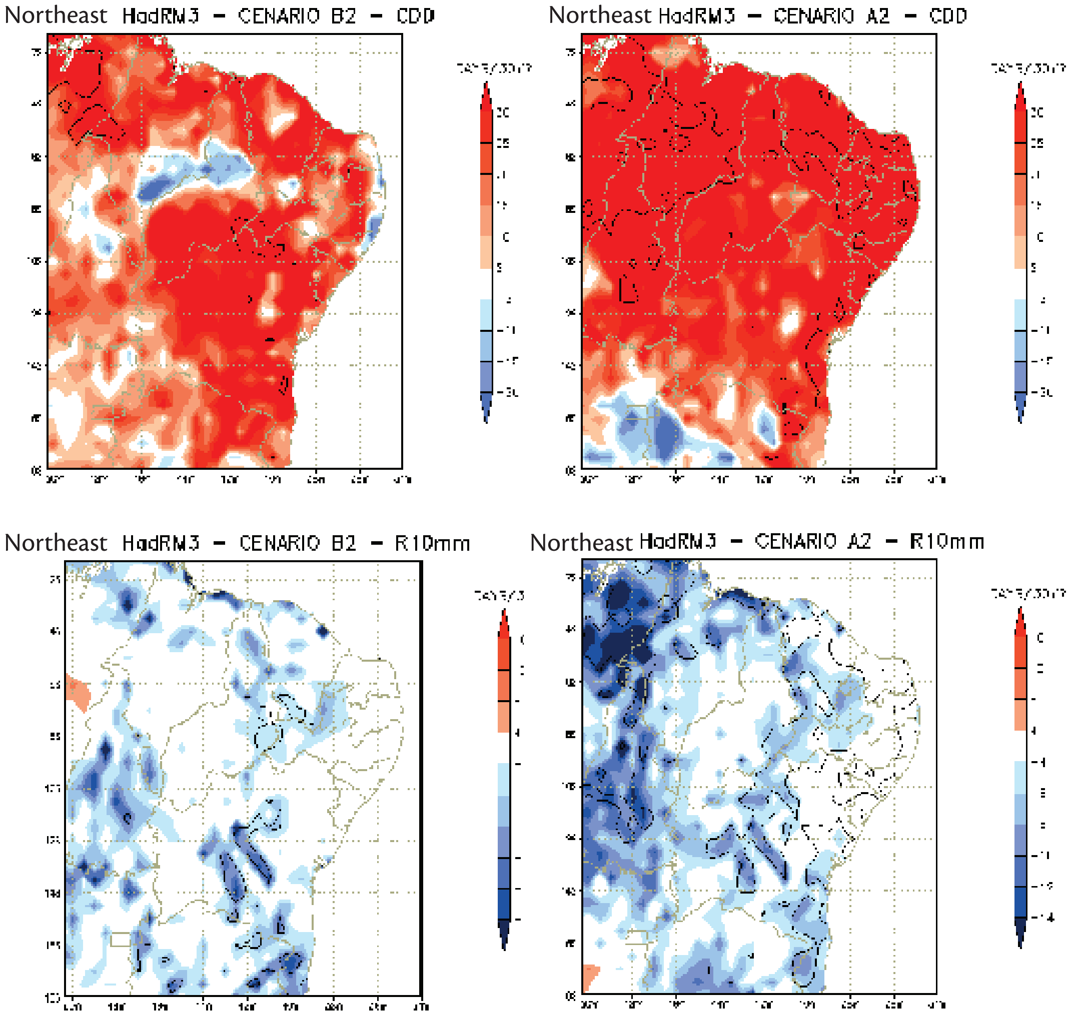
Source: Inpe Climate Report - www.cptec.inpe.br/mudanças_climaticas

The possible impacts of climate change in a global warming scenario, considering both the optimistic and the pessimistic scenarios identified by the IPCC and of the results of the Inpe Climate Report would be the following:

- An increase of 3°C or more in the average temperature would make areas which currently have the greatest water deficit in the semi-arid region even drier;
- The current short rainy season may disappear. If this problem occurs it will be impossible to practice agriculture without irrigation in the region, and access to water will be very difficult;
- The high potential for evaporation in the Northeast, combined with the increase in temperature, would cause a decrease in water levels of lakes and reservoirs;
- The Northeastern semi-arid region will be vulnerable to torrential and concentrated rainfalls over short periods, resulting in floods and serious socio-environmental impacts;
- A greater frequency of consecutive dry days is expected, as well as heat waves, due to more frequent *veranicos*;
- Subsistence agriculture may become impracticable over large areas, putting at risk the very survival of the human population;
- With soil degradation, migration to coastal cities will increase, making existing urban problems even worse;
- The *caatinga* vegetation may be substituted by vegetation more typical of arid zones, with a predominance of *cactaceas*. The deforestation of the Amazon will also affect the region.

The pessimistic scenario suggests a tendency for the water deficiency to increase (a higher frequency of consecutive dry days) for practically the entire year in the Northeast, which means a tendency to the 'aridization' of the semi-arid region by the end of the 21st century. Aridization is defined as a situation in which the water deficit currently presented in the semi-arid region for 6-7 months of the year is extended to the entire year as a consequence of the increase in temperature and the reduction of rainfall. In short, a great part of the Northeastern semi-arid, where non-irrigated agriculture is already a marginal activity, would be an even more marginal area for the practice of subsistence agriculture.

Results from the studies in the Report of Working Group II of the IPCC (2007b) show that, in the process of global warming, not only will it rain less and droughts will be more severe, but there is another danger – some indicators show that the process of global warming will also mean a decrease in water levels in underground reservoirs. Underground water is often spoken of as a way to permanently solve the water problems in the Northeastern semi-arid region. However, as a consequence of climate changes, a reduction of the amount of water is expected in the aquifers of the Northeast that may reach 70% by 2050. A study developed by a group of researchers of the United States Geological Service (MILLY *et al.* 2005) evaluates the impact of climate changes in the outflow of rivers on a global level. The average was made from 12 models of the IPCC AR4 for the period 2041-2060 in relation to the current climate (1900-70), and they detected a drop in the outflow of the São Francisco River of 15-20% to the period 2080-2099 in relation the present.



Northeast HadRM3 – CENARIO B2 – CDD

Northeast HadRM3 – CENARIO A2 – CDD

Northeast HadRM3 – CENARIO B2 – R10mm

Northeast HadRM3 – CENARIO A2 – R10mm

Figure 6-9: Linear tendencies in the index of consecutive dry days (CDDs) for the Northeast of Brazil (days/30 years) and for extremes of days with rainfall greater than 10 mm (R10s) (days/30 years) in the future (2071-2100), in relation to the current climate (1961-90). The maps show the average for the HadRM3P regional model (resolution of 50km lat.-long.) to emission scenarios of A2 - high emissions and B2 – low emissions. Red/Blue colors represent positive/negative tendencies of CDDs and R10s, and a scale of colors appears on the right side of each panel

Source: Inpe Climate Report - www.cptec.inpe.br/mudanças_climaticas.

Environmentalists are also preoccupied with the *caatinga*, which is indicated as being one of the ecosystems where very urgent measures should be taken. The *caatinga* is the only exclusively Brazilian biome and has unique flora and fauna, with many endemic species that cannot be found in any other part of the planet. It is one of the most threatened biomes in Brazil, and a great part of its area has already been greatly modified by extreme climatic conditions which have been observed over the last few years, and is potentially very vulnerable to climate changes. Results of modeling experiments on vegetation associated with high-emission climate change scenarios (SALAZAR et al., 2007, OYAMA and NOBRE, 2003) suggest that by the end of the 21st century, in the semi-arid region the *caatinga* may give place to vegetation more typical of arid regions, with a predominance of cacti.

6.8. Preliminary considerations concerning actions and the adoption of policies and strategies for adaptation to climate change

Land degradation and desertification are not problems restricted to Brazil; 33% of the Earth's surface, an area where approximately 2.6 billion people live, suffers from the same problems. In Sub-Saharan Africa in particular, an area where more than 200 million people live, 20-50% of lands are degraded. The destruction of the soil also is severe in Asia and Latin America, as well as in other regions of the world.

The impact of climate change on water resources in Brazil will be more dramatic, however, in the Northeast, where lack of water is already a problem. At present the availability of water *per capita* in the region is insufficient in the states of Rio Grande do Norte, Paraíba, Pernambuco, Alagoas and Sergipe, without taking into account regional variations in water deficit which make the situation even more intolerable for the inhabitants of the semi-arid region who are affected by water stress. Climate changes threaten to intensify the difficulties of gaining access to water. The combination of climatic changes with competition for water resources may lead to a potentially catastrophic crisis which will be experienced, above all, by poor farmers.

In a recent study Baettig et al. (2007) have built up a cumulative index of climate change (CCI) based on the extreme scenarios of high and low emissions in the IPCC AR4 scenarios. The results of this study for Latin America (Figure 6-10) indicate that more severe climate changes will occur in the tropical region by the end of the 21st century, specifically in the Amazon and in the Northeast of Brazil, with CCI (Climate Change Index) numbers varying from 7.5-11 in the Amazon and in the Northeastern *sertão*. These two regions constitute what could be called climatic change hot spots and represent the regions in Brazil that most vulnerable to climate change. This in an index based only on extremes of climate, temperature and precipitation.

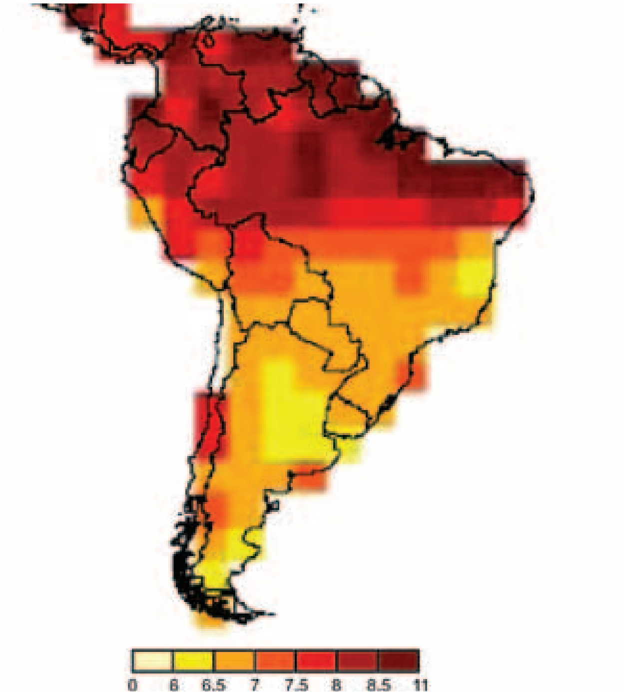


Figure 6-10: The News of the cumulative Climate Change Index (CC I) based on extreme scenarios of high and low emissions of the IPCC AR4 scenarios until the 21st century. Scale of colors varies from zero to 11.

Source: Baettig et al., 2007.

The Northeast is the Brazilian region most vulnerable to climate variability and possibly to climate change. One of the projections, taking into consideration the most critical scenario and the most precise model, points to the desertification of the Northeastern semi-arid region by the end of this century. The short rainy season currently occurring may disappear. If this problem is confirmed, it will be impossible to practice agriculture without irrigation in the region and access to water will be even more difficult. The Northeastern states present low social and health indicators, and also, the existence of a semi-arid climate in the greatest part of the region increases the socio-environmental vulnerability of the population. According to the UN Human Development Atlas (IBGE, 2007 <www.ibge.gov.br>), the indexes which evaluate life conditions of the population show their lowest values in this region. According to the UN Human Development Index (HDI), all the Northeastern states show results (HDI=0.517) lower than the average for Brazil (HDI=0.757). The Northeastern semi-arid region has an HDI of 0.405 if the seven regions of Piauí state, Pernambuco state and Bahia state are considered. Among the ten lowest HDI indexes in the country, eight are in the Northeastern states. The region also has the highest infant mortality rates and the lowest life expectancy in Brazil.

The poorest people will suffer more and the most affected region would be a quadrilateral in the Northeast, from the West of Piauí, to the South of Ceará, the North of Bahia and the West of Pernambuco, where the cities with the lowest Human Development Index are found. Climate projections indicate risks of intense droughts in the semi-arid region and reduction of rainfall up to as much as 40% and increases in temperature of 4-5°C in the worst scenario of greenhouse effect gases emissions until the end of the 21st century.

The National Water Agency (Agência Nacional de Águas - ANA) has recently released the *Water Atlas of the Northeast* (ANA, 2006). According to this document, more than 70% of the cities with populations of more than 5,000 inhabitants in the Northeastern semi-arid region will face crises in the supply of water for human consumption by 2005, regardless of the huge construction to redirect the São Francisco River. Supply problems will affect about 41 million inhabitants in the semi-arid region and surroundings, and population growth is estimated, as well as the demand for water in about 1,300 municipalities in the nine states of the Northeast and in the North of Minas Gerais state. In the region studied there would be enough water for a population estimated at 8.4 million inhabitants in 2025. Another 41 million would not have a guarantee of water for human consumption, if the investments recommended by the study are not made. This would be a scenario in which measures to stop water loss and improve management of demand are planned. Details of the study are available on the National Water Agency website (<www.ana.gov.br>).

Taking into consideration the sensitivity of the Northeast to climatic variations and facing potential climate change in this region, believed to be the most vulnerable to reduction of rain and increase in temperature, coordinated government action towards adaptation to climate change is required. The Brazilian government is creating a system to predict the occurrence of long periods of drought in the semi-arid region and to pinpoint the areas susceptible to suffering desertification caused by climate changes. The Environment and Science and Technology Ministries have launched an initiative called the Brazilian Drought and Desertification Early-Warning System, a project that aims to create and implement a system which allows a more rapid prediction of the major droughts that affect the region, as well as the creation of a diagnostic tool to identify the areas most affected by environmental degradation and more susceptible to desertification. This system is relevant to the Nation Program to Fight Desertification and Mitigate the Effects of Drought (*PAN-Brasil*). The program is a planning system which aims to define the directions and the main actions to fight and prevent the phenomenon of desertification in Brazilian regions with semi-arid and sub-humid dry climates.

Considering the climatic variability at present and the possible scenarios of climate change until the end of the 21st century, it can be concluded that the semi-arid region is more frequently affected by climatic events associated with water deficit. This serves as an initial indicator of regions that are potentially more vulnerable due to repeated critical climatic events. The climate scenarios of a hotter and dryer climate in the future, until the end of the 21st century, would also lead to a worsening of water deficit in the semi-arid, affecting subsistence agriculture and the *caatinga*. The effects are not only suffered by the farmers of the semi-arid region, but also by the populations of the big cities in the region, who depend on the former for their food supplies, a situation which may lead to an increase in the price of produce. It is important to mention that the current analysis is based only on climatic factors and does not take into account mitigation actions resulting from current public policies.

Studies of vulnerability of the semi-arid region to changes in the land use, climate, population increase and conflicts of use of natural resources are necessary, however, and this nationwide effort must include the development of a Map of Risks and Vulnerability of the Semi-arid region in Relation to Climate Change, including the different sectoral vulnerabilities (health, agriculture, economy, transport, water resources, rise in sea level, biodiversity, etc.) and linking these with the other causes of vulnerability, both social and environmental.

A plan to deal with climate change would include not only adaptative actions (like changing the zoning of coastal cities to prevent the sea from advancing or proposing a large-scale system of cisterns to store water) but also mitigation initiatives. In relation to adaptation, currently, most of cisterns in the Northeast are the result of the Joint Action in the Semi-arid Region action (Articulação do Semi-Árido - ASA), an NGO which brings together more than 700 bodies from civil society to fight the effects of drought in the country. The ASA has a program called "A million cisterns" which, in less than four years, has built 215,777 cisterns in the Northeast, 20,532 of these located in Piauí state. We may conclude that although droughts constitute a chronic and continuous situation in the semi-arid region, the population has not yet reached a level of adaptation to the phenomenon. Initiatives such as building cisterns and operating water-lorries may solve the problem of a drought lasting months or a few years, but would not solve the problems of a longer drought. Long-term environmental policies are required as well as an environmental education program to help the population understand the problem of climate change and its impacts. In this way the inhabitants of the semi-arid region would face the problem and adapt to the phenomenon by learning how to live with the impacts of climate change and carry out adaptation and mitigation actions.

The best way to mitigate the effects of possible desertification is to reduce the risk of global warming continuing unchecked, which means dramatically reducing global emissions of greenhouse effect gases from burning fossil fuels and also from deforestation. Global warming is an irreversible process, but it could be alleviated with this kind of mitigation measure. All these actions must be included in the National Plan for Climate Change which is currently being discussed in the scientific, academic and governmental areas, under the leadership of the Environment Ministry.

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7. Energy and water resources: vulnerability, impacts and possibilities for adapting hydroelectric power generation in Brazil to global climate change

Marcos Aurélio Vasconcelos de Freitas
João Leonardo da Silva Soito

7.1. Introduction

Brazil holds the greatest reserves of surface water on the planet, about 19.4%, and one of the world's greatest potential water resources. However, it is not in a comfortable situation in terms of the availability of water resources and the location of the demands for its consumable and non-consumable water (FREITAS, 2003). In fact, about 90% of the water is found in low-density drainage basins from the Amazon and Tocantins rivers, while about 90% of the population is supplied by the rest of the country's water resources.

Due to the large proportion of hydroelectric power stations in the Brazilian power grid, the generation of electric power in the country is highly dependent on the hydrological cycles of drainage basins. As there is a regional imbalance in water availability - which may be seen in the recurrent droughts in the Northeastern region, the degradation of rivers and soils in the Southeastern region, the socio-environmental risks of each region and the rapid growth in demand for water and power throughout the country – both new and old hydroelectric enterprises are, to a greater or lesser extent, vulnerable to climate change.

The risk of future global climate change, that is, of additional warming of the planet, may alter the hydrological cycle, and, in turn, the water regime and availability of water in the drainage basins. In fact, different changes in temperature lead to changes in atmospheric pressure and wind patterns. Therefore, changes in rainfall patterns are to be expected.

Predictions for global sea level increases for 2099 indicate figures ranging between 18-59cm, depending on different greenhouse effect gas emission scenarios. Occurrences of El Niño Southern Oscillation (ENSO) phenomena have been more frequent, longer and more severe over the last 20-30 years than they were during the preceding hundred years (WMO, 2004).

Thus it becomes important to carry out studies on predicting and evaluating climatic vulnerability in the generation of electric power in Brazil, with an emphasis on the assessment of water flow to hydroelectric power plants through climatic and hydrological prediction, both vital tools in the definition of scenarios in which hydrological risks (and consequently power shortage risks) can be anticipated[1].

7.2. Impacts, vulnerability and adaptation to climate change

Assessments from the Intergovernmental Panel on Climate Change (IPCC) indicate that developing countries are among the most vulnerable to changes in climate. The IPCC also claims that the greater the difficulty a country has when dealing with the natural variability of climate and its extreme events, the greater the effort it will to make when adapting to climate change (POPPE & ROVERE, 2005).

The impacts of climate change are not equally distributed among regions and populations. In fact, individuals, sectors and systems can be affected or benefited in greater or lesser measures. Thus, this relative pattern of distribution of climate vulnerability may vary in magnitude and intensity according to each affected region's geographical location, weather, social, economic and environmental conditions and infra-structure.

According to the IPCC (2003), climate vulnerability can be defined as "the degree of susceptibility (or incapacity of response) of individuals or systems to adverse effects of climate change, including climate variability and extreme events".

The impacts resulting from changes in climate are directly connected to the vulnerability to which natural and human systems are exposed. Learning to deal with vulnerability, and especially with sensitivity to its impacts and capacity of adaptation to them, will be the most efficient way to mitigate the problem of climate change. For this reason, it becomes important to define methods and strategies to direct studies and research in this area, and also to implement those in the different regions affected. For this purpose, the Third IPCC report (2003) established areas of action for studies on climate vulnerability in human systems, such as:

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[1] It is convenient, in longer time scales, to make a distinction between climate change and natural climate variability: Climate Change is the systematic tendency or variation in a given sense, of climate parameters. It may occur due to systematic change in the radiative forcing of the climatic system or by anthropogenic action. Climate Variability is inherent to the climatic system and presupposes alternation, that is, the superposition of cyclical or semi-cyclical variations. The detection of a tendency in climate requires, therefore, that the breadth of the natural variability be quantified. For this, a great variety of data and results of atmospheric models must be utilized. (OMM, 2004 and ANEEL, 2003).

- Rise in sea level;
- Water resources – droughts, floods and intense rainfall;
- Heat waves;
- Agriculture and food security;
- Human health;
- Economic activities;
- Coastal areas;
- Human settlements.

Smit et al., (1999) *apud* IPCC (2003) state that understanding adaptation is essential for an assessment of impact and vulnerability and, consequently, fundamental to estimating the costs and risks of climate change. The extent to which ecosystems, food supply and sustainable development are vulnerable depends on their exposure to the impacts of climate change and on the ability of the affected systems to adapt. Therefore, in order to evaluate the risk of climate change, the assessment of impact and vulnerability must consider the probability of the occurrence of autonomous adaptation to these changes, i.e. adaptation which would occur without direct human interference in the system (see Figure 7-1).

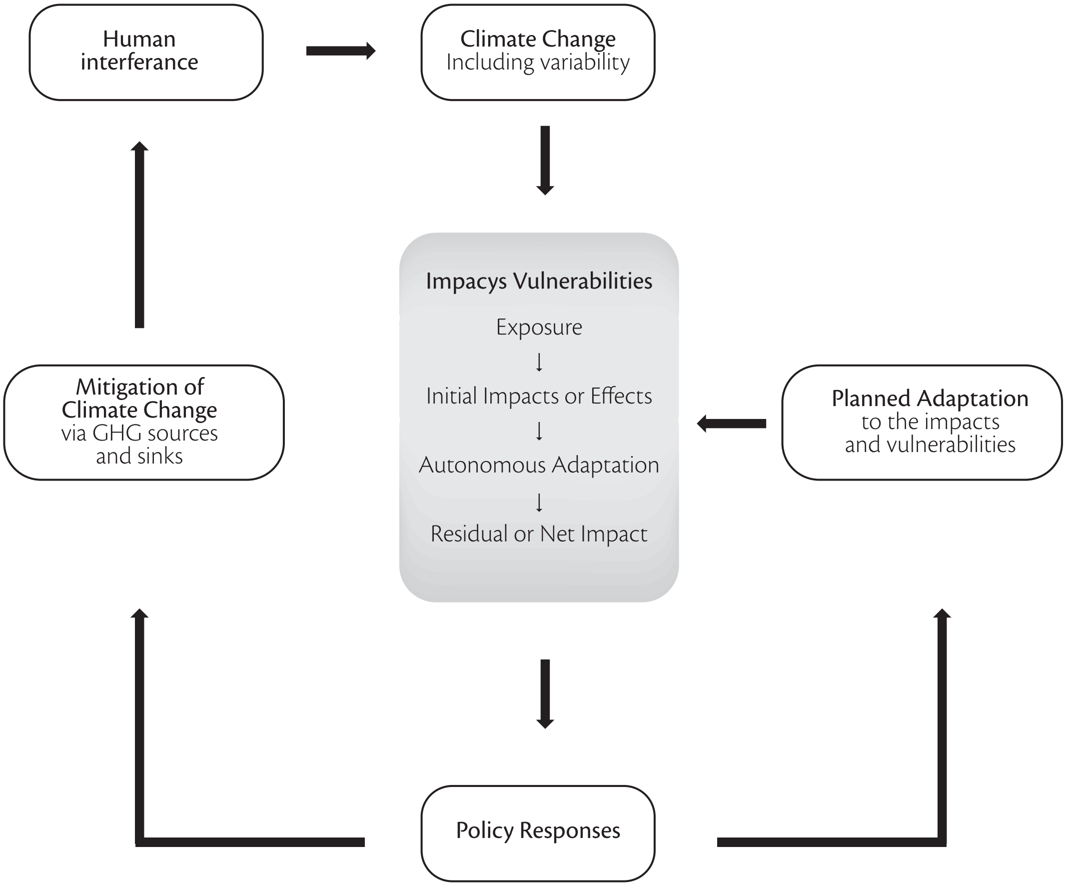

Figure 7-1: **The position of mitigation and adaptation action in the climate change context.**

Source: IPCC (2003)

Even with the prediction of reduction of greenhouse effect gas (GHG) emissions, adaptation is considered an important strategy, together with mitigation, due to the probable changes in climate, such as higher global temperatures, higher sea levels and more extreme events (in frequency and/or magnitude/severity). For this reason, developing adaptation strategies to deal with these risks is as relevant a process as the need for mitigation actions themselves.

The IPCC (2003) and Magrin et al., (2007) define adaptation, in a climate change context, as the "adjustment of natural, social and economic systems in response to current or future climatic stimuli and/or their impacts, which may be adverse (damage) or beneficial (opportunities)". In this context, adaptation refers to alterations in processes, practices and infra-structure to compensate for potential damage or to take advantage of opportunities associated with changes in climate.

The most relevant characteristic of climate change, with regard to vulnerability and the adaptation of water resources, is related to noticeable alterations in the variability of hydrological systems and extreme events, and not simply to average tendencies in climate change. Adaptation is an important factor in climate change and must be dealt with in two ways: assessment of impacts and vulnerability, as well as the development and implementation of strategies and concrete measures in risk management (KUNDZEWICZ, et al., 2007).

Most social sectors, regions and communities are reasonably well adapted to average conditions in climate change, particularly if the changes are gradual. However, in some sectors losses resulting from extreme climate variations are substantial and growing. These losses indicate that autonomous adaptation has not been sufficient to prevent damage associated with variations in climate conditions.

Communities have shown themselves to be more vulnerable and less adaptable to climate changes, especially in terms of extreme events.

Bergkamp et al. (2003) explain that adaptation may be described in different ways, differentiating between planned and spontaneous adaptations, as follows:

- **Planned adaptation** – league process of creating public policies based on an awareness of vulnerabilities and existing conditions. The attributes which will change and the required actions will serve to minimize losses and/or optimize benefits. These involve pro-active government actions.
- **Spontaneous adaptation** – frequently associated with a context of business adaptation, emphasizing the role of the private sector, in a reactive response. It is generally motivated by market changes, alterations in government social assistance and in society's choices.

7.3. Effects and climate vulnerability on hydrology and water resources.

7.3.1. IPCC evaluations

According to the IPCC (2003 and 2007 a, b), the effects of climate evolution on the flow of watercourses and the refilling of aquifers vary according to the regions and climatic scenarios that are created, especially regarding variations in projected rainfall. In projections carried out so far, the results for South America do not show agreement in flow projections, in the first place because of the different rainfall projections, and in the second place due to the different projections regarding evaporation, which may counterbalance the rise in precipitation. In general, the variations projected for the yearly average surface flow are less reliable than those based on temperature increase, mainly due to the fact that the evolution of rainfall varies widely for different projected scenarios (see Box 1).

Box 1 – The effect of climate change on water resources

At the level of drainage basins, the effect of a given climate change will vary according to the physical properties and vegetation of each basin, to which are added the alterations in the land cover (land use).

One third of the world's population – about 1.8 billion people – live today in countries and regions that suffer from medium and high levels of water stress[2]**.** According to projections from the United Nations, global demographic growth will place about 5 billion inhabitants in the same situation by 2025.

Thus, the predicted climate change may have a negative effect on the flow of rivers and on the refilling of groundwater reservoirs and aquifers in many countries which are exposed to water stress.

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[2] A classification of Water Stress Zones is proposed by Alcamo, J. et al. (2000):
Zones Without Water Stress – water withdrawals (demands) are below 0.1 of water availability (average);
Zones of Low Water Stress – water withdrawals (demands) are between 0.1 and 0.2 of water availability (average);
Zones of Medium Water Stress - water withdrawals (demands) are above 0.2 and below 0.4 of water availability (average);
Zones of High Water Stress - water withdrawals (demands) above 0.8 of water availability (average)

If water demand is generally increasing due to demographic growth and economic development, it is however decreasing in certain countries due to more efficient utilization practices.

Climate change will probably not exert a strong influence on water demand in cities and industries in general. However, it may have a considerable effect on the consumption of water for irrigation, which depends on the way evaporation is counterbalanced or accentuated by rainfall variations. A rise in temperatures, and consequently an increase in agricultural losses by evaporation, will normally represent an increase in demand for irrigation water.

Floods may increase in extent and frequency in many regions due to the increase of extreme rainfall events, increasing river flow in most zones but also facilitating the replacing of underground water in certain flood plains.

Changes in the soil may accentuate these phenomena. During low water periods the level of water streams will drop in several regions because of increased evaporation, the effects of which may be aggravated or neutralized according to rainfall levels.

Projected climate change may contribute in some areas to a lower quality of water resources – raising its temperature and increasing the pollutant load deriving from surface water flow and the overflowing of sewage treatment stations and sewage pipes.

In regions where lower rainfall levels are predicted, accompanied, therefore, by a drop in river flow, the quality of water will probably also decrease due to reduced dilution of the sewage pumped into rivers.

Special attention must be given to less well-regulated drainage basins, because they do not possess hydraulic structures, as well as to those which have already suffered extreme events, droughts and floods, and also to those which are carelessly exploited, with recurrent problems of pollution and water shortage, among other issues. In the case of unregulated systems which do not possess hydraulic infrastructure of sufficient quality to attenuate the effects of hydrological variability on the quality and quantity of water, vulnerability is higher. In the case of drainage basins which are exploited in a disorganized, non-sustainable way, the various users of the water and soil create additional restrictions which accentuate vulnerability to climate change.

However, it is possible to apply management tools to water resources, namely the integrated management of drainage basins, with a view to facilitate adaptation to the hydrological effects of climate change and to attenuate the different forms of vulnerability within each basin.

It is common nowadays to manage water supply (structural protection against floods, building of levees, use of water-storage zones and improvement of infra-structure for water withdrawal and distribution) instead of managing water demand (i.e. influencing the behavior of water users with a view to reducing losses and better managing the consumption of water in the drainage basin).

Source: IPCC, (2003) and (2007 a, b).

7.3.2. Projections for regional climate change and their limitations in terms of water resources

Projections for climate change on a regional level in terms of water resources, that is, predictions related to anomalies in rainfall on drainage basins in Brazilian territory, vary markedly from one model to the other. For example, according to the models from the Hadley Center (England), variations in average surface flow projected for 2050 in the Paraná river basin, assuming an increase of 1% in CO_2 concentration, appear as positive in the HadCM3 model (+ 50 to 150 mm/year in the basin's margins) and as negative in the HadCM2 (-50 to 150 mm/year in the basin's margins) (IPCC, 2003 AND 2007, b). The models are more ambiguous in the Southern Hemisphere due to its hydrometeorological observation network being smaller and more recently established than that of the Northern Hemisphere.

In Figure 7-2 we present the results for the river flow projections for 2050, showing the average of the 12 models used by the IPCC in its 2007 report on the A1B scenario. According to these projections, we would have outflow decreases in part of the Amazon and Tocantins river basins, which would be worrying, especially for new enterprises aiming to establish themselves in these basins with high hydroelectric potential. However, in terms of the Paraná river basin, we would be able to maintain the tendency for outflow increase, which would favor, above all, the hydroelectric power plant structure already installed in the region, such as the Itaipu Binational Hydroelectric Power Plant and the Porto Primavera Hydroelectric Power Plant.

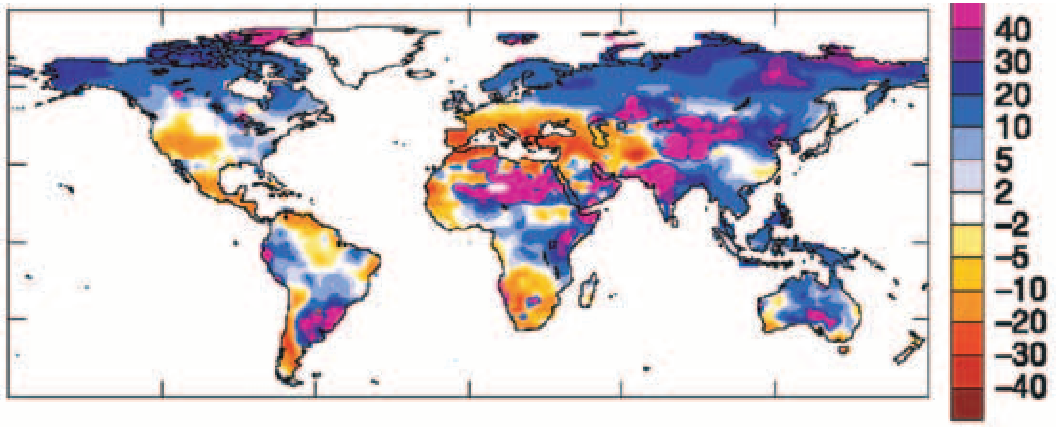

Figure 7-2: Change projections in river outflow levels until 2050 (average from 12 models from IPCC AR4, scenario A1B).

Source: IPCC, 2007a.

7.4. Hydroelectric power and uses of water in Brazil

7.4.1. Current status of the Brazilian hydroelectric potential

Brazilian hydroelectric potential, as recorded in December 2007 in Eletrobrás' Brazilian Hydroelectric Potential Information System (Sipot) was approximately 247 GW, 31% of which is represented by facilities under construction or in operation (ELETROBRÁS, 2007).

Figure 7-3 shows Brazilian hydroelectric potential divided by geographic region [North, Northeast, Mid-West, Southeast and South – trans]. The potential of each region is described according to the following categories: Estimated (*Estimados*), Being Studied (*Estudos*) and Under Construction/In Operation (*Operação/Construção*), that is, enterprises which are already operational or will become operational.

Numbers are in Metric System notation.

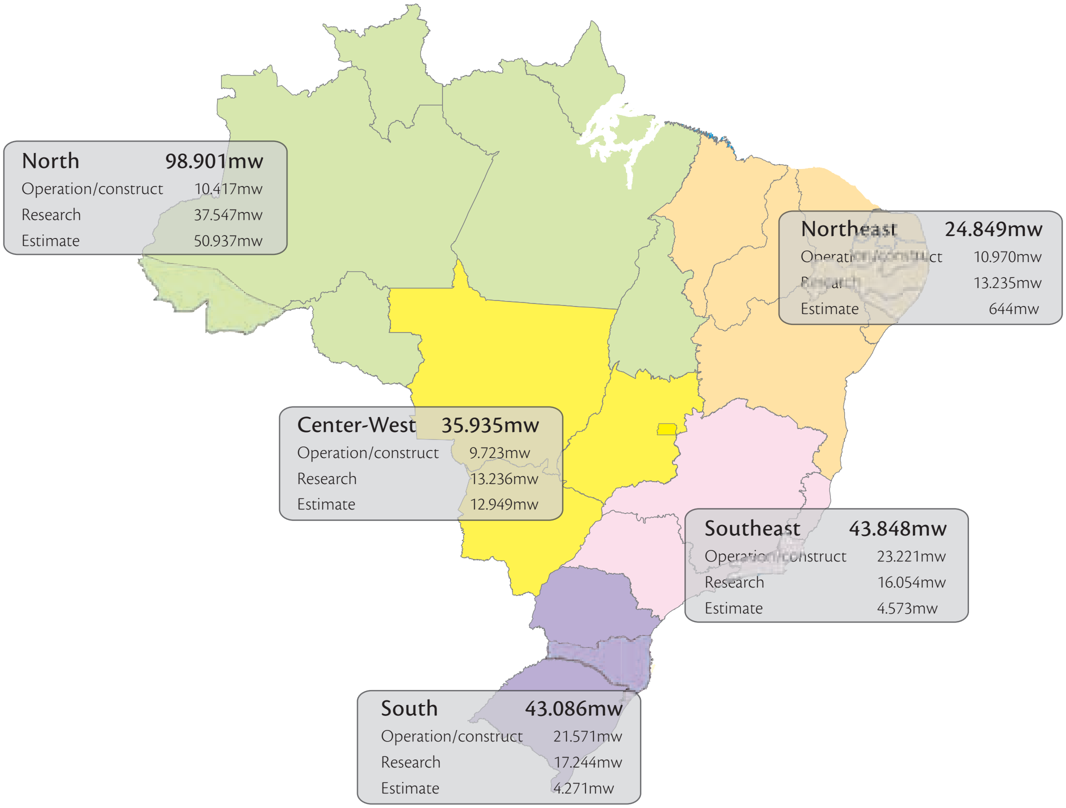

Figure 7-3: Brazilian Hydroelectric Potential – 2007.

Source: Eletrobrás, SIPOT (2007).

Observing figures 7-5 and 7-4 shown below, one can easily see that the South and Southeast regions together account for 59% of the hydroelectric potential in operation/under construction. On the other hand, the Northern region alone has 52% of the country's hydroelectric potential currently being studied or estimated. This indicates that currently, (in the short term) concerns about vulnerability should be focused on the South and Southeast regions, but that in the future the understanding of climate change and its relation to hydroelectric potential should give priority to the Northern region.

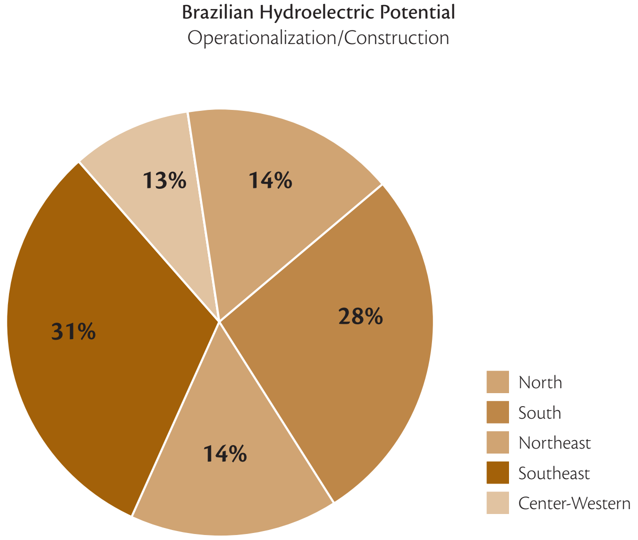

Figure 7-4: Brazilian Hydroelectric Potential – In Operation/Under Construction – 2007.

Source: Eletrobrás, SIPOT (2007).

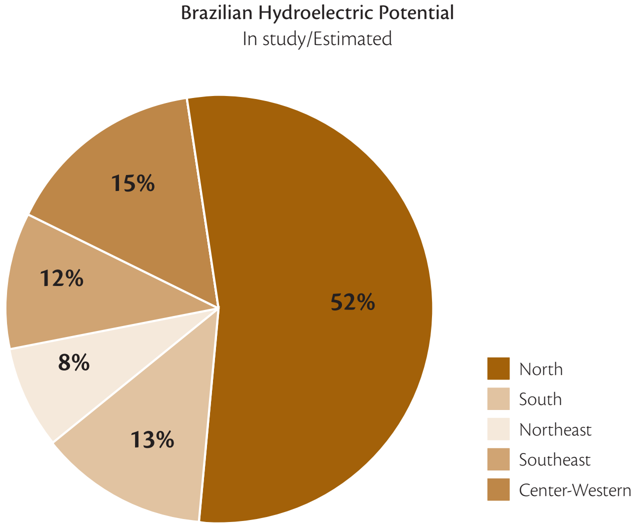

Figure 7-5: Brazilian Hydroelectric Potential – Being Studied/Estimated – 2007.

Source: Eletrobrás, SIPOT (2007).

Figure 7-6: **Brazilian hydroelectric potential (total and coming from PCHs) per hydrographic region – 2007.**

Source: Eletrobrás, SIPOT (2007).

Figure 7-6 represents Brazil's hydroelectric potential according to the national hydrographic division established by the National Water Resources Council's Resolution No. 32 of October 15th, 2003. Also shown is the hydroelectric potential of each of the hydrographic regions coming from Small Hydroelectric Stations (Pequenas Centrais Hidrelétricas - PCHs), which amounts to a total of 24,106 MW. This value accounts for 9.8% of the total hydroelectric potential of the country.

At a glance, it is possible to observe a significant concentration of hydroelectric energy generating in the basins located in the South and Southeast regions of Brazil, next to the largest consumer regions, and an under-utilization of the hydroelectric potential of North and Mid-West Regions, where these resources are abundant.

7.4.2. Changes in rainfall and river flow patterns in South America

The Brazilian Power Grid is highly dependent on short and medium-term water availability for the generation of 'firm energy'[3] and, therefore, for the guarantee of meeting demand. This system has been planned based on estimated-failure probability models, using historical series of flow patterns dating back to 1930 and to which are added yearly new sets of data from the national hydrometeorological network, currently managed by the Brazilian National Water Agency (ANA).

An increasingly integrated hydroelectric energy generation system considerably reduces the risks of not meeting energy demands should a given drainage basin suffer from an occasional dry spell. However, considering that most Brazilian power plants are located in the Paraná river basin, more than 55% of the country's present available generation capacity is subject to the same climatic vulnerabilities. We must, therefore, seek to improve the models for projecting streamflow patterns in the short- and medium-terms.

According to studies by IPH/UFRGS (Hydroelectric Research Institute from the Federal University of Rio Grande do Sul) and IAG/USP (University of São Paulo Institute of Astronomy, Geophysics and Atmospheric Science), since 1970 the Mid-West, South and Southeast regions have presented average river flow patterns approximately 30% higher than those of the preceding period (1940-1970). If this increase is permanent, it would be possible to reassess the firm energy capacity of the power plants, in other words, it would be possible to generate more energy with the capacity already installed, and with a smaller risk of failure (TUCCI, et. al., 2002).

Increase in streamflow patterns occurs due to two factors (TUCCI, op. cit.):

- Increase in rainfall levels in the regions of Brazil referred to;
- Changes in the use of land in the same regions.

In the first case, the changes may represent a type of variability that, in the medium- and long-terms, will tend to change in the sense of reducing quoted generation capacity and average production levels.

In the second case, the increase would be permanent, and, therefore, would to a certain extent represent an energy gain, despite other environmentally harmful aspects.

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[3] The 'firm energy' of a hydroelectric power plant corresponds to the maximum continuously produced energy that can obtained at that plant, assuming the lowest baseflow period registered in the history of streamflow patterns for the region in which it is built.

According to the results obtained from the IPCC Workgroup 2 Report of 2007, the rainfall patterns in South America between 1960 and 2000 reinforce the thesis of increased rainfall in the River Plate basin and a decrease in the same values in the Chilean and Peruvian Pacific. In other areas the signs are not clear (see Figure 7-7).

Figure 7-7: South America – Rainfall Patterns from 1960 to 2000.

Note: The circles indicate a tendency to reduction and the crosses a tendency to increase in rainfall. Symbols in bold are used to indicate more accentuated tendencies.

Source: IPCC, WG II (2007, b).

7.4.3. Conflicts, impacts and vulnerabilities in generating hydroelectric power.

An aggravating factor in the Brazilian experience of using its hydroelectric potential concerns the great diversity found among the country's regions in terms of the availability of water. While droughts are a recurrent phenomenon in the Northeastern *sertão*, in the Southeast it is industrial and urban pollution, allied to river silting, that are the worrying trends. Also, further South there is more concern with agricultural production and cattle-raising, which are responsible for a diffused type of pollution of the surface and underground bodies of water that is difficult to control. Even in the planet's largest drainage basin there are problems arising from demographic expansion and unplanned settlements. Some of these are specific, such as the pollution of *igarapés* [streams originating in forests – trans.] and rivers that pass through urban areas, and others affect whole regions, such as the transmission of diseases by water and the decrease in water quality in smaller communities during the low-water period.

Thus, it is important to highlight that, in the medium- and long-term usage scenarios for Brazilian drainage basins, demand for water will tend to increase as a function of demographic growth, and above all, of economic development. Figure 7-8 summarizes this delicate scenario of conflicts between energy, environment and water resources.

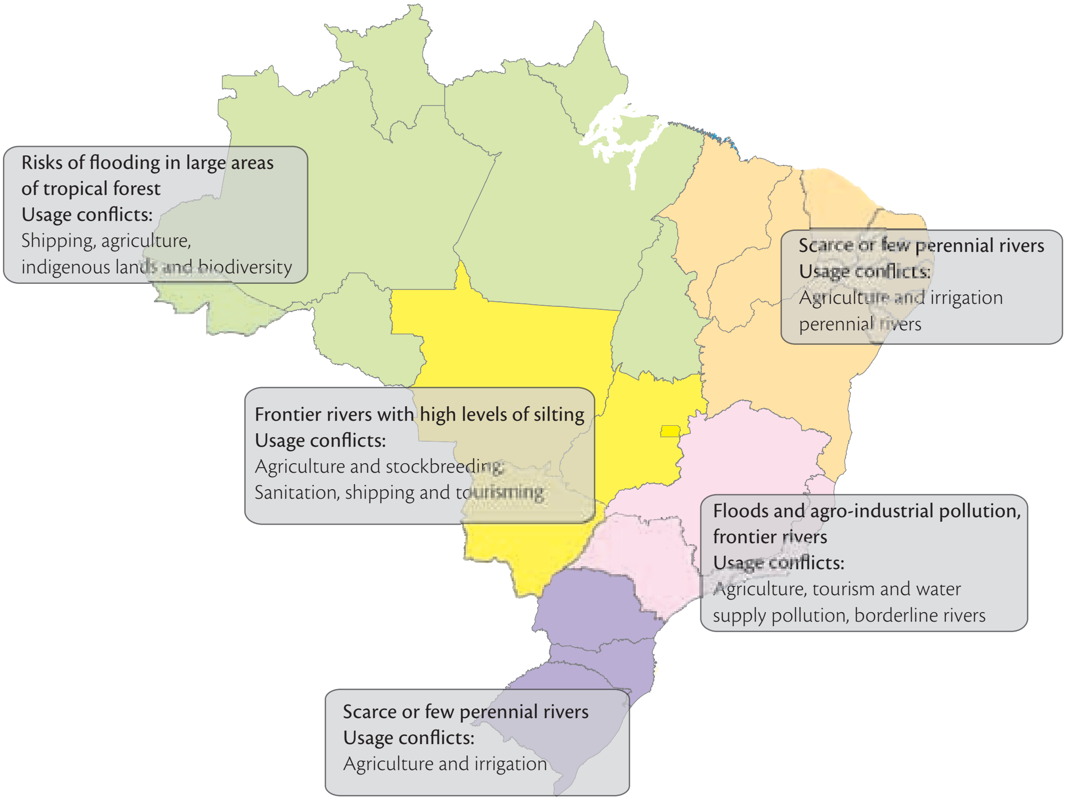

Figure 7-8: Restrictions and usage vulnerabilities of the use of hydroelectric potential per region

Source: The author's own material.

7.4.3.1. Drainage basins

In this section we present a synthesis of the water resources available for their several uses, highlighting the present vulnerabilities in their use and the main water usage conflicts currently in effect.

7.4.3.1.1. The São Francisco River Basin – water resources, vulnerabilities and main water usage conflicts

The São Francisco River Basin currently contains an installed hydroelectric power generation capacity of about 10.23 GW, average long-term streamflow of 2,850 m^3/s at the river mouth, a drainage area of 645,000 km^2 and a population of more than 15,000,000. It currently registers an official required demand of 500 m^3/s for irrigation purposes, although current consumption levels have not surpassed 150 m^3/s, which indicates that official demands are overstated, despite some uncertainties.[4] For 2025, it is possible to consider an average official demand for consumption in the order of 335 m3/s, which might suggest an impact on the generation of energy in the region of an average 300-900 MW, depending on the exact location on the São Francisco river from which the water would be drawn[5] and the way in which the water resources are to be used (irrigation, human and animal supply, etc.).

In Figure 7-9 it is possible to identify the main uses and potential water usage conflicts in the São Francisco river basin.

In terms of climate change, the São Francisco river basin is mainly characterized by its water availability, which is only available for agriculture, water for human consumption and for the dilution of pollutants coming from industrial drains and urban sewers. This being the case, a possible change in the rainfall regime could cause an increase in the intensity of conflicts over water usage. Actions that increase efficiency in the use of water resources for irrigation and in the treatment of urban pollutants should be prioritized. In terms of hydroelectric potential, a reduction of 50 m3/s in the average streamflow of the São Francisco River could produce a decrease in energy generation of about 80-160 MW/year, which should be complemented by other sources in the country's interconnected power grid.

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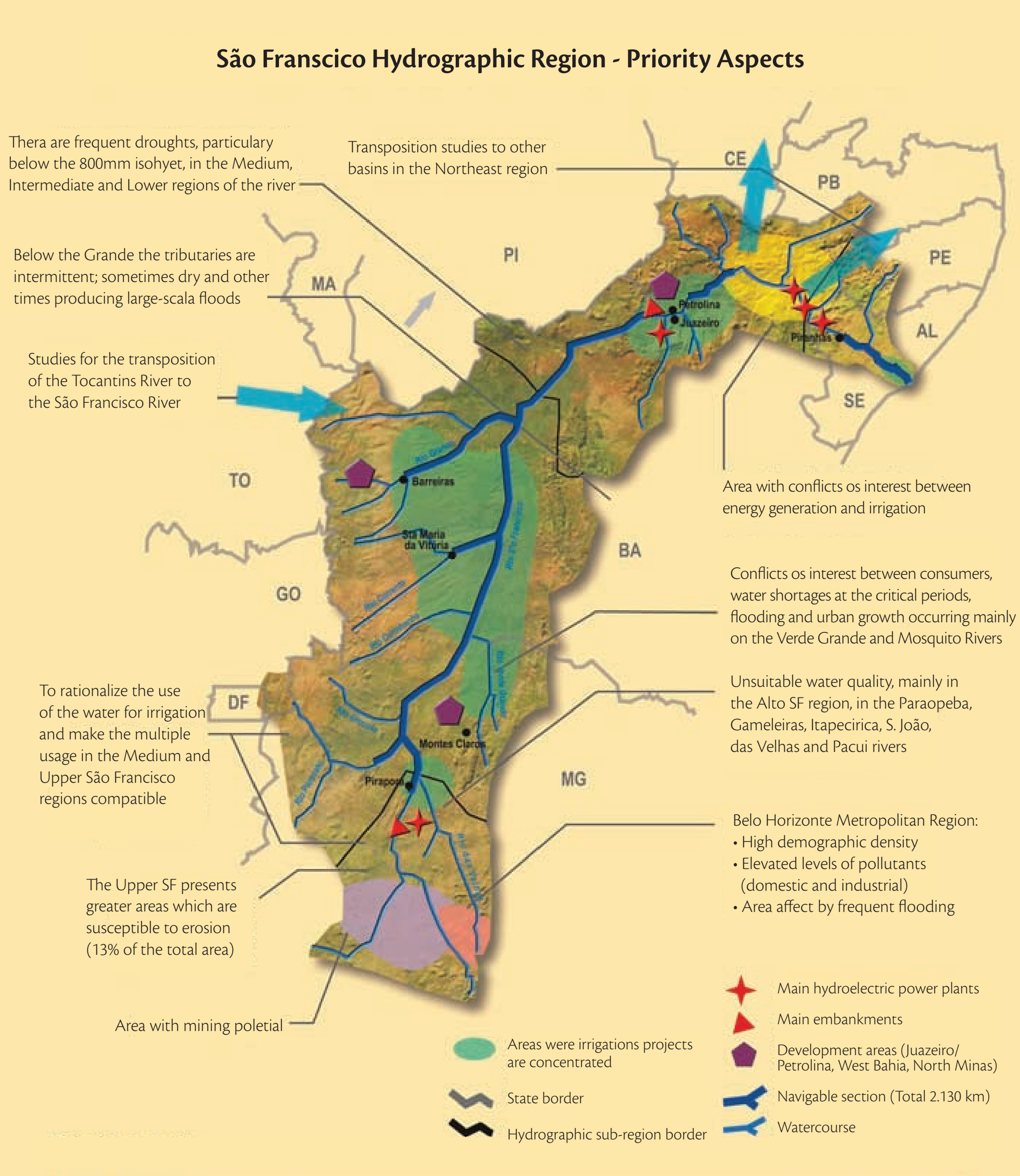
[4] According to ANA studies, 350,000 ha of irrigated area are estimated to exist in the São Francisco basin, which would be equivalent to an average usage demand of about207 m3/s.

[5] The accumulated energy loss for each m3/s consumed from the São Francisco waterfall varies from 1.06 average MW in the Xingó Hydroelectric Power Plant to an average 3.22 MW upstream towards the Três Marias Hydroelectric Power Plant.



São Franscico Hydrographic Region - Priority Aspects

Thera are frequent droughts, particulary below the 800mm isohyet, in the Medium, Intermediate and Lower regions of the river

Transposition studies to other basins in the Northeast region

Below the Grande the tributaries are intermittent; sometimes dry and other times producing large-scala floods

Studies for the transposition of the Tocantins River to the São Francisco River

To rationalize the use of the water for irrigation and make the multiple usage in the Medium and Upper São Francisco regions compatible

The Upper SF presents greater areas which are susceptible to erosion (13% of the total area)

Area with mining poletial

Area with conflicts os interest between energy generation and irrigation

Conflicts os interest between consumers, water shortages at the critical periods, flooding and urban growth occurring mainly on the Verde Grande and Mosquito Rivers

Unsuitable water quality, mainly in the Alto SF region, in the Paraopeba, Gameleiras, Itapecirica, S. João, das Velhas and Pacui rivers

Belo Horizonte Metropolitan Region:
- High demographic density
- Elevated levels of pollutants (domestic and industrial)
- Area affect by frequent flooding

Figure 7-9: São Francisco River basin – main conflicts in water usage.

Source: ANA, 2002a.

7.4.3.1.2. The Paraná Basin – Vulnerabilities and main conflicts in water usage

The Paraná river basin is of vital importance to the Brazilian hydroelectric power system, as it contains more than 50% of the country's installed energy generation capacity, including the Itaipu power plant, which generates 14,000 MW. However, this basin is also the one with the highest demographic density, which leads to several conflicts over land and water use, both urban and rural in origin. This could not only prevent a future use of the region's hydroelectric potential, but above all, restrict the generating of energy in power plants already installed and functional.

This being the case, the Paraná basin demands that serious attention be given to its conflicts, as these often translate into vulnerabilities in generating hydroelectric power. This, in turn, means these conflicts deserve more focus from the energy sector and water managers as they will tend to become worse in the future, either because of the growth in demand for water resources or because of the higher occurrence and duration of low-water periods, caused by global warming. We present below a few of these conflicts:

- river transport sector, with emphasis on the Paraná-Tietê *hidrovia* [a shipping channel composed entirely of rivers – trans.], responsible for transporting a large percentage of the grain produced in the Mid-west, South and Southeast regions of the country, a process that needs a minimum depth of water in the Rivers and priority given to the operation of the locks in the Pereira Barreto Channel, for example.
- Tourism and leisure; a conflict worth noting is that in the Furnas Lake, in the Rio Grande basin, in Minas Gerais, where 33 river-bank municipalities have taken legal action in order to demand compensation from Furnas Centrais Elétricas for lowering the level of the river bed by 12 meters in 2001, the year of the country's energy crisis (ANA & EFEI, 2001).
- Sanitation sector; the conflicts are numerous, but one worth highlighting is that in Santos, in the greater São Paulo area. The Henry Borden Power Plant, an the Cubatão river, reduced its generation capacity from 880 MW to less than 100 MW due to the high level of pollution of the Tietê River, which made it impossible for the river water to be force-pumped to the Pinheiros river channel, where it would then be streamed to the Billings Dam and end up in the Henry Borden Power Plant (see Box 2) (CAPOBIANCO, 2002).

With regard to climate change, the Paraná basin has been notorious mainly for the risk of flooding, and more so in the years of anomalous heating of the Pacific Ocean, in other words when the *El Niño* phenomenon occurs. The range of hydroelectric power plants in the region has been used in regulating the availability of water resources and in managing extreme events (flooding). Trans-border integration is fundamental if it is hoped to achieve higher levels of success in this enterprise.

In other words, Brazil, Argentina, Paraguay, Uruguay and Bolivia must increase the integration of their meteorology systems, water resources and hydroelectric energy generating to take the best advantage of the benefits of climatic variability, which has provoked a significant increase in water availability. This must be done, however, without disregarding the protection of land and water use downstream from the dams. In terms of hydroelectric potential, an increase of 30% in long-period streamflow in the Paraná River has brought about a considerable addition to hydroelectric potential. Streamflow statistics between the periods 1941-1971 and 1972-2000 showed an average variation of more than 36%[6]. Thus, the Itaipu Hydroelectric Power Plant, which was planned in the 1970s to generate an installed capacity of 12,600 MW can, as of 2007, increase its generation capacity to 14,000 MW.

Box 2 – Vulnerabilities in the Billings Dam Lake – São Paulo Metropolitan Region

The quality of the water in the Billings Dam is highly compromised due to the amount of polluted water pumped from the Tietê and Pinheiros rivers, to the re-suspension of contaminated sediments caused by the pumping process, and to the uncontrolled human occupation of its drainage basin.

The concentration of pollutants present in the liquid environment is a consequence both of external factors, that is, they have been thrown directly in the reservoir or came from its tributaries, and internal factors, that is, originating from the sediments themselves, which permanently react with the river's liquid environment. This happens mainly due to the re-suspension of sediments phenomenon, a result of the movement of water caused by the wind, rain or temperature changes. Thus, even if the dumping of pollutants could be completely halted in a specific dam, the presence of sediments that have accumulated in its river bed during all the years when which it was receiving these pollutants from domestic and industrial sewers may mean that the dam will still present high concentrations of contaminated substances for a long time.

The highest concerns with the water in the Billings Dam are euthrophization, the concentration of heavy metal and the presence of pathogenic micro-organisms and potentially toxic algae.

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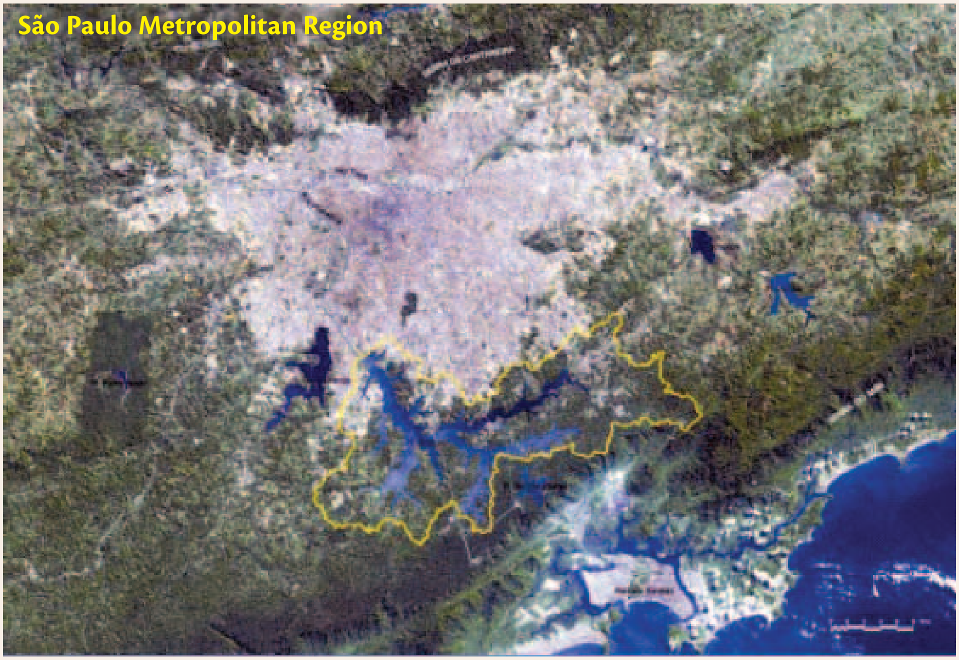
[6] According to Silva & Guetter, an acceleration of the hydrological cycle has been observed in some areas of the Paraná basin since the beginning of the 1970s, a fact that can be confirmed by the increased frequency of heavier rain, an increase in average streamflow levels and longer low water periods

Billings Dam Lake



Source: Capobianco, 2002.

7.4.3.1.3. The Amazon river basin – water resources, climatic vulnerability and variability and main water usage conflicts

The continental Amazon River basin is the world's largest drainage basin, approximately 6,1000,000 km^2 in area. Located in the intertropical zone, it receives an average of 2,460mm of rainfall every year. Average streamflow at the mouth of the Amazon River at the Atlantic Ocean is an estimated 209,000 m^3/s (MOLINIER et. al., 2002).

Box 3 presents basic issues regarding current scientific knowledge on the climatic vulnerability of the Amazon River basin.

Box 3 – The Amazon River basin

Basic aspects and uncertainties regarding climate vulnerability and variability and hydro-meteorological regimeAccording to the results of the Hydrology and Geochemistry of the Amazon River Basin Project (HiBAm) (FREITAS, 2004 and FILIZOLA, 2002), the Amazon River Basin is affected by climatic variability caused by the El Niño Southern Oscillation (ENSO), which causes a significant decrease in rainfall (ACEITUNO, 1988; RAO e HADA, 1987). The impacts of this specific instance of climatic variability on the hydrology of the Amazon River and its main tributaries have been studied by several authors (MARENGO and HASTENRATH, 1993; MARENGO, 1995), but these results are in part invalid due to the fact that they do not consider the phenomenon of some hydraulic blockages along the main course of the Amazon (MOLINIER et. al., 1996). The impact of this climatic variability on erosion and on the flow of objects transported throughout the Amazon River basin remains to be discovered.

Among the certainties and uncertainties regarding the hydro-meteorological cycle of the Amazon River basin are the following:

- Rainfall variability is relatively understood for the Brazilian Amazon (MARENGO and HASTENRATH, 1993; ROUCOU, 1997), as well as in the Tropical Andes (ACEITUNO, 1988; RONCHAIL, 1996, 1998 and 2002). However, there is still a zone that has not been thoroughly studied or understood (between Southern Latitude Parallels 5 and 25), since it is connected, a priori, to the Amazon Plains (Llanos) of Bolivia, Peru and the extreme West of Brazil.
- The current hydrological regimes are understood for the rivers of the Bolivian and Brazilian Amazon, thanks to the data surveys provided by the PHICAB and HiBAm programs (ROCHE and FERNANDEZ, 1992; MOLINIER et al., 1996, 1997). However, there is practically no information regarding hydrology and erosion in streams in the Tropical Andes (Colombia, Ecuador and Peru), and that has led to holding up the process of hydrological modeling of the Amazon Basin as a whole. The ENSO–hydrology relationship has been little explored for the Amazon River and some of its major tributaries (MARENGO, 1995). To sum up, it can be said that the impact of climate variability on hydrology in the whole of the Amazon Basin is still fairly unknown.

Source: Freitas, 2006

Box 4 and Figure 7-10 present socio-environmental restrictions on the use of the hydroelectric potential of the Amazon Basin.

Box 4 – Hydroelectric power plants and the environment in the Amazon

The building of power plants in the Brazilian Amazon was begun in the 1970s with the installation of the Coaracy Nunes Power Plant in the state of Amapá in 1975. The plant generates 40 MW of power and uses 23 km^2 of flooded area. Since then, six hydroelectric power plants have been built in the area, amounting to a total of 6,050 MW of generated power and 7,600 km^2 of flooded area. The socio-environmental impacts of implementing these enterprises in the planet's largest rainforest ecosystem, which is also an area of high cultural and biological diversity, are the basis for studies and assessments that have been guiding new enterprises.

Among the cases studied, that of the Tucuruí Power Plant, located in the Tocantins River basin in an area of tropical rainforest, is certainly one of the most significant ones. It is the plant that generates the most power and inundates the largest area among those built in the region (4,240 MW and 2,800 km^2, respectively), having dislodged 4,407 families.

Construction started in 1976 and the plant was put into operation in 1984, initially aiming to generate electricity for the towns of the Eastern Amazon region to stimulate occupation of the area and encourage the development of the Northern region of Brazil. It also endeavored to facilitate navigation in the region's rivers through the use of locks. However, the enormous mineral potential of the area attracted electricity-intensive industries to the region, especially aluminum companies, which require high levels of electricity. To satisfy these demands, the Tucuruí power plant also provided power for the region's industrial sector. Currently, the plant provides 50% of its output for industry and uses the other half to provide electricity for the states of Pará and Maranhão.

The lack of specific environmental legislation at the time, the disrespect for legislation that was in force and the lack of data regarding the region have brought about a series of impacts, expected or otherwise. The Brazilian power sector has learned much from Tucuruí.

Among the unexpected impacts, the following stand out: isolation of the river-dwelling populations after the filling of the reservoirs; irregular and disorganized settlements; water usage conflicts; lack of infra-structure; severe proliferation of flies; intensification of predatory timber extraction; loss of fishing zones downstream from the dam; appearance of large schools of fish above the dam;

enormous animal losses with the filling of reservoirs; emission of greenhouse effect gases from the surface of the dam lake; re-settlement in areas unsuitable for agriculture; high level of abandonment of allocated dwellings, and the sale of these; pressure on the local landowning structure; destruction of social bonds of the indigenous communities that lived in the area; selective power supply, with lack of service to the populations affected; population under-qualified for the jobs offered in the region; conflicts between commercial and small-scale fishing, and problems regarding the amount to be paid as compensation to those who had their homes flooded. Among the expected impacts, the loss of the region's rich biodiversity is worth emphasizing.

The environmental variable was incorporated too late into the planning of the electric sector.

In the construction stage, the measures for handling social issues were implemented in a reactive way by the company responsible without being guided by policies directed towards the proper reallocation and compensation of the affected populations and towards dealing with emergency situations.

In the light of all the scenarios created by the undertaking, some lessons were learned, such as:

- Future hydroelectric enterprises must be implemented with local and regional development goals from their very conception, not restricting themselves to the generation of power for enterprises that will bring benefits to other areas.
- The implementation of new hydroelectric enterprises must be preceded by the elaboration of a hydraulic inventory of the whole basin, incorporating not only the physical consequences, but also an assessment of all social and environmental impacts that will ensue.
- The importance of a prior assessment of the environmental impact of several different alternatives calls for the creation and fine-tuning of new mechanisms for public participation in all stages of projects for large dams.
- The implementation of hydroelectric enterprises must involve the evaluation and support of a drainage basin committee, which should mediate negotiations between the various agents and water users involved in the process.
- The criteria for definition of the area directly impacted by the hydroelectric enterprise should be subject to legal scrutiny, and compensation rights should be offered to all involved. Such a study should not be restricted to the flooded area alone, and social control mechanisms should be created to make sure the financial resources invested are directed to the right place and used correctly.

- Scientific uncertainty concerning the magnitude and relevance of the environmental impacts and risks brought by the enterprise should be addressed by the adoption of the 'principle of caution' throughout all stages of planning, building and operating the project.
- Recognition, on the part of the entrepreneur, that social movements are legitimate voices in defining public policies and in taking decisions that affect their way of life.
- The need to ensure access to technical information, in language appropriate for laymen, concerning the project and associated impacts.
- The need to create permanent channels of communication between the entrepreneur and the communities affected by the enterprise throughout the entire cycle of the project.
- Promotion of integrated development actions for rural areas with an emphasis on renewable energy projects and improvement of quality of life for the population, taking into consideration ease of access to the benefits brought by the enterprises to the urban populations and the low rate of services rendered to the rural populations of the Amazon.
- The lessons learned from the case of the Tucuruí Power Plant should be of service in the planning, building and operation of other hydroelectric projects in the Amazon, so that these can contribute to the sustainable and participative development of the region and of the country.

Source: World Commission on Dams, 2000 and Freitas, 2003 and 2004.

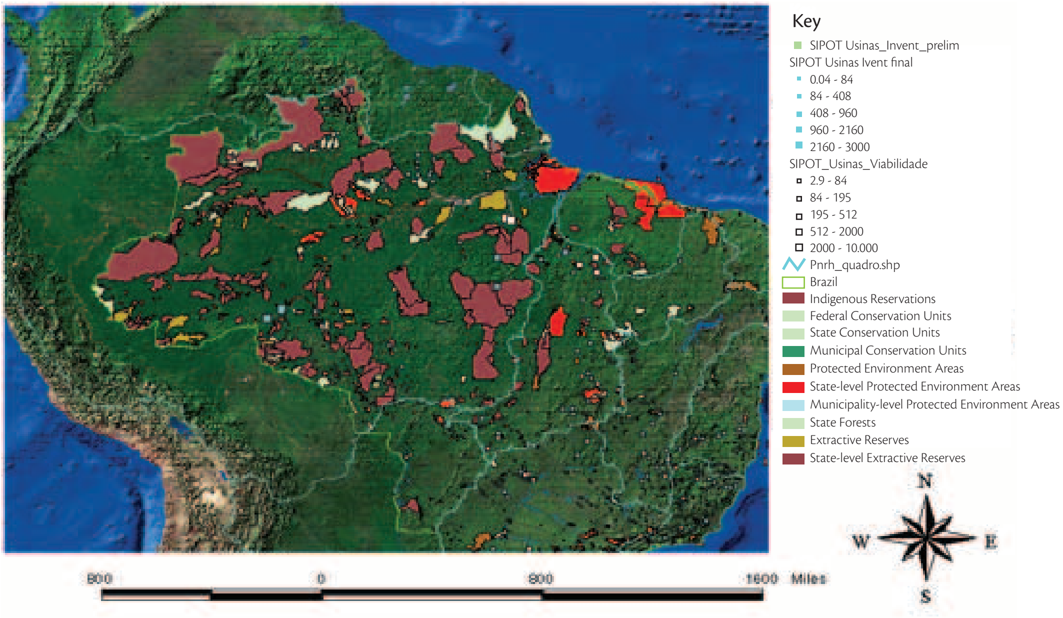


Figure 7-10: Amazon and Tocantins River Basins – Hydroelectric Power Plants (already planned and in study) and conservation units/indigenous reservations.

Source: Author's own material.

It is important to highlight the important technical breakthroughs achieved during the latest projects for hydroelectric power plants in the Amazon Basin, in other words, there is a clear concern on the part of both public and private entrepreneurs in the power sector in building smaller reservoirs for power plants, as can be seen in the Santo Antônio (3,150 MW) and Jirau (3,300 MW) power plants on the River Madeira, with estimated flooded areas of 271 and 258 km^2, respectively, as well as the Belo Monte plant, with an estimated flooded area of 400 km^2 and generated power capacity of 7,500 MW (Furnas, 2005).

Box 5 – Power Plants in the Amazon Region – reservoir area/plant generated power ratio

Power Plant in the Amazon Region	Resevoir Area (km²)	Power (MW)	Reservoir Area / Generated Power Ratio (km² / MW)
Balbina	2,360	250	9.44
Samuel	584	217	2.69
Manso	387	210	1.84
Tucuruí			
Stage 1	2,414	4,000	0.61
Stage 2		8,000	0.3
Jirau	258	3,300	0.08
Santo Antônio	271	3,150	0.086

Source: Furnas 2005.

With regard to global issues, the Amazon Basin has a fundamental role in the climatic dynamics and hydrological cycle of the planet. The basin represents approximately 16% of the world's surface freshwater stocks, and, consequently, contributes greatly to the rainfall and evapotranspiration regimes in South America and the whole world. Regional and global changes have caused changes in the climate and hydrology of the region: namely, changes in the use of the soil, with the conversion of more than 700,000 km² of rainforest into pasture, as well the global climate warming phenomenon, which has registered increases in average temperature of 0.6-0.9°C over the last hundred years. Actually, marked changes in temperature may lead to other changes in the environment, including the intensification of the global hydrological cycle, which will in turn lead to more impacts on water resources at regional levels. In fact, different changes in temperature in the atmosphere, continents and oceans lead to changes of atmospheric pressure and wind patterns, therefore, we may expect changes in rainfall patterns, as has been predicted by the mathematical models for global climate change prediction of the Hadley Center for 2050, which predict average reductions of 150-250 mm/year in rainfall in the area.

It should be pointed out that, if the occurrence of anomalous increases in Surface Temperature in the Pacific and Atlantic Oceans intensifies, rainfall, and consequently streamflow levels will be reduced. In fact, in terms of the Pacific Ocean, "the occurrences of El Niño have brought events of extreme lack of rain, and, consequently, low discharges into the rivers in the region, especially in the Northeastern part of the Amazon". Tendencies to drier conditions were observed during the El Niño events of 1903, 1912, 1925-26, 1982-83, 1986-87 and 1997-98. Regarding the Atlantic Ocean, according to the Brazilian Center for Weather Forecasting and Climate Studies (CPTEC/Inpe) and the Brazilian National Meteorology Institute (INMET), during the period from September 2004 to September 2005, the Sea Surface Temperature was 0.5-1.5°C above the average for the Northern Atlantic Ocean, in other words, an abnormal persistent warming phenomenon was registered. This phenomenon, possibly responsible for the 2005 drought in the Amazon, eventually altered the currents of humid air mass in the Amazon region, especially in important areas of the drainage basins of the Solimões, Negro, Madeira, Juruá and other rivers (FREITAS, 2006). As to hydroelectric potential, the tendency to create reservoirs with smaller capacities, as mentioned above, will leave the region more vulnerable in terms of hydroelectric generation in years of water deficiency.

7.5. Adaptation measures in the Brazilian hydroelectric system and in water use to the risks of global climate change

Given the uncertainties of the current climatologic models when predicting future rainfall patterns in the Brazilian drainage basins, the recommendations made here are concentrated above all on reducing the vulnerabilities already detected with a view to expanding and sustaining the generation of hydroelectric power in Brazil.

7.5.1. Conflicts between hydroelectric energy and other users of water resources

The occurrence of extreme events, such as droughts and floods, more often and more severely will increase conflict among water users in the various drainage basins of Brazil. In terms of hydroelectric enterprises specifically, the increase in demand for water resources – in absolute terms and in their various forms – will require a more profound knowledge of the area where those enterprises are, as well as constant supervision of generating conditions, and not only in the power plant or in the reservoir areas. Hydrological balance will have to become more precise, surveys regarding environmental and economic impacts will have to be more detailed, etc. To sum up, the power plant's social responsibility towards the river-dwelling peoples and other users will tend to increase. The challenge in hydroelectric power generation is including in its planning new ideas – and, therefore, new competences – that are often very different.

7.5.2. Conflicts between hydroelectric energy and other users of the land

Demographic growth and expansion of occupation (organized or not) of Brazilian territory tends to increase the number of individuals affected by hydroelectric enterprises, who then gain political power when making their demands. This means the process of making a project viable and putting it into practice becomes an extremely critical stage, since it now depends not only on long-term financing but also on increasingly longer negotiations, with higher transaction costs and fewer guarantees of success. It is important to revise the laws defining the compensation criteria for individuals affected by hydroelectric undertakings. For instance, there is no legislation today regarding populations and municipalities downstream from dams, nor regarding specific groups such as indigenous populations.

7.5.3. Multiple and integrated management of reservoirs

The increase in frequency and intensity of extreme events, such as the anomalous warming phenomena of the Pacific (El Niño) and Atlantic Oceans, require a more flexible approach to the management of reservoirs, apart from the mere optimization of hydroelectric power generation. Measures must be taken to reduce the negative impacts and increase the benefits to the basin and to the users involved. Such measures are taken both at the moment when the decision is made to build the power plant as well as when deciding how to manage its reservoir, and as a consequence many social costs may finally be imposed on the generating company by the Government, a tendency already observed internationally. Therefore, there should be an increase in investments previously considered marginal to the main line of business, such as conservation of vegetation growth, regulation of streamflow from the rivers and their tributaries, controlled disposal of industrial waste, the acquisition of hydrological information and the establishment of orderly use of the land in the drainage basin.

7.5.4. New institutional and regulatory arrangements for the generation of hydroelectric power

Reducing vulnerability in hydroelectric enterprises requires above all a major acceptance of those enterprises by society. It has to be accepted that the complexity of the most recent projects is far greater than that observed until the 1980s, essentially due to changes in legislation. Today numerous institutional arrangements and political connections must take place before the decision is made to invest in the building of a dam, a hydroelectric power plant or a large thermal power generation center. Authorizations must be obtained from regulatory agencies in the power, water and environmental sectors, as well as agreements that must be made with governors, mayors and local community associations. The current regulatory requirements not only demand a series of environmental licenses for the exploitation of hydroelectric potential and permits for the use of water, but also impose heavy fees for its use, consumption and discharge, as well as obligations regarding the acquisition and provision of hydrological information. It is no wonder that, of the several projects projected for the power sector in the 1980s, few were not cancelled, postponed or completely reformulated during the 1990s.

7.5.5. Technological and economic opportunities in the electricity generating sector

The reduction of vulnerability in the generating sector of the Brazilian power grid depends strongly on integration with other sources of energy and enterprises on several levels. In other words, an additional challenge to be considered concerns the changes that have occurred in the generation industry itself, both in the technological and economic fields. Technical-economic paradigms, such as those of large power plants, have been strongly opposed for instance, and new business opportunities have arisen in the field of establishing and operating small power stations. We see today a proliferation of small power plants based on small streams and waterfalls, the reutilization of biomass residues, wind farms in coastal areas and even aviation-derived turbines fueled by natural gas that can be installed in city buildings. The economic impact has been almost immediate: less dependent on large-scale profits, the new generating technologies have enabled new products to enter the market, significantly improving competition. This move has been reinforced by the general deregulation of infrastructure services in developing and developed countries. In this completely remodeled scenario, the list of most important actors in the process includes some large multinational groups, working from the basis of the planetary scale of their operations, as well as growing economies (either in breadth or scope) that are emerging among the different infrastructure sectors. But the new actors in the spotlight are companies or conglomerates on a regional or local scale, which have entered the energy generating business encouraged by the availability of smaller units that can be placed near consumer centers, built more quickly and in modules, are fairly flexible in their operation and can work if necessary only during peak hours. Another factor in favor of these smaller enterprises is the pressure for profitability that appeared in the 1990s and began with speculation in stock markets throughout the world. In the infrastructure sector, and especially in the energy generating sector, the *leitmotiv* has become speed of return on investment and the mitigation of risks, two concepts that perfectly agree with the philosophy and cost structure of these new projects.

Finally, as a conclusion, we provide suggestions for structural and non-structural actions in the drainage basins and in the management of hydroelectric potential, mainly in the generation of electrical power. We take into consideration the uncertainties of the streamflow projection models, as well as the vulnerability of drainage basins and the energy sector (and, consequently, of the whole Brazilian power grid) to climate change risks.

Structural actions

1) Building/modification of physical infrastructure

   It will be necessary, as soon as physically possible, to revise the arrangements in effect in hydroelectric energy generation in the plants already in operation, especially regarding the multiple uses of water, be it for extreme dry or flood periods or to better adapt to the needs demanded by the demographic and economic growth in drainage basins.

2) Removal of sediments from reservoirs

   It is fundamentally important to implement measures to periodically remove sediments from the bottom of reservoirs to ensure higher water storage capacity and consequently sustain higher capacity of energy generation and the useful life of the installation.

3) Transfers of energy and water between drainage basins (regional and continental integration).

   The encouragement of greater regional and continental integration between drainage basins and electricity systems is fundamental. This action can, without a doubt, considerably reduce vulnerability concerning energy and water availability among countries and consumer markets.

Nowadays, the operation of the Brazilian Interconnected Power System ensures compensation for seasonal and 10-yearly imbalances in relation to drainage basins and consumer markets for electrical power. A drought in the São Francisco River basin does not present major risks to the consumption of electric power in the Northeastern region of the country.

On the other hand, regional integration is still at quite an initial stage, with national political instabilities bringing restrictions to the intensification of energy interchange among the countries in South America. Examples such as the Brazil-Bolivia Gas Pipeline and the Itaipu Binational Power Plant (Brazil and Paraguay) must be perfected to become a model for South-American integration. Recently, in April 2008, an agreement signed between the Brazilian and Argentinean governments provided for the Brazilian system to provide power to Argentina during winter, when its demand for power increases for the purposes of heating heating, with the opposite happening in Summer when the demand for power in Brazil increases, for cooling the environment.

Non-structural actions

1) Adaptable management of existent water provision systems

   Configuring the water provision systems to adapt to periods of lower quotas and with the integration of alternative power-supply systems.

2) Changes in operational guidelines

   The operational guidelines for hydroelectric power plants need to be reviewed in cases of unforeseen events, and the plants need to be well-informed of the restrictions on these rules arising from various consumption and non-consumption uses.

3) Joint use of atmospheric, surface and underground water

   The projected management of water use is heading in the direction of an attempt to create an integrated approach to the hydrological cycle. In other words, drainage basin systems, aquifers and air masses must be taken into consideration according to different time scales, but also integrated, with an emphasis on the potential and the restrictions of each of these systems. An attempt at integration in the waters of the River Plate Basin may be carried out with discussion concerning the Guarani Aquifer and the management of the air and vapor masses that affect the region, involving Argentina, Brazil, Bolivia, Paraguay and Uruguay.

4) Integrating operating systems for reservoirs

   Today there is an integrated system in the operation of hydroelectric power plant reservoirs; however, there is no interaction between these reservoirs and others that are responsible for urban and rural energy supply. Besides, continental interaction between reservoirs is rare and does not take into consideration the limitations of trans-border drainage basins such as those in the River Plate and the Amazon.

5) Increasing space-time coordination between supply and demand of water and energy, that is, between drainage basins, energy systems and climatic seasonality, variability and vulnerability. Emphasis should be given to the following factors:

   - Water
   - Consumption and non-consumption uses
   - Energy
   - Renewable and non-renewable resources
   - Efficient use of energy.

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8. The impacts of climate change on brazilian cities

Wagner Costa Ribeiro

8.1. Introduction

The publication of the 4th Report of the Intergovernmental Panel on Climate Change (IPCC AR 4) raised a substantial number of questions for discussion and analysis. The main conclusion of this report was its confirmation of the probable contribution to global warming by human activity.

A number of uncertainties remain regarding the real impacts of global warming. It is not known for sure, for example, how high temperatures will rise or exactly how rainfall patterns are likely to affect the planet in future. These changes will depend to a great extent on the capacity to regulate greenhouse gas emissions, which in turn requires the various international environmental negotiating rounds concerned with the world climate (such as the UN Convention on Climate Change and the Kyoto Protocol) to determine the levels of emissions. Meanwhile, regardless of the ongoing international policy deliberations on climate change, national and local policies are urgently called for in order to prepare societies to acknowledge and deal with the changes that are already taking place.

According to the IPCC (2007), heat waves are likely to affect urban areas more frequently in future and are likely to last longer and be more severe. Moreover, air quality is likely to deteriorate and the number of risk areas in the cities will almost certainly increase, particularly in tropical cities subjected to heavier rainstorms, leading to flooding, landslides and other damage.

Awaiting scientific proof before measures are adopted to soften the impacts caused by climate change is out of the question. It is vital to devise strategies here and now for dealing with climate change, heeding the evidence already assembled about future climate scenarios by researchers throughout the world. Now is the right time to adopt theP Precautionary Principle and propose measures that can mitigate the consequences of global climate change arising from higher temperatures. The present article, in suggesting a number of initiatives that could be taken in Brazilian cities to adapt to climate change, seeks to contribute to finding ways of reducing emissions in urban areas, as well as of alleviating serious socio-environmental factors which could result in the loss of human life and property.

This text is divided into three sections: (1) the urbanization process in Brazil - a short description of the particular way in which the country became urbanized, which was characterized by the speed with which the growth of urban areas happened, and the concentration of wealth in enclaves surrounded by belts of poverty; (2) a section on adaptation (to climate change), vulnerability and socio-environmental risk in Brazilian cities, which discusses concepts useful for formulating actions that should be implemented over the short, medium and long term in Brazil; and (3) the situations of risk and adaptation in Brazilian cities, pointing to the socio-environmental problems arising from climate change in the cities and proposing a number of ways for ameliorating such problems. The latter item is divided into three groups of problems related to their specific causes: temperature increase, heavy rainfall patterns and rising sea levels. The Final Considerations section summarizes the study.

It is important at the outset to draw attention to the fact that Brazil's social situation is responsible for aggravating the socio-environmental impact of climate change in Brazilian cities. Centuries of segregation have to be taken into account when considering the kind of actions needed to deal with the climatic changes predicted by the IPCC scientists. A substantial number of Brazilians living in risk-prone areas will be more seriously affected by climate change problems than better-off residents higher up the social ladder. Combating socio-environmental exclusion has therefore to be the first step towards avoiding the worst outcomes: loss of human life caused by extreme climatic events affecting Brazil's cities.

8.2. Urbanization in Brazil

According to a number of academic authors such as the geographers Milton Santos (1990 and 1993) and Ana Fani Carlos (2001), the urbanization process in Brazil is a case apart. While Santos draws attention to factors such as the speed and intensity of the process, Carlos argues that it was largely driven by land and property speculation - which led to previously vacant plots in urban areas being occupied by wealthy districts in the middle of poverty and to the occupation of inappropriate urban sites that have become unsuitable environmental risk areas, as analyzed by writers such as Yvette Veiret (2007) and Ulrich Beck (1986).

These risk areas are home to poorer people who generally have to endure living in subhuman (according to UN criteria) conditions, living in shanty towns (*favelas*) perilously close to the edges of streams or located on steep slopes. Others inhabit overcrowded and decaying tenement-type buildings (*cortiços*), forced to share limited drinking water, toilets and other facilities. The worst situation is experienced by poorer people with no homes at all. Thousands live on the streets or seek shelter in public parks and squares to sleep at night.

Brazil's population is concentrated in metropolitan regions and large and medium-sized cities. Urbanization in Brazil is a fairly recent phenomenon when compared to what took place in central countries. The speed with which Brazil's cities were built - for example, the city of Maringá (PR) which at present contains around 320,000 inhabitants[1], despite being only 60 years old - cannot justify the level of social exclusion in Brazil's urban areas. Social exclusion arises from the production of urban space.

As pointed out by the economists Paul Singer (1977) and Milton Santos (1994), the political economy in Brazil's cities tend to focus on urban land as if it were an item of merchandise. The transformation of huge tracts of rural land into urban areas is a product of property market speculation, which involves viewing urban land as little more than a source of profit and capital appreciation. This explosive model of capital accumulation is the major factor part responsible for the socio-spatial segregation in Brazilian cities.

According to the sociologist Manuel Castells (1983) and the geographer Horacio Capel (2002 and 2003), among others, in other countries the State has been responsible for urban growth. In Brazil, even the few so-called planned cities have gradually fallen into the hands of financial speculators and property developers, who frequently choose to disregard city master plans, as in the cases of Belo Horizonte and Goiânia. In Brazil, urban land is seen almost exclusively as merchandise and only very rarely as fulfilling a social function. The introduction of the City Statute (*Estatuto da Cidade*) in 2001[2] might eventually improve this discouraging picture, but judging from progress to date, optimism is not an option. This key instrument for providing a proper framework for urban areas lacks a detailed set of regulations and, despite having introduced interesting measures such as neighborhood impact studies and encouraging participation by local residents in city management, it has not yet filtered down to benefit Brazilian society as a whole.

The relationship between industrialization and urbanization is fundamental to explain some of the problems of the urban environment. Whereas the main function of cities was initially to serve as centers for business and the distribution of goods, this scenario was radically transformed by the arrival of industry. The city gradually took on the additional role of producer of manufactured goods.

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[1] MARINGÁ. *Site*. Available at: <http://www.maringa.pr.gov.br accessed in November 2007>. Accessed: 20 Nov. 2009.

[2] The City Statute was created by Law No.10,257 (10th July, 2001) and came into effect on 10th October 2001 to regulate Articles 182 and 183 of the Federal Constitution. It is the result of the struggles of urban social movements which have had some of their demands granted.

But industry is not just any economic activity; it requires a series of urban services to be able to establish itself and operate, as well as large amounts of manpower, as was the case with the São Paulo Metropolitan Region earlier in the 20th century. In order to set up an industrial installation, roads are planned as well as integrated systems of energy distribution and living quarters must be built, at first by the industries themselves, to house workers. The latter were the famous 'workers townships', which today remain as symbols of the industrial legacy in some of Brazil's older industrial cities.

Up to the 1980s the main industrial areas of Brazil were in and around São Paulo, spreading over a radius of about 100 km and including the cities of Sorocaba, Campinas, São José dos Campos and Cubatão. A number of other major industrial clusters scattered throughout the state of Minas Gerais, in Belo Horizonte and Ipatinga, in Rio Grande do Sul, with Caxias do Sul and Porto Alegre, in Santa Catarina, in the Itajaí Valley, and others in the state of Rio de Janeiro such as Barra Mansa, as well as in some isolated towns in the Northeast, such as Recife and Paulista in Pernambuco or even in Salvador in the state of Bahia. The tax-free Zona Franca of Manaus, capital of Amazonas state, has been a major assembly hub for electronic consumer goods since 1967. This city has witnessed substantial population growth, from 200,000 inhabitants in 1960 to around 600,000 in 1980 and 1,400,000 in 2000[3]. Obviously, a growth population about seven times in 40 years cannot occur without generating serious social, environmental and economic problems.

The rapid growth of cities in Brazil has made urban land more expensive. Given that most factories require large areas for their installations many cities have ceased to be options for industrial plant by reason of high property costs.

In the 1990s the change in patterns of production and policies for attracting industry altered the distribution framework of industries in Brazil. Known as the 'fiscal war', this was the result of industrial growth in states such as Goiás, Ceará, Bahia, Minas Gerais, Rio de Janeiro, Rio Grande do Sul and Paraná, and it revitalized the secondary sector of the economy in Brazil.

The financial incentives offered by these states of the Federation led to the establishment of new industries, but of a type that created less employment than those in the states of São Paulo and Minas Gerais. The inevitable population migration generated by the new industries did not result in higher tax income. As a result, more people needed to use public services which the municipalities were not equipped to offer, as the economist Marcio Pochmann (2003) pointed out. This led to the reproduction of social processes found in metropolitan centers such as shantytowns and the occupation of risk areas in Brazil's new industrial cities.

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[3] INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. *Censos demográficos*. Available at: <http://www.ibge.gov.br/home/estatistica/populacao/default_censo_2000.shtm> accessed: 20 Nov. 2009.

Parallel to this second phase of Brazilian industrialization a "conservative modernization", to quote the words of the sociologist Renato Ortiz (1989) occurred in the rural areas of Brazil. The introduction of agricultural machinery together with debts incurred by small farmers led to many workers previously employed as agricultural laborers losing their jobs.

The increased drift from the land no longer headed for Brazil's two major metropolitan areas, São Paulo and Rio de Janeiro, as in the past. The destination for those who had lost their jobs in the countryside or on the land became regional metropolis such as Fortaleza, Salvador and Recife. This pattern of urban growth, with well-known social consequences, became common in other parts of the country. Favelas and cortiços were no longer the exclusive preserve of São Paulo and Rio de Janeiro. Brasilia Teimosa in Recife and the Dendê shantytown in Fortaleza came to be as well-known as Paraisópolis (São Paulo) or Rocinha (Rio de Janeiro).

Urban socio-environmental problems have now spread throughout the whole of Brazil, solutions need to be considered at national level even though they will have to be put into practice at a local level. In other words, it will not be possible to alleviate socio-environmental impacts and propose measures for dealing with climate change through the activation of municipal public policies alone. A genuine joint effort, mobilizing a range of different ministries, is called for, such as the Ministry of the Environment, the Ministry for Cities and the Health Ministry, among others, in view of the fact that many of the new industrial cities and even the regional metropolitan areas which have undergone substantial population growth in recent years do not possess sufficient technical and economic resources for funding the alterations necessary adapt to climate change.

Joint 'mobilizing action' needs to be started as soon as possible. One useful initiative would be a 'Sustainable Growth Acceleration Plan' (Plano de Aceleração do Crescimento Sustentável - PACSUS) targeted at rehabilitating decaying city areas, thereby improving the quality of life of the Brazilian population as a whole. Economic growth activity should differ from that which occurred up to and including the 20th century. It is important to review mistakes committed in the past and not repeat them. Simply proposing to increase manufacturing automobiles and other consumer goods is no longer enough to meet the challenges of the 21st century.

A substantial amount of work will be needed to repair what the hegemonic model of the last century undermined. This change of pattern is beginning to occur, and the country which can apply it before others will have an advantage since it will need to be developed and implemented by scientific and technical knowledge. Creating the technology to repair the environment is a challenge for researchers, the business world and the governments responsible, as well as the need for technologies to reduce emissions of greenhouse effect gases and which enable adaptation to global climate changes, themes which will be dealt with below.

8.3. Adaptation, vulnerability and socio-environmental risk in brazilian cities

Desmond Tutu's (2007) words apply to the world situation as a whole but mirror the situation in Brazil: "Adaptation has become a euphemism for globalized social injustice. While citizens of the developed world have been rescued, the poor, the vulnerable and the hungry are exposed every day of their lives to the hard reality of climate change".[4]

In Brazil we also find a section of the population that can adapt very well to the consequences of climate change in towns, but the great majority are subject to risks and are unable to meet the challenges which the scenarios indicate. Adaptation, in the terms of this article, is defined as investments in infrastructure to protect the population and also as the ability of people to know how to react in the face of the risk situations that will arise in most Brazilian towns.

The situation of social inequality in Brazil, although it has become less severe in recent years, is still far from being a balanced one. For this reason it is necessary to take advantage of every opportunity that appears to solve problems and implement socio-environmental measures to gradually correct inequalities in income and access to services in the country.

Citizenship is also an expression of the quality of life (RIBEIRO, 2002). In this sense, Brazil has still not achieved democratic status. Even with the reforms that are being carried out, access to suitable living environments is confined to a minority of the Brazilian population, precisely that minority which contributes most to greenhouse gas emissions in towns. These are the people who use individual modes of transport, have a decent housing and will be least affected by climate changes.

The most difficult task to be negotiated politically, both nationally and internationally[5] is to convince those who enjoy the advantages provided by a consumer society that makes intensive use of fossil-fuel energy resources, to change their habits. Financial measures such as higher taxes for using cars in big cities, and in particular in city centers, may be recalled as one method of changing this picture.

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[4] TUTU, Desmond. Adapting to climate change does not require apartheid. In: UNDP: Human Development Report 2007-2008. Madrid, 2007.

[5] For an analysis of international negotiations on climate changes, see RIBEIRO (2002 and 2001).

It is also necessary to regulate the use of motorcycles, the emissions of which are greater than necessary because of the lack of a decision taken at Federal level to redefine the emissions from their engines to levels more in tune with contemporary reality.

Even if the pollution generated by all road vehicles were to decline rapidly, which is highly improbable, the effects of global warming will be felt by the population of Brazilian cities and metropolitan areas for many years to come. These will be the result of greenhouse gases produced in the past, especially by the older industrialized countries.

There is as yet no consensus regarding the effects of global warming in Brazil. Whereas the models employed to simulate the global warming scenario over the coming years are useful for determining results at regional and national level, we still do not possess consolidated models that can point to where Brazil is moving in this respect. However, it is possible to find literature on a number of interesting cases, such as that of New York (DEGAETANO, 1999), comparative studies on megacities (MITCHELL, 1999) and more general analytical studies that may be potentially useful for developing future research (ARNELL, 2004, and KOUSKY and SCHNEIDER, 2003).

The above papers give an idea of the difficulties of qualifying the socio-environmental impacts of climate change on Brazilian towns. It is necessary to produce a conceptual review to assist in classifying possible impacts. The following definitions of concepts related to socio-environmental risks (taken from VEIRET, 2007: 24) could be used to evaluate and propose measures for mitigation and adaptation to confront the problems resulting from global warming in Brazil towns:

- **Risk** - the perception of a possible danger, which can to a greater or lesser extent be foreseen by a social group or an individual exposed to it;
- **Uncertainty** - the possibility of a dangerous event occurring without people being aware of its probability;
- **Indeterminacy** - a situation in which an unknown event could take place, for example in the case of a businessman who invests in a new form of technology without evaluating all the implications of his decision;
- **Hazard** - a possible event; it could be a natural, technological, social, economic event which could probably happen;
- **Danger** - a term also used to define the objective consequences of a hazard on an individual, a group of individuals, territorial organization or on the environment. A potential and objective fact;
- **Target** - Persons, goods, equipment and environments threatened by the hazard and subject to harm and damage;

- **Vulnerability** - the predictable impact of a hazard on targets. Vulnerability can be human, socio-economic and environmental;
- **Crisis** - the occurrence of an event the magnitude of which exceeds the capacity of people affected by it to deal with it spontaneously; and
- **Catastrophe** (from the Greek *katastrophê* meaning devastation) - defined as the high level of losses caused to people and goods. No correlation necessarily exists between the size of a hazard and the extent of damage caused.

The outcome of climate change in Brazilian cities can be expressed in terms of uncertainty and indeterminacy as described above. Uncertainty caused by the absence of precise knowledge concerning temperature increase over the next hundred years. A further aspect that escapes precise definition is the alteration of the rainfall regime. It is not possible to gauge the volume of torrential and concentrated rainstorms at particular periods, although the models indicate these outcomes as being probable. In other words, it has not yet been possible to define the probable consequences of climate change in Brazilian cities, since the key vectors such as rising temperature and rainfall patterns cannot be accurately anticipated. Therefore, an indetermination exists as for the impacts socio-ambientais, in other words, the changes will generate events in ignored intensity, although they can be, in certain way, extent.

Nevertheless, there is no doubt that Brazilian cities can be affected by hazards, that is, they are places where events related to climate change will occur. In order to avoid both crises and a catastrophe we must now seek to identify the dangers, as well as the targets most likely to be affected. The measures should be taken with base in the Precautionary Principle, , particularly when human lives are at risk. In other words, when in doubt as to the socio--environmental impacts on Brazilian cities, we must act to solve all the problems resulting from the rapid and particular manner in which Brazil was urbanized and to make a determined assault mainly on the unacceptable living conditions of the majority of the population living in Brazil's cities and metropolitan areas.

The concept of vulnerability[6] is of fundamental importance and this concept needs to be re-evaluated in the light of changes arising from global warming. Although no conclusive studies exist in this respect, some of the problems needing to be faced by the population and requiring the application of public policies at national, state and regional levels, can certainly be highlighted.

The real danger, as pointed out by Veiret (2007), arises from the massive urbanization that has taken place in Brazil over the years. As pointed out at the beginning of this paper, this process led to a large influx into the cities of people with low-incomes who had no alternative but to live in risk areas such

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[6] This concept has been dealt with by authors such as BOHLE, DOWNING & WATTS (1994), BURTON (1997), VEIRET (2007) and NOVEMBER (2002).

as valley bottoms, river banks and steep hillsides, or in poorly maintained and semi-derelict tenement-type buildings. These situations expose their inhabitants to the dangers arising from global warming and generate a series of risks calling for firm action.

8.4. Risk and adaptation situations in brazilian cities.

A number of different risks arising from global climate change exist in Brazilian cities. These can be listed under three main headings: higher temperatures, heavier rainfall and the rise in sea levels.

8.4.1. Higher temperatures

If forecasts are confirmed, cities in Brazil will experience hotter day and night temperatures than hitherto, a situation which is likely to have repercussions on quality of life and calls for new thinking on both the use and size of buildings. Other aspects requiring consideration include air pollution and the effects of the heat island that have been studied by the geographer Magda Lombardo (1985).

At local level, air pollution is one of the most serious consequences of emissions. The situation increases the number of people hospitalized with respiratory problems during the dry season, particularly in winter and especially in the cities in the South and Southeast which frequently experience thermal inversion. The concentration of pollution agents causes eye irritation and speeds up the development of influenza, colds and coughs. These are serious health problems because they mainly affect those at the opposite extremes of the population pyramid: children below the age of five and the elderly.

The population is accustomed to adopting solutions of its own to minimize health problems caused by high concentrations of pollutants: avoiding stuffy environments, keeping receptacles filled with water on bedside tables, avoiding physical activity outdoors after 10 a.m., etc. None of these precautions have however been sufficient to persuade people to change the behavior imposed by the means of transport used: the predominant use of the car.

In terms of the urban heat island, Brazilian metropolitan areas and the cities suffer from this problem, which affects the health of those suffering from hypertension and may increase numbers of deaths. One solution to this problem is found in adapting regulations at municipal level by means of a Building Code and the City Master Plan. For this to happen, awareness campaigns need to be mounted *vis-à-vis* local people in to encourage them to put pressure on mayors and councilors to ensure that the specifications of new constructions are properly adapted to future predicted climatic conditions.

The biggest obstacle to introducing modifications in the Building Code is the private real estate sector, which generally maintains close relations with the authorities, as described by Santos (1990), who revealed that pressure exerted by the civil construction sector and property agents led to the adoption of technical solutions giving priority to higher buildings that produced increased population density in upmarket areas in São Paulo.

In many cities and metropolitan areas, keeping buildings at the smaller sizes it has today will mean that more people will install air-conditioners in their homes and workplaces in order to have a more comfortable environment. The increased use of energy to cool urban environments also has to be taken into account.

It will not be possible to reduce the temperature of each room in every building by installing air conditioning. It will be necessary to renovate buildings to allow better air circulation and to cool internal environments and in addition, to establish building regulations clearly setting out the need to plan for larger, better ventilated spaces.

Increased temperatures will directly affect the thermal comfort-level in buildings. The absurdity glass towers, which may be suitable for countries with temperate climates, are not appropriate in tropical countries and must be avoided. These buildings are at present made habitable only thanks to powerful cooling systems which keep ambient temperature at around 22°C. Measures such as those adopted by the municipality of São Paulo, obliging developers and construction firms to install water-heating equipment that use solar energy, need to be applied on a wider scale and could also be used for generating the electricity used in the buildings.

In the medium term, however, the construction of glass-covered buildings must be discouraged. In addition to requiring more energy to run the cooling systems they also produce hot air, contributing to the formation of heat islands over Brazilian cities.

Another consequence of climate change will be the higher frequency of heavy rainfall. One explanation could be the higher temperatures at ground level in the cities caused both by global warming but also by the heat generated by traffic and cooling systems which blow out from buildings the warm air they draw from inside (LOMBARDO, 1985). As a result the descending colder air masses produce heavier rainfall at localized points and results in more severe problems at ground level, such as flooding of roads and streets, traffic bottlenecks, loss of living areas for low-income families, material damage and, most seriously, deaths - generally of people living in risk areas[7] who have no alternative but to live close to rivers and streams or on steep slopes and who are subject to landslides caused by the saturation of the soil resulting from intense rainfall.

A further cause of warming is the manner in which urban space is created, which in Brazil means meeting private demand for the accumulation of wealth without any feeling of public responsibility.[8] Buildings create real barriers to circulation of winds and this changes the natural flow of air and diverts wind currents, thus affecting the frequency and intensity of rainfall (LOMBARDO, 1985).

These problems demonstrate that it will be necessary to lower surface temperatures in Brazilian cities and metropolitan areas. To this end, it is vital to encourage people to desist from using motor vehicles or to quickly change the design of engines so that they do not emit heat, a task which will take a long time to achieve. In addition, regulating the extraction of heat from closed environments and avoiding the building of new structures that need this technical solution to be inhabitable are among the proper measures that should be applied. It will also be necessary to put a stop to the construction of skyscrapers, some of which are over 40 floors high, both for residential and office use. In this case, one alternative would be to organize seminars with architects and engineers as a means of discussing ways of bringing building designs into line with tropical standards, with natural air circulation and lighting, in accordance with the measures of natural light typical of tropical countries. Finally, urgent encouragement needs to be given to adopting new construction techniques adapted to the higher temperatures that Brazil is likely to experience in future years.

Tree-planting, a measure which may be carried out on a large scale and in a short period of time, can reduce land surface temperatures in Brazil's urban areas. Experts need to be consulted for advice on planting the best kind of species in accordance with the size of the streets and sidewalks. It is common to find unsuitable trees on the sidewalks which not only cause cracks and holes in the sidewalk structure but also make walking difficult for ordinary pedestrians, and especially for people in wheelchairs. Tree species should be combined in order to produce a range of blossoms during the flowering season. The existence of more trees in our cities will reduce surface temperatures, which in turn could reduce the kind of heavy downpours experienced in recent years, apart from providing a more pleasant and attractive environment.

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7 For an analysis of environmental risks in urban areas GARCIA-TORNEL (2001) and NOVEMBER (2002). JACOBI (1999) edited a book containing articles on this subject.

8 For an analysis of the case of São Paulo see SANTOS (1994, 1993 and 1990) and CARLOS (2001).

A further effect of global warming will be the more frequent incidence of so-called ‘urban infestations’ of insects such as mosquitoes and termites caused by higher temperatures, which have a negative effect on the quality of life of the inhabitants. Even today many people already complain about the proliferation of termites in particular, which can destroy furniture and sometimes affect the physical structure of properties to a point where they sometimes at risk of being uninhabitable. A campaign is needed to combat such infestations in order to avoid them causing nuisance and spreading disease among city residents.

8.4.2. Heavy rainfall

Increased rainfall can worsen the problems already experienced by many Brazilians with flooding and landslides.

Potential flood victims include people living in valley bottoms, generally close to rivers and streams and sometimes even occupying flood-plains. Policies are needed urgently to relocate people living in such areas, a complex task since it has been undertaken in a number of municipalities without eradicating the problem.

The strategies traditionally employed for population relocation leave much to be desired. What is needed is either to install services and amenities in such areas or simply to rehabilitate and retain them as ‘natural’ areas, but with for proper supervision in order to prevent other families occupying the vacated spaces and creating a new risk situation.

Attention should be drawn to the linear parks project being carried out in the municipality of São Paulo, which consists in removing people and restoring the environment of the area. The people are moved to social housing in another district and it should be noted that the relocation tries to allow residents to maintain their links with the place where they used to live since that is where they found work and have cultural and emotional links.

From an environmental point of view, linear parks are characterized by the reintroduction of species that flourished there. In addition, they are given facilities to make them pleasant and useful as leisure centers for the surrounding population. Another environmental advantage is the recovery of riverbank vegetation which holds back water and in the medium term can supply most of the municipality’s demand for water, as well as preventing the erosion of the banks of bodies of water and subsequent silting, thus increasing their natural capacity to absorb rain water. This is another possibility that could be applied in other parts of the country.

As for human occupation on hillsides, the situation is more serious. Large cities such as São Paulo, Rio de Janeiro, Belo Horizonte, Salvador and Recife are home to large numbers of people living on slopes with more than a 70° incline, which is completely unacceptable. Buildings located in such places fail to meet minimum technical criteria and frequently put the lives of their occupants at serious risk.

This unappealing scenario is made worse by the custom of 'self-building', since construction progresses according to the financial situation of the family, which finds itself living permanently in an improvised situation and even worse, subject to the collapse of a slabs and other parts of the building which, exposed to the weather, quickly degrade. The cycle seems to be endless: lack of money prevents the building being completed, which results in an unfinished dwelling, built in defiance of building regulations in a location that is at risk.

A further risk factor that will be aggravated by climate change is erosion in streams. As rainfall will be more intense in some areas, the water will have sufficient speed and force to bring down sediment and carve out trenches or furrows likely to cause and/or accelerate erosive processes, which can put homes at risk or, in the worst case, occur during a rainstorm and wash away everything on the surface, including people and their homes. More severe erosion can also contribute even more to the silting-up of bodies of water, heightening the possibility of flooding in valley bottoms.

With regard to the alternatives available for people living in these conditions it is worth mentioning the project undertaken in Santos (São Paulo State) in the early 1990s. Risk areas were mapped in detail, on a scale of 1:5000, with the properties most likely to be at risk on each slope identified. The population was told, by means of direct communication, of the dangers involved in continuing to live in such places, which reduced their resistance to being relocated. The civil defense authorities also gave residents intensive training in how to leave their homes in the case of heavy rains. The result was important: for many years no deaths were recorded in Santos due to landslides in the Serra do Mar area.

A similar project was developed in Angra dos Reis (Rio de Janeiro State) from the late 1990s onwards. However the project was abandoned and a number of deaths were recorded in Angra resulting from the torrential downpours experienced around 2005.

Removing people from such places is rarely carried out without resistance. Although necessary, such initiatives are lengthy and expensive. Palliative measures such as organizing community workshops to train local inhabitants in emergency evacuation in the case of heavy rainfall, can be easily organized and avoid the unnecessary loss of lives. However, the ultimate solution is to face up to and resolve this problem by removing entire populations, offering alternative accommodation and ensuring that the uprooted people are able to retain social, cultural and employment links acquired in their present neighborhoods.

One possibility would be to transfer families to the same housing complex, which at least would help to maintain their cultural and other links. Jobs will need to be available in the new areas as a means of providing income generation opportunities for the relocated families.

As for life in the *cortiços*, the situation is equally serious. The fact that many families are clustered in a single large building causes such properties to decay quickly given the intensive use, far beyond the buildings´ original planned purpose, to which they are put. Worse still, these tenement buildings are in general operating illegally, with somebody renting the property and subletting to other families. As a result maintenance is overlooked in most of these old buildings.

The poor state of conservation of many of these buildings makes them risk areas. Heavy rainfall, together with strong winds, can affect the structure, and water penetration can lead to serious damage - occasionally resulting in a *cortiço* collapsing completely. Cases of serious injury and even death have been experienced by the occupants of tenements, with roofs and ceilings falling in during or after periods of heavy rain.

As with the hillside *favelas*, the situation in the tenements also calls for families to be relocated. This involves confronting the same problems, involving relocating families while ensuring that their cultural, employment and other links are maintained. However, one particular aspect distinguishes the *cortiço* occupants from those living in the *favelas*. In general the tenements are located in the centre of the city (or nearby), which means that work is more easily obtainable. For this reason greater resistance to relocation can be expected from *cortiço* occupiers than from the people living in peripheral areas of the city.

Finally, it is important to recall that in many cities in Brazil road-building has caused many water courses to be covered with impermeable materials and for roads to be routed along valley floors. The expected strong rainstorms are therefore likely to aggravate the already familiar flooding of public highways, which cause significant inconvenience, property damage and risk to human life every year.

A radical solution is required in such cases, involving the vacating of floodplains and the re-routing of roads/streets that have been built over water bodies. This has been done successfully in Denver in the USA and in a number of towns in Germany. Moreover, it is absolutely vital to match these efforts by increasing the number of railway and metro lines with a view to offering real public transport alternatives and encouraging people to desist from using motorcars.

Climate change will also affect the 'built architectural heritage'. Higher temperatures and increased rainfall will require more careful maintenance of buildings of this type in the cities of Brazil.

The sad situation of Ouro Preto in the state of Minas Gerais (a World Heritage Site) must neither be repeated nor followed as an example. The decay of historic buildings in that old colonial city and the lack of funding needed for their conservation has resulted in the abandonment of entire city blocks with the consequence 'change of use' and subsequent removal of the population that used to live in the area.

The same can be said of the *Pelourinho* area in Salvador, where state government intervention led to the previous occupants being driven out to make way for its use as a tourist attraction (ZANIRATO, 2004). The entire area is also a UNESCO World Heritage Site but now lacks the population that used to give life to it. Land use in Pelourinho has effectively been 'redefined' with the installation of commercial services, food-shops and hotel accommodation basically aimed at the tourist trade.

Heavy rainfall can also affect the 'preserved' built heritage of our cities. The results of this will be that Brazilians will lose sight of the country's past, its historic landmarks, its examples of older building techniques etc. A further aspect to be considered is that tourism - an economic activity that is currently much in vogue and which depends on exploiting Brazil's cultural heritage - is likely to lose its *raison d'etre.*

8.4.3. Rise of sea level

Cities located near the sea contain vulnerable elements which deserve special attention in order to avoid material damage and deaths.

A common characteristic in these cities is the presence of tall buildings ('verticalization'), as in Santos and São Vicente – both large urban agglomerations in the state of São Paulo - and in metropolitan regions elsewhere such as Fortaleza and Recife (plus of course Rio de Janeiro). In most of these towns the coastal promenade is used for traffic purposes, often with expressways running alongside the sea. It is obvious that the use of these places for traffic will have to be re-evaluated in the light of climate change.

A rise in sea levels of around 1m would be sufficient to impede traffic movement along most of the aforementioned highways, some of which have been constructed on landfills (areas recovered from the sea). The patterns of traffic circulation in the coastal cities will need to be reviewed and the road configurations altered. It will be no easy task to place these roads further back from the sea, in the internal parts of the cities, given the highly expensive property expropriation which will need to be undertaken. Solving the problem will fall to the state authorities, which is traditionally responsible for managing traffic planning.

Rising sea levels can also lead to buildings being vacated, as well as to a need to relocate people living near the sea or working in establishments along the beaches. The question arises: Who will pay the bill - private property owners?

As for the low-income population living, for example, in 'stilt houses' near and over the sea, intervention will be called for by the federal, state and municipal governments. Given that these people lack financial resources, government action will be essential for transferring them to more appropriate risk-free locations.

A further difficulty to be faced by the coastal cities will be how to dispose of sewage. In many cities such as in Guarujá (São Paulo State) untreated sewage is collected and dumped in the sea by means of a series of underwater pipelines. Calculations regarding the dispersal of these wastewaters have traditionally been done on the basis of lower sea levels than those expected as a result of climate change. The various conduits and pipe networks will need to be upgraded in order to avoid sewage re-entering the city, which could lead to the propagation of waterborne diseases.

Industries along Brazil's coastline will also need to be protected. Industrial centres such as Cubatão in São Paulo will almost certainly experience problems if sea levels increase.

The prospect of removing people who normally derive their living from the sea will become a reality unless steps are taken to contain the increased sea levels. Fishermen along Brazil's coasts will, for example, face increasing difficulties and it is likely that many of them will have to abandon their traditional fishing activities and migrate to urban areas, thereby putting more pressure on social services.

Seawater containment systems will be vital for resolving the above-mentioned problems. It is worth recording that many poor countries already possess plans for adapting to global climate change, as in the case of São Tomé e Príncipe. Lessons from such countries can be learned as one way of dealing with similar problems faced by Brazil.

8.5. Final considerations

There can be little doubt that it is "better to be safe than sorry", to use the popular expression. This maxim should be applied to Brazilian cities when projections for warming and alteration in rainfall regimes are analyzed.

The main problem produced by the fast urbanization to the cities has been the concentration of wealth. This has produced socio-environmental risk areas affecting especially the low-income population, which is more likely to be a victim of the fallout from climate change than any other segment of the population.

The central thrust of the present paper is therefore to suggest that housing alternatives for Brazil's poorer population in Brazil should be urgently sought. It is only with safe, well-built housing in appropriate areas that the most damaging effects of climate change in Brazil will be eliminated. The ultimate result of climate change in these circumstances could be the deaths of poor people currently living in substandard accommodation.

The main recommendation of this text is that people living in 'risk areas' should be relocated. The federal authorities need to suggest to rich countries, particularly those that have created greenhouse gases in the past, directing more resources for building popular housing. This should of course be done in addition to the federal and other levels of government themselves directing funds to this end.

Other measures are equally important such as those outlined above for mitigating the problems caused by high temperatures. The widespread use of trees in cities, for example, will not only help to bring down ambient temperatures but will also make the cities more attractive as places to live and work in. Furthermore, buildings constructed to tropical specifications and more in keeping with the kind of climate found in most of Brazil, is another key recommendation - which is likely to be carried out only when the official Building Codes at present under the aegis of municipal authorities, are given new regulatory frameworks.

A further important initiative will be to look carefully at ideas for re-routing road systems and reorganizing sewage collection, particularly in Brazil's coastal cities. Radical changes in land use of the traffic corridors along the seafront in certain Brazilian cities and halting land reclamation schemes ('landfills') are also important. In cases where land reclamation can be reverted, the sea will be able to once again be able to take its rightful place "quickly and without prior warning".

A further key recommendation is that no more bureaucratic structures should be established to deal with problems arising from global warming. The various problems need to be analyzed within the remit of the existing administrative structure, involving closer liaison between ministries and state/municipal secretariats. Another aspect for consideration is international cooperation. This should be sought within the parameters established in the Climate Change Convention, in the Fund for Less-Developed Countries and in the Special Climate Change Fund, all of which are sources which could perhaps provide financial support and technical assistance for implementing the measures that Brazilian cities need to take to adapt to climate change.

A further recommendation is to acknowledge the diversity of different Brazilian urban conglomerations. Policies which are appropriate to a particular city are not necessarily applicable to others. Each case needs to be studied on its merits and in accordance with its special characteristics.

Research on technologies that could be used for attenuating future climate change could be a useful source of income for Brazil. Exporting knowledge and alternative techniques for mitigating and adapting populations and cities to climate change is a worthwhile target in this respect. Calls for climate change-related research and technological development project tenders should be undertaken as soon as possible.

It is particularly important to employ techniques for resolving socio-environmental problems in Brazil. Failing this we are likely to miss one more chance for improving the living conditions of a large part of the country's population – a population which still has only limited access to the benefits that the consumption of fossil fuels have generated and which will be the segment most seriously affected by future climate changes in our cities.

The consequences of global warning are an opportunity to deal with major problems resulting from the unequal urbanization process which has taken place in Brazil. With or without climate change these problems will need to be resolved.

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9. Global climate change and human health in Brazil

Ulisses E. C. Confalonieri

9.1. Introduction

The vulnerability to the effects of climate can be defined as the "assemblage of characteristics of a person or a group that determines its capacity to anticipate, survive, resist and recover from the impacts of dangerous climatic factors" (BLAIKIE et al., 1994). The IPCC defines it as "the degree of susceptibility of individuals or systems or their incapacity to react to adverse effects of climate change, including climatic variations and extreme events" (IPCC, 2001).

The possible impacts on the health of human populations caused by the processes arising from global climate change have been the object of attention not only of academic institutions and national governments, but also by intergovernmental agencies and programs, specifically in the health sector. Amongst these should be initially highlighted the Health Commission of the Intergovernmental Panel on Climate Change (IPCC) which, since its Second Assessment Report (1966), including the recent report published in 2007 (Fourth Assessment Report – AR4), has sought to bring together knowledge on the interrelationship between climate and health, both in the general reports produced every five years, and in specific reports such as that dealing with the transfer of technologies. (McMICHAEL; CONFALONIERI; GITHEKO et al., 1999). As well as the evaluation process of this Group II of the IPCC ("Impacts, Adaptation, Vulnerability"), the World Health Organization (WHO) has also sought to update the available evidence on the impacts of climate on human health, which has resulted in the publication of two volumes on the subject, one in 1996 and the other in 2003 (WHO, 1996; McMICHAEL et al., 2003). In 2003 the WHO also published, through its Regional Office for Europe, a volume dealing with the "Evaluation Methods of the Vulnerability of Human Health and the Adaptation of Public Health to Climate Change" (WHO, 2003).

One of the most important aspects in the study of the relationship between climate and human health deals with the analysis of the socio-environmental vulnerability of the population. The application of this vulnerability concept is fundamental for mapping of populations at greater risks of being affected and, consequently, for decision-making related to the methods of adaptation or protection against the harmful effects of climate on health.

Until now, few countries have developed studies of climate change that includes a health component. Among those that have are the USA (PATZ et al., 2000; USGCRP, 2000; 2001), the United Kingdom (UK-DH, 2001), Japan (ANDO et al., 1998), Bolivia (BOLIVIA, 2000), Antigua and Barbuda (O'MARDE & MICHAEL, 2000), New Zealand (WOODWARD et al., 2001), Australia (McMICHAEL, 2002); Portugal (CASEMIRO et al., 2002).; Canada (RIEDEL, 2004); Germany (ZEBISCH et al., 2005); Finland (RASSI & RYTKONEN, 2005); Spain (MORENO, 2005); Japan (KOIKE, 2006) and Holland (BRESSER, 2006).

This project presents an updated version of the one published in 2005 in the "Caderno NAE Mudança do Clima". The need for an update was due to new understandings of the subject developed during the period 2005-2007. The results presented are based on three independent processes that broaden the perspective on climate changes in the world and in Brazil, as well as its importance to public health, these being:

- The Fourth Evaluation Report of the Intergovernmental Panel of Climate Changes (IPCC AR4, 2007);
- The conclusion of the project "Vulnerability Analysis of the Brazilian Population to the Effects of Climate Change on Health" ("Análise da Vulnerabilidade da População Brasileira aos Efeitos da Mudança Climática sobre a Saúde"), undertaken by Fiocruz, and sponsored by the Ministry of Science and Technology (2006);
- The conclusion of the first stage of the CPTEC project on the Modeling of Regional Climate Scenarios for Brazil (2007).

The latter study (MARENGO et al., 2007) relates to the construction of regionalized scenarios of future climate, which are important for studies to evaluate the impact of climate changes in Brazil. The work was undertaken within the scope of different projects coordinated by the Center for Weather Forecasting and Climate Studies (Centro de Previsão do Tempo e Estudos Climáticos - INPE/ Ministry of Science and Technology) and its principal products were high-resolution Regional Climatic Models (50km horizontal resolution), for the period 2071-2100. Temperature and precipitation anomalies – at various levels of reliability - (related to historical averages from 1961-1990) were projected for the various regions in the country according to two basic IPCC scenarios: A2 (high level emissions of greenhouse effect gases) and B2 (low levels of emissions).

Based on averages of different models of general atmospheric circulation (General Circulation Models), all models regionalized for Brazil indicated that warming will tend to intensify in varying degrees in all regions of the country until 2080. The uncertainties were greater when it came to rainfall projections, especially in the Southeast and Mid-west regions. In relation to precipitation, the region which presented the highest level of reliability in future climate projections (2071-2100), was the Northeast, mainly because of the peak of the rainy season (March to May). The scenarios indicated lower precipitation levels during this period and a tendency for the rainfall deficiency to extend practically throughout the whole year in this region. In the same way, an increase in temperature and a decrease in rainfall were projected for the Amazon Region, although at a lower level of reliability.

Chapters III and IV of this text will briefly and separately analyze documents 1 and 2 and, then, bringing together their results, these will be applied to the situation of public health in Brazil.

9.2. Methodological aspects

The possible impacts of climate change on public health – a recent scientific concern – have introduced a new aspect into research in public health disciplines, especially epidemiology, which has as its objective the study of determining factors in and the distribution of health deterioration in human populations. Efforts have been concentrated on developing new methodological approaches for evaluating the impacts of climate on health.

The Fourth IPCC Report (CONFALONIERI & MENNE, 2007) referred to the existence of two principal approaches in the study of the relationship between climate and human health.

a) Empirical Studies
b) Predictive Modeling

The 'empirical studies' can be classified as follows:

1) Spatial studies where climate is an explanatory variable in the distribution of an illness or its vector;
2) Temporal studies that evaluate the effects of climatic variability on health, on a yearly or decade basis, or changes in temperature and precipitation on a short-term basis (daily, weekly).
3) Analyses of the impacts on health of isolated, extreme events;
4) Experimental laboratory and field studies on the biology of vectors and pathogens and their control according to time and climate;
5) Intervention studies that examine the efficacy of the public health measures used to protect the population from climatic hazards.

The main challenge in undertaking empirical studies is the need to analyze, within the temporal studies, extensive series of data, both epidemiological and climatic, that are seldom available in developing countries. In population observation studies, (i.e. non-experimental studies) there is also generally a need to separate out which are the non-climatic variables concerning health, which are frequently mistaken for the effects of climatic factors.

'Predictive modelling' is the quantitative representation of the relationships between the variables of a complex system, which is later evaluated according to the consistency of the empirical data observed. It can be of two basic types (ROGERS & RANDOLPH, 2006):

- ***Biological Models,*** which describe, in the event of infectious diseases, some aspects of the transmission process and how they would be affected by climate change. The only endemic disease sensitive to climate for which this model was developed, is malaria. Malaria, however, is a complex disease difficult to model, and all the models published have limited parameterization of the factors that influence its distribution/transmission.
- ***Statistical Models***, which aim to adapt the current distribution of the disease to the known climatic variables within a statistical structure in which interpolations and extrapolations of the results are made in order to explore the possible future climate impacts. Despite the inadequacies in this approach due to the fact that it does not represent the dynamic of the transmission process, this type of model can be useful when knowledge of the biological cycles is incomplete.

9.3. The fourth report of the IPCC

The Fourth Report of the Intergovernmental Panel on Climate Changes (IPCC AR4) consists of the findings of three Working Groups: WG 1 ("Climatic Science"); WG II ("Adaptation, Impacts and Vulnerability") and WG III ("Mitigation"). In Group II's section, Chapter 8 deals with the theme "Human Health" (CONFALONIERI & MENNE, 2007).

This chapter, written by a team of eight researchers of different nationalities analyzed, compared and synthesized the results of nearly 530 scientific studies and research reports. The text presents, amongst other information, the mechanisms with which global climate change is affecting or could affect the health of the human population. These mechanisms are illustrated in Figure 9-1.

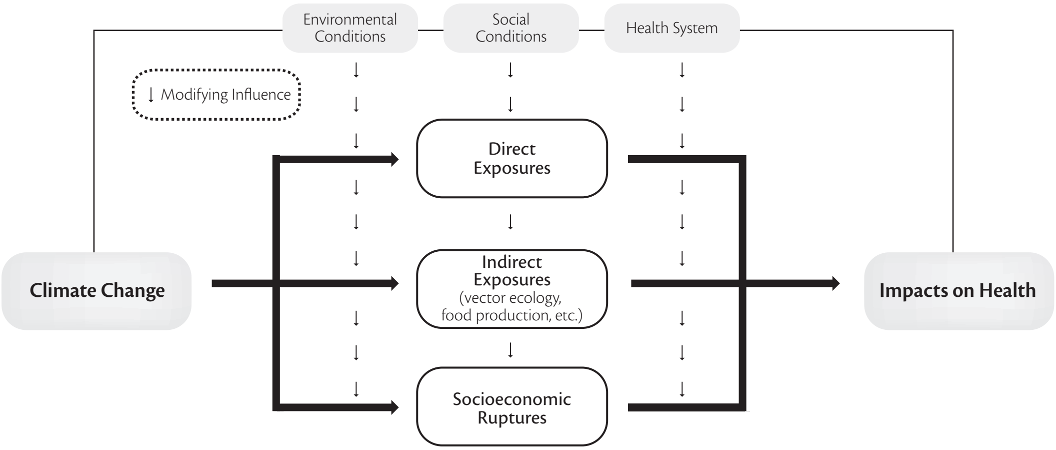

Figure 9-1: Schematic diagram of the mechanisms by which global climate change affects the human population, according to the IPCC

In summary, what the Figure shows is that the three principal mechanisms are:

- Direct influences of the physical factors of climate on the physiology and the integrity of the human body (heatwaves affecting the circulatory system, traumas and drownings in storms and floods, etc.);
- Environmental changes caused by the climate, affecting human health determinants (for example, a drop in agricultural production, affecting the quality of diet; an increase in the population vectors of infectious agents that increase the risk of these diseases, etc.);
- Indirect effects through social upheavals usually caused by climatic disasters (prolonged droughts causing the migration of refugees etc.).

These effects are modulated by both natural factors (environmental characteristics) and social factors, such as the efficiency of the health system and the institutional actions (vertical lines in the diagram).

In its AR4 the IPCC recognized only the following, previously observed effects of the global climate change on human health and its risk factors:

- Increase in morbidity and mortality through heatwaves, particularly during the European summer of 2003 when nearly 32,000 (mainly elderly) people, died;
- Spatial redistribution of encephalitis transmitted by ticks, with the extension of its distribution to higher latitudes, in Scandinavia, and to higher altitudes in the mountains of Central Europe;

- Increase of allergenic pollen concentration in the atmosphere, with the consequent increase in the risk of respiratory allergies due to the earlier spring in the Northern hemisphere.

The record of these effects, observed mainly in the northern hemisphere and especially in Europe, reflects a higher investment in research in this region, and not an unequal distribution of climatic impacts on a global level.

The IPCC – AR4 health commission recognized as future (projected) effects the following impacts:

- Alterations in the spatial distribution and intensity of the transmission of endemic infectious diseases, particularly those transmitted by vectors such as malaria, dengue, leishmaniasis, West Nile fever, etc;
- Increased risk of diarrhea, especially in children, due to reduced access to drinking water, particularly in arid tropical regions;
- Worsening of child nutrition with damage to their development, in areas already affected by inadequate food supplies and suffering prolonged periods of drought (developing countries);
- Increased risk of cardio-respiratory diseases due to the higher concentration of pollutants in the troposphere (especially ozone) influenced by the higher temperature;
- Increase in the risk of negative impacts on population groups considered to be more vulnerable, such as children, the elderly, indigenous populations and traditional communities, poor urban communities, coastal populations and populations that depend directly on the natural resources affected by climate change.

The AR4 chapter on health did not identify specific vulnerabilities of countries or regions. This task was left to the authors of the regional chapters (for example, “Latin America”). However, some of the scenarios produced on a global level for the occurrence of tropical diseases due to climate changes mention, as expected, the situations of different continents and regions. The AR4 essentially analyzed two recent studies, one of them being on the situation with malaria (VAN LIESHOUT et al., 2004) and the other on dengue fever (HALES et al., 2001).

Although these studies aimed to produce reliable and useful information for countries, they failed to take into consideration the peculiarities of the regional dynamics of the tropical diseases studied. Thus it is that the Van Lieshout and co-workers’ study projects “an increase of malaria in areas around the southern limit of occurrence of the disease in South America”, an assertion that was made without the knowledge of the history of the distribution of the disease in Brazil (see discussion in the section “Vulnerabilities and Adaptation”). The authors also affirm a “...decrease in the transmission season (= period) in the Amazon and in Central America...” an incorrect premise, considering that there are no specific periods of malaria transmission in the Amazon (the disease is transmitted all year round, despite seasonal variations). In the same way, the model produced for dengue global scenarios (HALES et al., loc cit.) did not use updated geographical distribution data for Brazil, predicting its expansion to areas where the disease had already occurred.

9.4. Vulnerability study in Brazil

In 2005, Fiocruz completed a study financed by the Ministry of Science and Technology's Program for Global Climate Change (Programa de Mudança Global do Clima), with the aim of constructing a synthetic indicator of vulnerability of the Brazilian population to the impacts of climate on health (CONFALONIERI et al., 2005a; 2007). The study adopted as a conceptual model that presented in a previous article (CONFALONIERI, 2005b). It was a vulnerability study for the period in which it was executed (1996-2001) and not a modeling of scenarios. The construction of a combined vulnerability index was based on three principal components: the socio-economic component; the epidemiological component and the climatic component.

The socio-economic component used indicators produced by the IBGE related to family income, education level, housing quality, urban density, access to health care, sanitation indicators, child mortality and life expectancy at birth.

The second component (epidemiological) was related to seven infectious endemic diseases sensitive to climatic variation: malaria, dengue fever, tegumentary and visceral leishmaniasis, cholera, leptospirosis, and Hantavirus pulmonary syndrome. Data from 1996-2001 related to the incidence, lethalness, hospital care costs and technologies for the control of these diseases were used.

For the climatic component, a series of historic rainfall data over a 42 year period was used. Extreme events, of either significant or little rainfall for each state of the Federation, were checked.

These indicators were grouped for each component, obtaining a synthetic index, varying between 0 and 1. Thus the synthetic index of a dimension is the simple arithmetical average of its standardized indicators. At a later stage, a weighting per component was attributed to each synthetic index for the calculation of the general vulnerability index.

In Table 9-1 following, the final values of the Index of General Vulnerability (Índice de Vulnerabilidade Geral - IVG) are stated separately for each Brazilian state. The closer the final value obtained is to 1, the higher the level of vulnerability.

Table 9-1 – Classification of the States according to the IVG.

		VALUE	STATE
I	Higher vulnerability ↓	0,1< IVG < = 0,2	RS, MS, DF, PR, RO, SC, AM, GO, AC
II		0,2< IVG < = 0,3	MG, SP, AP, RJ, MT, ES, RR, PA, TO
III		0,3< IVG < = 0,4	RN, PB, SE
IV		0,4< IVG < = 0,5	PI, CE, PE, BA, MA
V		0,5< IVG < = 0,7	AL

In Figures 9-2 and 9-3 following, the IVGs are represented graphically on the map of Brazil, the final values for each State (Figure 9-3), and the different levels of the three components of the IVG for each state, (Figure 9-2).

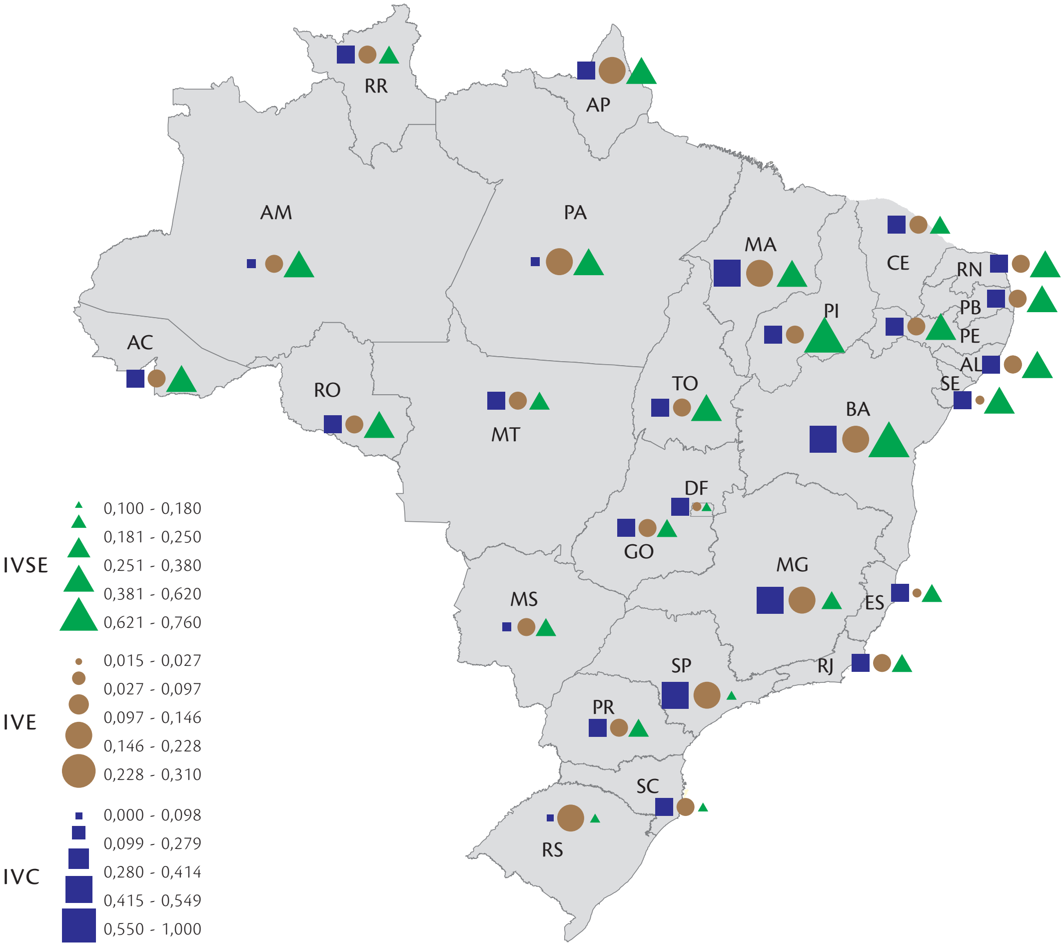

Figure 9-2: Map of the IVSE, IVE and IVC in the Brazilian states (IVSE – Index of Socio-economic Vulnerability; IVE – Index of Epidemiological Vulnerability; IVC – Index of Climatic Vulnerability).

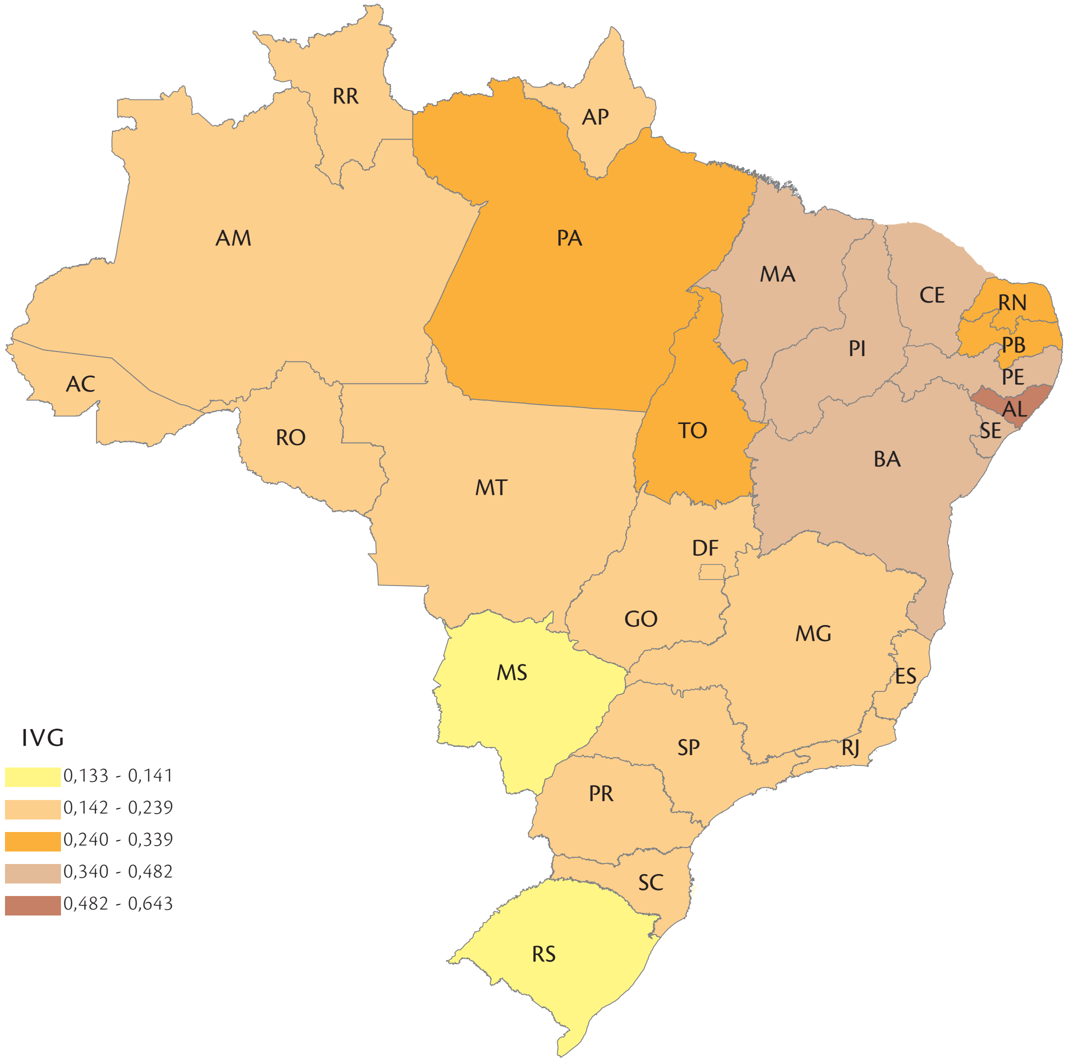

Figure 9-3: Index of General Vulnerability (IVG)

The general conclusions of this study, according to Confalonieri et al. (2005; 2007), were:

- The methodology utilized proved adequate for an initial characterization of Brazilian vulnerability to the potential effects of climate changes on health;
- The indexes were constructed to 'classify' the federal states, in other words, with the objective of measuring the level of relative vulnerability between the states;
- The Northeast region proved to be the most vulnerable, according to the data of the period of the study;
- The geographical unit chosen was the state, but the methodology can be applied to municipalities or regions;
- This methodology can be broadened to encompass other important elements such as nutrition, the rainfall cycle, the availability of water and levels of atmospheric pollution in large urban areas.

9.4.1. The case of the Northeast region

In terms of the perspectives of the impact of climate changes on the health of the Brazilian population, the Northeast Region deserves special attention. This is due to the following factors:

- The regionalized scenarios indicate, within the coming decades, increased temperature and decreased rainfall in the region (MARENGO et al., 2007);
- The Climate Change Index (CCI) also indicates, for both the Northeast and the Northern regions, the highest level of climate change (BAETTIG et al., 2007);
- The vulnerability study prepared by Fiocruz indicated the Northeastern states as those most vulnerable to the impacts of climate on health (CONFALONIERI et al., 2005; 2007);
- The predominance, in the region, of a semi-arid climate subject to periodic droughts and a population with low socio-economic indicators, making this the drylands area with the highest human population density in the world.

This group of characteristics indicates the Northeast Region as a priority in Brazil for actions aimed at a careful evaluation of the sectoral vulnerabilities of the impacts of climate, also on the health sector.

The following diagram (Figure 9-4) shows a probable chain of events for the Northeast Region under a highly unfavourable climate scenario with a reduction in seasonal rainfall and increasing temperature.

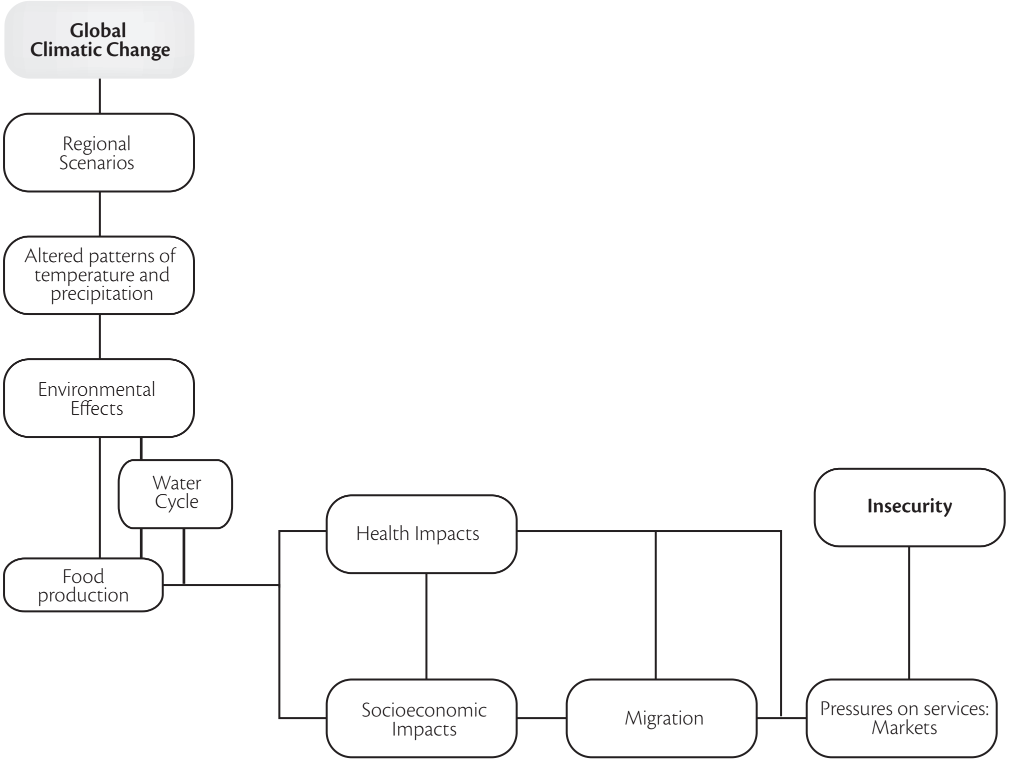

Figure 9-4: Chain of events due to droughts for the Northeast Region

There are some 20 million inhabitants in the Brazilian semi-arid region (Ministry of National Integration, 2005) where subsistence farming is still an important economic activity. In the absence of seasonal rainfall – as occurs during periods of drought – this population has historically migrated from rural to urban areas in search of governmental assistance. Thus, demographic shift can be one of the main elements that work with extreme climatic phenomena (in this case, drought) to have an affect on the economy and health. The displacement – intra or inter-regional – of 'environment refugees' causes significant changes in the regional economy and increases public insecurity in the regions to which the immigrants flock, due to the increase in the demand on public services in general, including those of the Health System (SUS).

Specifically from a public health point of view, the possible impacts of this complex climatic-economic-demographic process are represented in Figure 9-5.

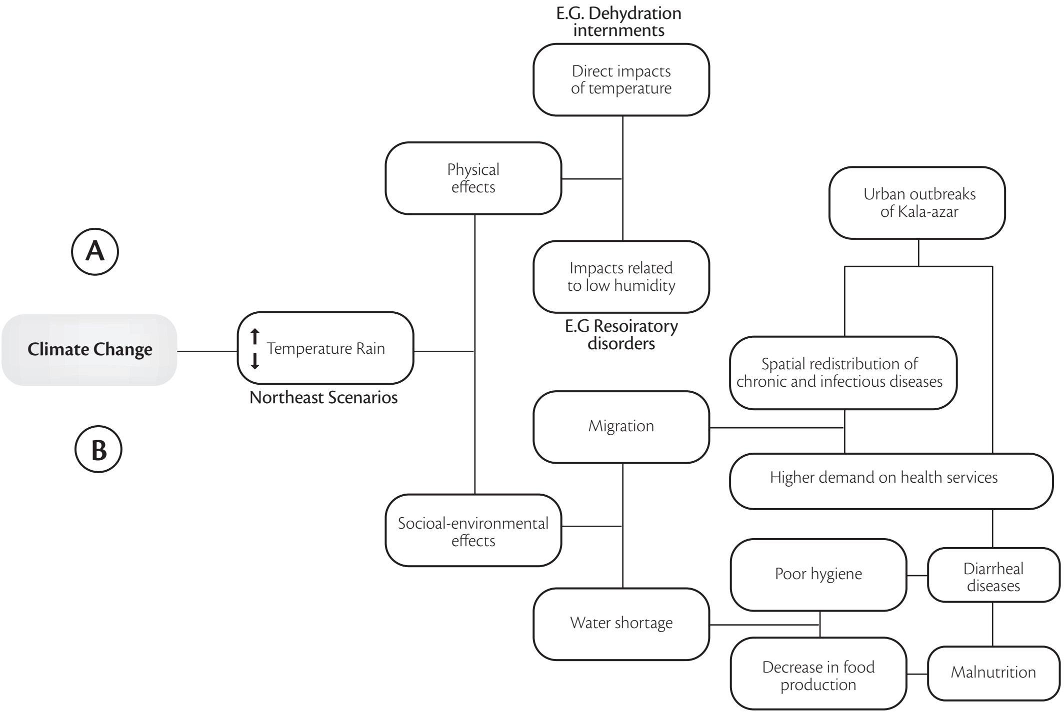

Figure 9-5: Impacts of this complex climatic-economic-demographic process

Applying knowledge of the direct and indirect climatic effects on health to the projected circumstances for the region, we have a situation of higher complexity associated with the way socio-environmental mechanisms act on health ("B"). The relatively restricted direct effects of climate are in "A". The critical factor is the rainfall shortage, which can influence the epidemiological situation of diseases linked to poor hygiene (for example, infectious infant diarrhea), as well as worsen the state of inadequate diet that can lead to malnutrition. One important effect of the uncertainty of the food supply is the triggering of migratory flows – typically in the rural-urban direction – that can redistribute both chronic and infectious diseases. The following graphs (Figures 9-6 and 9-7) show records of the epidemic increases of visceral leishmaniasis (*cala-azar)* in capitals of the Northeast in the early 80s and 90s, when prolonged droughts affected the region. The migratory flows of infected persons coming from endemic rural areas resulted in the occurrence of peri-urban cycles of transmission of the disease (CONFALONIERI, 2003).

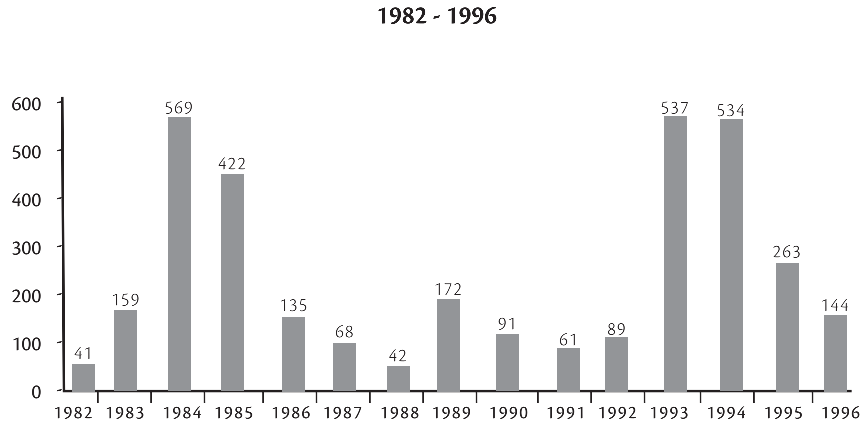

Figure 9-6: Number of cases of visceral Leishmaniasis in the State of Maranhão

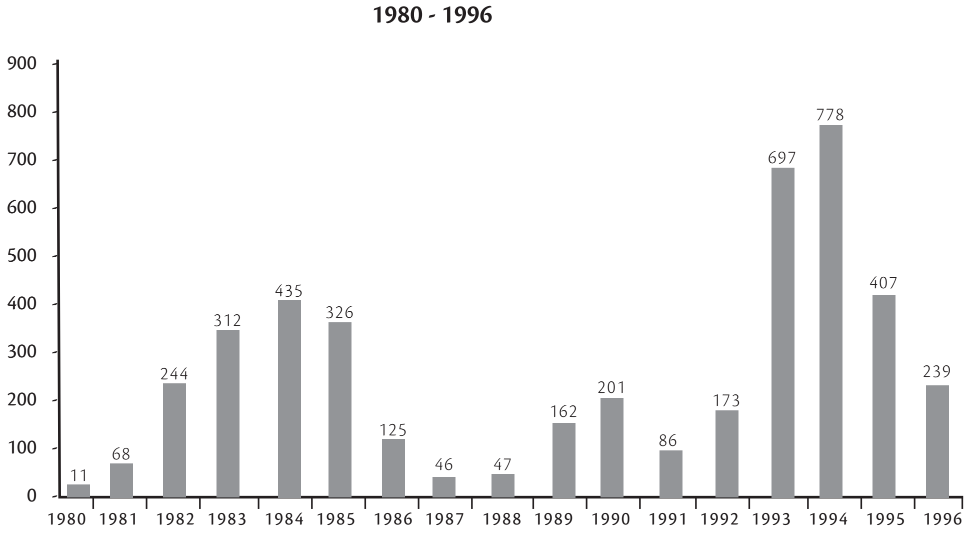

Figure 9-7: Number of cases of visceral Leishmaniasis in the State of Piaui.

9.5. Vulnerabilities and adaptation

The current Brazilian situation with regard to the threat of climate changes on public health is characterized by the following aspects:

- Better knowledge of future climatic scenarios for the country with the identification of the areas which are more likely to suffer more serious changes, such as extreme anomalies of temperature and precipitation;
- Persistence of the structural situation of vulnerability in which different determinants of an unfavorable profile of health-sickness operate (e.g. the spread of dengue);
- Little involvement, on the part of Federal Government, of those sectors of the health system responsible for programs to control health deterioration in discussions on a national plan for adapting to the impacts of climate change.

The year 2007 was characterized by the widespread publicity concerning the IPCC's Fourth Evaluation Report, which had great national and international repercussions. In Brazil, the public agencies of the Federal, state and municipal administrations took initiatives in discussing the implementation of the strategies for adapting to the global climate changes in their respective sectors. On the Federal level, two important initiatives stand out:

- Setting up a research network on the subject of "Global Environmental Changes", with emphasis on the climate issue. The Ministry of Science and Technology is responsible for the coordination of the network while Fiocruz has become the institutional reference point on health issues;
- Discussions, primarily in the Ministry of the Environment, for establishing an inter-ministerial National Adaptation Plan to Climate changes.

The first initiative aims to organize and integrate research efforts in this area in Brazil in order to best apply the supporting resources. The research products of the institutions of the network should initially provide for the elaboration of a plan of activities and governmental initiatives for implementation.

On a municipal level, some governments have recently promoted activities and events on the local perspectives of the impact of climate change and included the subject of health. This was the case of the urban planning agency of the municipality of Rio de Janeiro (Instituto de Urbanismo Pereira Passos <www.rio.rj.gov/ipp>) which sought support from the academic sector for the seminar "Rio: próximos 100 anos" (Rio: the next 100 years), which took place in October 2007. These initiatives demonstrated the concern of the government in discussing strategies for facing the risks and transformations brought about by climate change on a large scale.

With regard specifically to the health sector, there has not been sufficient involvement of the government in the discussion of a national plan on adaptation to climate changes. Two main reasons that may be contributing to this are:

- The enormous load the administration and financing of the Health System (SUS) represents on the Ministry of Health as well as on State and Municipal Health Secretariats.
- The lack of knowledge and expertise on the subject matter on the part of the specialist staff of those bodies.

Concerning this, much misinformation appears in the media, for example, considering global climate change as being "responsible for spreading new diseases." This aspect will be discussed in more detail below.

Some of the Brazil's neighboring countries are already mobilizing their inter-sectoral and health resources to implement plans to adapt to climate change. Colombia and Bolivia are two examples. Colombia is developing a protection plan for climate changes which involves three main aspects: water availability, the protection of a number of threatened ecosystems and the implementation of early-warning systems for outbreaks of dengue and malaria (G. POVEDA, 2007, personal communication). In Bolivia, estimates have been made of the impact of climate changes on infectious endemic diseases and inter-sectoral studies were undertaken on the strategies to be adopted on a local level with the participation of the community (BOLÍVIA, 2000; PARDO et al., 2007).

In Brazil, with the existing knowledge of the health processes and profiles of disease and their geographical distribution, together with the recently produced scenarios for the climate for the next few decades, one can highlight the following points in the discussion on adaptation strategies:

a) The main concern must be the extant group of threats (accidents from storms, landslides and floods, especially in densely populated urban areas; infectious endemic diseases, like malaria, dengue and leptospirosis, etc.) to the population, capable of being affected by the changes in climatic parameters. Known situations of risk may be aggravated by different mechanisms;

b) Special attention must be given to infectious endemic diseases, especially malaria (in the Amazon region), dengue, leishmaniasis, leptospirosis and infectious infant diarrhea.

   The modified climate may alter the dynamics of the transmission of these processes as well as their geographic distribution. For an intensification and/or extension of the distribution to occur, from a strictly climatic point of view, the combination of optimum conditions, both of temperature and of humidity, is necessary. The occurrence of only one of these parameters, on its own, is not sufficient.

In the specific case of malaria there is the mistaken perception that, due to global warming, the disease may become endemic in areas outside the Amazon. This should not be expected since the disease existed in most of the country – including in the Southern Region – until some 60 years ago. Its eradication outside the Amazon occurred because of a combination of vigilance and control efforts (early treatment of those infected; combat of the vector mosquitoes) and due to a change in land-use (deforestation, urbanization, etc.), that eliminated the greatest part of the breeding areas. In other words, there is presently no climatic limitation for the occurrence of malaria in the greater part of the country (except for the winter periods in the South and parts of the Southeast).

In terms of the situation of malaria in the Amazon Region, the future scenarios for the disease, considering only environmental factors, will depend on what will happen, due to the influence of the climate, both with the forest and especially with its hydrological cycle.

Dengue fever, the other endemic disease widely-spread in Brazil and sensitive to climate, is subject to seasonal influence. The result of this is its greater incidence today during summer periods. This is due to the persistence of favorable temperatures and humidity, as well as the greater exposure of the population during this period of the year. The direction in which the possible modifications in the epidemiology of dengue in Brazil will occur will depend on what will happen, on a national or sub-regional level, with climate change. The scenarios predicted for the Northeast Region, for example, would not be favorable to the dengue cycle from an environmental point of view because the increase in temperature would be followed by a reduction in humidity, which does not favor its development.

c) An issue equally relevant to the planning and implementation of the adaptation strategies to the impacts of the climate refers to the aspects of vulnerability of the urban populations, especially the underprivileged ones. These are vulnerable to three major risks:

- Landslides on inhabited hillsides during periods of heavy rainfall;
- Risk of epidemics of leptospirosis in areas subject to flooding and not properly served by garbage collection during floods;
- Exposure to atmospheric pollutants, like ozone, concentrations of which can increase because of higher temperatures.

The historic effects of heavy rainfall, whether or not followed by floods, on the morbidity and mortality of the human population, are known for various Brazilian cities. In the city of Rio de Janeiro, for example, a study carried out an the period of 1966-1996 was able to identify at least 527 fatalities from accidents caused by rain and floods.

In the same way, significant outbreaks of leptospirosis have occurred in this city. During the period 1975-2006, 4,643 cases were reported, with a large epidemic in Jacarepagua in 1996 when 1,797 cases were confirmed (CONFALONIERI & MARINHO, 2007). This was one of the largest epidemics of this disease ever recorded in the world. Similar problems are found in other large cities in Brazil resulting from precarious sanitation infrastructure and improper urban land-use.

d) From the point of view of regional vulnerabilities, one that must be emphasized, as mentioned previously, is the situation of the Northeastern Region of the country. Historically affected by periodical droughts, with serious economic consequences, this region is under risk of worsening aridity should the scenarios for an increase in temperature and a reduction in seasonal rains be confirmed. An estimate of the possible outcomes of a demographic, social, economic and sanitary nature is necessary due to the probable inviability of subsistence farming. This should be especially evaluated for the areas of the Northeastern scrublands (the *sertão*), which will be more severely affected according to the climate change models. From a public health perspective, apart from a worsening of the food situation, the spatial redistribution of endemic diseases present in the region may come to be of great importance. Amongst these, the main ones are dengue, *calaazar* (visceral leishmaniasis), schistosomiasis and Chagas disease, with only the latter being under control. The sanitation problems due to the scarcity and bad quality of water for domestic consumption, which are very well known by the sanitary authorities, must also be considered. In years of severe drought associated with *El Niño*, a significant increase in infant mortality rates from diarrhea-related diseases was reported. Although many of the adaptation strategies outside the health sector (farming, water resources, etc.) are extremely important for public health, specific sectoral actions for the reduction of the vulnerability of the population to extreme climate must also be considered. For this region, two strategies have a more immediate relevance:

- Improvement in the efficacy of control programs for the aforementioned endemic diseases;
- Increase in capacity to attend to the spontaneous demand on the public health network (SUS) for all illnesses due to rural-urban migratory flows.

e) Still on the subject of regional vulnerability, and according to the climatic scenarios, two particular situations must be considered:

- The reduction in rainfall and an increase in the average temperature in the Amazon Region;
- The increase in the frequency of extreme events of rainfall in the South and Southeast regions.

In the Amazon, the possible impacts of reduced rainfall and increased temperature are related to four main aspects:

- Deterioration in the situation of access to drinking water;
- Reduction in the abundance of the basis of extractive subsistence (for example, fishing);
- Increase in the inhalation of smoke particles coming from forest fires;
- Alteration in the cycles of contagious endemic diseases (malaria, leishmaniasis, etc).

The drought that occurred in 2005 in the central Brazilian Amazon can serve as an example to illustrate the scale of the expected impacts on the environment and on health. Small riverside communities were isolated without sufficient water or the possibility of fishing due to the drying up of the access streams (CONFALONIERI & MENNE, 2007; WORLD BANK, 2005). This can become a common event in the 'drying' Amazon scenario in the coming decades.

In the South and Southeast regions where the models indicated the possibility of a greater incidence of extreme rainfall events, a more dangerous situation would come about from exposure to storms and floods. Events of heavy rainfall and flooding with fatalities have historically been registered in these regions on numerous occasions. One of the events of highest impact was the storms and floods associated with the *El Niño* phenomenon from 1982-1983 which caused more than a hundred deaths from accidents in the states of Santa Catarina and Paraná. Factors that contributed to a greater vulnerability of the populations to these events in these regions were:

- High population density;
- High elevation of urban zones;
- Occupation of risk zones by residential buildings;
- Lack of an efficient early-warning system.

Another situation of risk globally associated with climate change is the increase in sea level, estimated to reach 80cm by the end of the 21st century. The resulting coastal impacts will stem principally from the salinization of the soil with the loss of farming areas and the deterioration of reservoirs of drinking water. There could also be damage to the infrastructure of sanitation, electricity, etc., caused by erosion. Possible effects on health would be indirect, due to the aforementioned processes. The increase in sea level, when compared to the other risks related to extreme climatic phenomena, becomes less significant to health. The reasons for this are, besides the indirect effects, the slow development of the process, which will allow for the implementation of adaptation strategies. Studies also report a low physical vulnerability of the greater part of the Brazilian coast to this phenomenon. (MAGRIN; GARCIA et al., 2007).

9.6. Conclusions and recommendations

1) The structural factors that determine the country's and the population's vulnerability to the effects of global climate changes on health persist, and will only be reduced with medium- and long-term public policies. These should focus on the following aspects:
    - Education and access to information;
    - Creation of jobs and income;
    - Improvements in housing conditions;
    - The health system and the control of endemic diseases;
    - Proper urban land-use;
    - Security of food supply;
    - Adequate basic sanitation.
2) An update and expansion of the previous vulnerability study (CONFALONIERI et al, 2005; 2007) through the incorporation of data and information from other directly relevant sectors, such as factors determining the health of the population, is necessary. It is crucial to understand how priorities like climate change will affect food security and the availability of water for human consumption.
3) The expansion of regional climatic modeling studies is equally important for the construction of climatic scenarios that are not so far away in time. A better integration of climatic scenarios is more plausible with demographic, socioeconomic, and environmental projections for the period 2020-2050 than with the scenarios that exist for the period up to the end of the 21st century.
4) Evaluations for natural ecosystems must be considered as part of the new studies for the scenarios for the coming decades. In addition to their importance for conserving biological diversity, these ecosystems house a large number of vector species and reserves of infectious agents, as well as human parasite carriers. Many of the tropical endemic diseases in Brazil of this 'focal' kind, which can become radically altered in future climatic situations.
5) Different studies agree that the North and Northeast Regions are the ones that will suffer the greatest impacts, in the environmental, socio-economical and health areas, with the change in the climatic system. Although it is desirable to have a nationwide adaptation plan to the climate changes, this plan must contain clearly defined strategies to attend to the needs of these two regions.

6) Considering the current collection of evidence, we can state that the following general adaptation measures would be adequate for the health sector:
    - Improvement of the control programs of infectious, highly endemic, widespread diseases that are climate sensitive, particularly malaria and dengue;
    - A reduction of the general conditioning factors of the social vulnerability of the population at risk of suffering health threats (particularly infectious diseases and accidents), by means of economic, educational and housing policies;
    - Development of early-warning systems, combining predictions of extreme climatic events with maps of vulnerability and contingency plans that involve specific health assistance.
7) Greater participation must be sought from the Ministry of Health in the efforts to draw up, on a Federal level, a National Plan of Adaptation to the Climate changes.
8) The health sector should not expect the appearance of 'new diseases', but rather the worsening of known situations and threats. Specific adaptation actions for the health sector should concentrate on reducing the incidence of endemic infectious diseases, as well as reducting the exposure of urban populations to climatic risks. This can be done with the development of early-warning systems for extreme events.
9) This is a very favorable moment for the development of support studies for adaptation processes to climate change. This is due to the recent awareness and mobilization of sectors of society, both in Brazil and around the globe (government, firms, the press and the academic world) regarding the issue. The Fourth Report of the IPCC and its conclusions, the social importance of which were validated by the Nobel Peace Prize it received in 2007, is a fundamental contributor to this moment.

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10. Information for a national science technology and innovation agenda on vulnerability, impacts and adaptation (VIA) related to climate change

Jörgen Leeuwestein

Antonio Rocha Magalhães

10.1. Vulnerabilities, potential impacts and possible methods of adaptation

10.1.1. Introduction

All regions of Brazil are affected by actual climate variations and will be even more so in the future with the impacts of climate change as envisaged by the IPCC and other research centers. In Brazil, temperatures could be much higher and different types of extreme events could occur more intensely and frequently, such as drought, floods, temperature peaks and hurricanes. The rise in the level of the Atlantic Ocean will affect coastal areas, especially low-lying cities and those on rivers banks such as the Sao Francisco, Parnaiba and Amazon. All these phenomena could cause significant impacts on society, the economy and ecosystems.

These impacts will be much more serious according to the level of vulnerability of particular regions, the people who live in them and the activities they carry out there. The more serious the impacts, the greater the need for adaptation measures. These are issues that will be present for a long time on the agendas of public policy and society. It is evident that mitigation and adaptation measures should be implemented to contain global warming and to reduce the effects of the inevitable changes, to the benefit of current and future generations.

For these reasons it is necessary to encourage the increase of our knowledge about the whole cycle of climate change and its consequences: climate scenarios and extreme events, vulnerability and social, economic and environmental impacts and strategies of adaptation of society to these changes.

The following pages will outline scenarios for the different topics analyzed here – forestry, agriculture, the semi-arid region, biodiversity, coastal zones, urban areas, energy and water resources, and health – as well as suggest actions and specific strategies towards its adaptation to climate change.

10.1.2. Forests

The IPCC's climatic models indicate that the South American regions most vulnerable to climate change, both in their socio-economic component and in terms of biodiversity, would be Amazonia and the Northeast of Brazil. The IPCC predicts, with a high level of confidence, that by the middle of this century, the temperature increase and associated decrease in ground water will lead to a gradual replacement of tropical forest by savannah in part of Amazonia (CGEE, 2008). It is very likely (probability more than 90%) that natural occurrences, such as fires, insects and diseases, may be altered by the change in climate, both in their frequency as in intensity, affecting the forests and forestry sector. However, it is difficult to estimate the exact impact of climate change on these disturbances.

Understanding the potential impacts of climate change on forest ecosystems is of particular importance for Brazil, which contains about 30% of the world's tropical forests (FAO, 2005) and which has more than half of its territory covered by native forest in its six biomes, particularly in Amazonia and the Cerrado (a vast tropical savanna ecoregion of Brazil).

The primary forest of Legal Amazonia covers an area of approximately 3.5 million km^2 (including the "Cerradao", which is a Cerrado biome forest formation that, from a physiognomic point of view, is a forest). The Cerrado (Cerrado Parkland, Cerrado in its strict sense, Campo Cerrado, amongst others) covers about 2 million km^2, distributed over Central Brazil (CGEE, 2008). The other Brazilian biomes have less significant forest cover. The Atlantic Rainforest, for example, today holds less than 7% of its original vegetation.

According to Scholze et al. (2006) there is a risk of losing more than 40% of the forest in some parts of the Amazon, in the scenarios that give a change in temperature greater than 3°C. On the other hand, if there were to be an increasing trend in precipitation, this would act to counterbalance the reduction in rainfall due to deforestation and the end result would be more favorable to the maintenance of ecosystems and species. Studies by the Amazon Research Institute – IPAM show that in the context of global warming and more frequent droughts, the Amazon Region forest loses much humidity, making it more vulnerable to fires and there could be a significant increase in tree mortality, with the consequent increase of carbon emissions into the atmosphere. Fragmented forests are more vulnerable to periodic drought damage caused by El Niño than those that are intact. Amongst the damage being registered there is a high rate of tree deaths, changes in plant phenology and other ecological changes, especially on the forest fringe. For example, drought caused by El Niño in the north of the country, during 1997 - 1998, was responsible for the large-scale forest fires in the State of Roraima which affected a significant portion of its primary forest.

However, some types of forests can benefit from climate change, particularly those that are currently affected by limitations to their minimum temperature requirements and rainfall, or with net gains in their productivity, as a result of CO_2 fertilization (although the scale of this effect will remain still uncertain).

To the climate changes arising out of global warming we must add those caused by changes in plant cover. There are projections that the deforestation of the Amazon rainforest will lead to a warmer and drier climate in the region (Nobre et al., 1991, Sampaio et al., 2007, Costa et al., 2007). Studies also indicate that the loss of the Amazon forest can alter the levels of precipitation in vast areas of the South American region (Marengo, 2006). Evapotranspiration in the Amazon feeds the rains that pass over the Andes and arrive in the Central South, South East and South of Brazil. Reduction of the forest would thus reduce regional precipitation.

When the gases released into the atmosphere, as a result of deforestation fires are taken into account, Brazil is the planet's fourth largest emitter (Marengo, 2006). However, forestry policies have a significant potential to mitigate climate change, including reforestation and forestation, forest management activities, reducing rates of deforestation and the use of forest products and waste in the production of bio-energy to replace fossil fuels, amongst others.

The adaptation of species to climate change can occur through evolution or migration to more appropriate locations, the latter being probably the most common response in the past (CGEE, 2008). The practices for land use and management likely to maintain the biodiversity and ecological functions of the forest during climate change include, amongst others, the protection of primary forests, containment of fragmentation and the representation of forest types throughout environmental gradients in reserves, the practice of low-intensity forest exploitation, maintaining a diverse genetic bank and the identification and protection of functional groups and relevant species.

10.1.3. Agriculture

Agriculture is largely dependent upon climatic factors, which changes can affect crop productivity and management with social, economic and political consequences. The IPCC predicts a high probability of the occurrence of degradation of natural resources such as soil and water due to temperature and rainfall changes, which will have negative consequences for agriculture (2007a). It also projects a decrease in the productivity of many crops, even when the direct effects of doubling of CO_2 concentrations are taken into account, as well as those of implementing moderate adaptation measures at farm level. Climate change may also lead to losses of organic matter in the soil, disrupting the balance of the entrance and exit of nutrients in such a way as to influence the productivity of agricultural systems.

There are estimates that livestock production in Latin America, predominantly characterized by a grazing system, will be adversely affected by greater variability in rainfall. Another factor is that heat stress can affect milk production, the breeding of milk cows and the fertility of pigs, as well as the breeding of chickens.

In Brazil, some events in Rio Grande do Sul in recent years provide an example of impacts related to prolonged floods and droughts. These events were respectively related to the phenomena of El Niño (warming of the Pacific Ocean) and La Niña (cooling of the Pacific Ocean) and resulted in harvest loss (Berlato and Cordeiro, 2005). The rural poor are more drastically affected by the loss of crops, and in more extreme situations are affected by hunger, as was seen during the droughts in the Northeast of the country.

The National Plan on Climate Change states that, according to the study, "Global Warming and the New Geography of Agricultural Production in Brazil", climate changes may affect the geography of national production (CIM, 2008). Scenarios of climatic risk zoning indicate a reduction in areas favorable for the cultivation of important national crops and that some crops could be adversely affected in certain areas and under specific climatic conditions (CGEE, 2008). It should be noted that there is lack of validation of the results using field experiments. Moreover there is uncertainty concerning the 'fertilization' effect of CO_2, which may result in greater crop production.

Another possible impact is the increase of pest and disease outbreaks due to gradual changes of climate (through changes in invertebrate carriers or increasing temperature and water stress in plants) and a greater frequency of unusual climate patterns (dry periods tend to favor insect vectors and viruses, whilst humid spells favor fungal and bacteria pathogens) (Anderson et al., 2004).

Embrapa's (the Brazilian Agricultural Research Corporation) National Program for Research and Development in Agriculture (Embrapa, 2008b) foresees that the impacts generated by climate change will mean new social behavior and there will be greater pressure for the conservation and rational management of environmental resources in the production process, and with more stringent environmental regulations.

The analysis of the vulnerability of production systems is therefore of fundamental importance so that adaptation strategies can be adopted. One of the adaptation measures is the use of agro-climatological zoning as a tool to identify the best areas for each type of crop, thus allowing higher yields, as has happened with rice-growing in the highlands in the State of Mato Grosso (CGEE 2008). Plant improvement is the key to the adaptation of crops in conditions of stress. The management of production systems – such as tree planting to help in the production of grain and pasture, direct planting and the encouragement of mixed production systems – may contribute more immediately to alleviate the problem.

10.1.4. Biodiversity

The IPCC report on the region of South America and the Caribbean indicates a decline in the diversity of species of plants and animals, with changes in the composition of ecosystems and distribution of biomes. The future distribution of biomes in South America could be affected by the combination of the impacts of climate change and the change in land use, and may cause the system to turn to savannah in parts of Amazonia and become desert in parts of the Semi-arid region of Brazil (MMA, 2007).

Natural systems may be especially vulnerable to climate change because of their limited adaptation capacity, and some of these systems may suffer significant and irreversible damage (CGEE, 2008). Climate change could result in significant rearrangements of biomes, with serious consequences for the maintenance of the mega-biodiversity of Brazilian biomes, with the most likely outcome being a noticeable biological impoverishment.

Populations of endangered species face a greater risk of extinction as a result of the synergy of adverse pressures, including changes of land use and fragmentation of habitats. The Amazon forest contains a large part of the world's biodiversity and, therefore, threats to the existence of the forest indicate serious threats to its biodiversity. The coastal mangroves areas, in low-lying coastal areas, will be very vulnerable to rises in sea levels, temperature increases and more frequent and intense hurricanes.

The projections for the impact of climate change on Brazilian biodiversity are based on a few case studies which use a small amount of data associated with selected biomes. There is, for example, a case study on the impact of climate change on tree species of the Brazilian Cerrado, which indicates a significant loss of biodiversity due to the increase in the average temperature by 2 °C over a period of 50 years (Siqueira and Peterson, 2003).

The study "Climate Change and Possible Changes in the Biomes of Atlantic Forest Biomes" points out that climate change may cause, in parts of the State of Rio de Janeiro, an extension of seasonal forest area into rainforest area (the northern region and lakeside areas). Another study of Atlantic Forest tree species (Colombo, 2007) shows a reduction in the area for all 38 species analyzed of, on average, 25% (the most optimistic scenario) and 50% (more pessimistic scenario) with a dislocation of these species to the south.

Hulne and Sheard (1999) argue that any significant increase of flow in the Pantanal as a result of climate change or deforestation will negatively affect the ability to retain and control this enormous flooded area, affecting the habitat of a large variety of wild life.

Some results from ProBio (Salati, 2006) indicate that the Semi-arid region will become more arrid in high-emission scenarios. This would have negative consequences in the Caatinga, which is one of the most threatened biomes in Brazil.

Without adaptation, some species defined as 'critically endangered' will be extinct in the coming decades, and species classified as 'threatened or vulnerable' will become rarer during this century (CGEE, 2008). Possible methods of adaptation to the loss of species include the establishment of refuges, parks and reserves with ecological corridors to allow species to migrate, with associated measures to encourage breeding in captivity, the establishment of embryo and germplasm banks, and measures to remove species. However, all these options are limited by the cost factor.

10.1.5. The Semi-arid region

The Northeast of Brazil occupies 1,600,000 km^2 and the Drought Polygon which accounts for 62% of it, is a semi-arid region of 940,000 km^2 covering nine states in the Northeast and faces a chronic problem from lack of water and a rainfall level of less than 800mm per year (CGEE, 2008). More than 20 million people, over 10% of the national population, live in the Semi-arid region, which spreads across 86% of the Northeastern territory, the most densely populated dry region in the world. The Semi-arid region is a heterogeneous area composed by many different semi-arid systems, including also remains of the Atlantic Forest ecosystem. These regions are threatened by anthropic pressure with increasing environmental degradation.

The rains of the Semi-arid region of the Northeast show great spatial and temporal variability. Years of drought and abundant rains alternate erratically, and the greatest droughts were 1710-11, 1723-27, 1736-37, 1744-45, 1777-78, 1808-09, 1824-25, 1835-37, 1844-45, 1877-79, 1982-83, 1997-98, and intense rain in 1924, 1974, 2004 and 2009.

The Climate Report of the National Institute for Space Research – INPE (Marengo et al., 2007a and b; Ambrizzi et al., 2007) have shown scenarios of drought and extreme rainfall in large areas of Brazil. According to this report, based on the institution's regional model, using the pessimistic scenario, suggests a temperature increase of between 2° and 4 °C and a rainfall reduction of between 15 and 20% (2-4mm) in the Northeast by the end of the 21st century. In an optimistic scenario, the warming would be between 1-3°C and rainfall would be between 10-15% (1-2mm/day) lower. The deforestation of the Amazon could generate adverse effects on the Semi-arid region, making it drier.

The combination of climate change, in the form of a lack of rain or little rain accompanied by high temperatures and high rates of evaporation, along with competition for water resources, may lead to a serious crisis. The poorest people and subsistence farmers will be the most affected (CGEE, 2008).

With the possible consequence of a more arid Semi-arid region and with an increased frequency of drought and intense or excessive rainfall, the impacts could have a very negative effect on the economy and society. The support base for human activities – such as agriculture, mining, industry, hydroelectric energy and tourism – would diminish, probably bringing increases in the movement of the population to the cities or to areas where it would be possible to develop irrigated agriculture. With regard to the impacts on biodiversity, parts of the Caatinga would give way to vegetation that is more typical of arid areas, affecting the conditions for survival of some species.

The Semi-arid region is considered to be the most vulnerable to possible climate change, since the amount of water per capita available in much of the area is already inadequate and over 50% of the population live in poverty. The region has low social and health indicators (HDI). In fact, of the ten lowest HDI rates in the country, eight are in the states of the Northeast (GCEE, 2008). When a semi-arid climate is added to these conditions, the vulnerability of the population increases. The region also has the highest rates of infant mortality and the lowest life expectancy in Brazil. This situation may worsen with the increase in temperature. Increased rainfall can impact negatively on health. For example, up to the end of May 2009, intense rain affected 664,000 people in six states in the Northeast and North of Brazil.

The agricultural sector in the Northeast was responsible for about 30% of the GDP in the sixties. This figure is about 7% nowadays. However, 30% of the population of this region still depend on agricultural activities, which means that a large part of the labor force is of very low productivity. This explains the rural poverty in the Northeast.

Coordinated action is needed to address the change of climate in the Semi-arid region. Some initiatives implemented include the Brazilian Early Warning System for Drought and Desertification and the National Program to Combat Desertification and Mitigate the Effects of Drought (PAN-Brazil). In November 2008, during the 2nd Seminar on Climate Change and the Northeast, the "National Commission to Combat Desertification and for Mitigating the Effects of Droughts" was set up. The "Fortaleza Charter" was adopted at the event, with recommendations for mitigation and adaptation activities in the context of regional development plans.

The Northeast Semi-arid region has a long history of adaptation policies to climate variability, specially related to droughts. From this rich experience many lessons could be learned. This includes the creation of institutions, the construction of hydro and transportation infrastructures, the relief actions taken during droughts, agricultural research and extension, and the reduction of economic activities depending on rainfall, like rainfed agriculture. Examples of adaptation are the creation of emergency jobs in dry periods (in 1983, 3 million jobs were created in "working fronts"), the accumulation of water in reservoirs and cisterns, public and private irrigation, water resources management, the revitalization of river basins, including micro-basins and the development of activities less dependent on climate resources.

In order to meet the challenges in the Semi-arid region it is necessary to carry out studies of vulnerability to climatic events, changes in land use, population growth and conflict concerning the use of natural resources (CGEE, 2008). Efforts should be made to plan and implement actions which lead to the sustainable development of the region, strengthening the adaptive capacity of society, economy and environment, and to contribute at the same time to mitigation initiatives to reduce the causes of climate change.

Long-term environmental polices are also necessary, as well as of environmental education programs. The understanding of the Caatinga ecosystem should be improved. It is necessary to prepare a "Map of Risks and Vulnerability of the Semiarid Region to Climate Change", incorporating various sectoral vulnerabilities and their respective causes, which should serve as a guide to orient planning of adaptation strategies.

Just as the Semi-arid region is vulnerable to climate change, it is also a region with potential that needs to be better understood and incorporated into plans for adaptation and sustainable regional development.

10.1.6. Energy and water resources

According to IPCC (2007 a, b), the effects of climate evolution on the flow of watercourses and refilling of aquifers vary with the regions and predicted climate scenarios, especially in view of projected changes in rainfall. In the projections made to date, the results for South America are not consistent in the prediction of water flow. Firstly, as a result of different rainfall projections and secondly as a result of different projections for evaporation, which can counterbalance the increase in rainfall.

Brazil has the largest reserves of surface water on the planet, approximately 19.4%, and one of the largest hydraulic potential. However there is a disparity between the water availability and the localization of the water demands (Freitas, 2003). In fact, somewhere around 90% of the water is found in catchment areas of low population density in the Amazon and Tocantins rivers, while around 90% of the population live with the remaining 10% of the water resources.

Due to the high use of hydroelectric power in the Brazilian Electricity System, the generation of electricity in the country is heavily dependent on the hydrological regimes of river basins (CGEE, 2008). As there is regional instability in the availability of water – as can be seen through recurring droughts in the Northeast region, the degradation of rivers and land in the Southeast, the social and environmental risks in each region and the rapid increase in demand for water and energy in the whole country – new and old hydroelectric plants are to a greater or lesser degree vulnerable to climate change. For example, the crisis in 2001/2002 affected electrical supply and distribution and resulted in interruptions to and rationing of electricity.

The Sao Francisco river basin is principally characterized by the demands of consumptive use, such as irrigation for food production, water supply for human use and the dilution of pollutants from urban and industrial sewage. For this reason a possible change in the hydrologic regime could cause an increase in water use conflicts. The Northeast region could be the most affected both in the production of hydroelectric power, because of the possible reduction of flow in this basin.

The Parana basin is of vital importance to the Brazilian electrical system, accounting for more than 50% of the country's installed capacity. This is highlighted by the Itaipu Hydroelectric Scheme with an installed power of 14,000MW. However, this is the basin with the largest population density, which leads to various conflicts over the use of land and water, be it urban or rural. This may impede future use of the hydraulic potential and, especially, limit the generation of energy in existing hydroelectric power stations. In relation to climate change, the Parana River basin has been noted for the risks of flooding, most frequently in the years of abnormal warming in the Pacific Ocean or as a result of the El Nino phenomenon. The water released from of hydroelectric plants has been used to regulate water availability and in the management of extreme flooding events.

The Amazon basin is the largest hydrographic basin in the world, with a surface of approximately 6,100,000 km^2 and is of enormous importance in the dynamics of climate and the hydrological cycle of the planet. The basin accounts for approximately 16% of the stock of fresh surface water and consequently makes an important contribution to the rainfall system and evapotranspiration in South America and in the World. Regional alterations have caused changes in climate and hydrology in the region, notably the changes in soil use with the conversion of tropical forests into pasture. The global change in temperature can lead to several other changes in the environment, including the intensification of the global hydrological cycle which will cause impacts on water resources at a regional level.

Large stretches of the Amazon have received below-average rainfall since September 1997. This has had adverse repercussions on the generation of hydroelectricity with a reduction in the levels of the reservoirs and an increased demand for thermoelectric power (Marengo, 2006). However the impact of climatic variability on the hydrology of the Amazon basin is still not known.

Among the possible measures for adapting to global climate change are: promoting integrated and multiple management of reservoirs; integrating water resource plans with the planning and operation of hydro electric generation and other uses of water; developing new institutional and regulatory arrangements for the generation of hydropower; increasing the rational and efficient use of energy; expanding the supply of electricity through the use of alternative fuels such as municipal solid waste, sugar cane husks, wind and solar energy; promoting the management of demand for and increase of the supply of biofuels, especially biodiesel.

10.1.7. Coastal zones

The IPCC study (IPCC, 2007b) predicts, based on the different scenarios of GHG emissions, that the combination of thermal water expansion with the melting of continental glaciers would result in an increase in average sea levels of between 18 and 59cm between 2090-2099, relative to 1980-1990.

Climate change and the rise in sea levels could result in more frequent erosion of coastal areas, bleaching and mortality in coral reefs, and could have negative impacts on mangroves and coastal wetlands. In Latin America, the rise in sea levels increases the risk of flooding in lowland areas, particularly affecting river deltas and coastal urban areas.

The Brazilian coast extends from the equatorial region of the Northern Hemisphere to the subtropical latitudes of the Southern Hemisphere, a distance of about 8,000 kilometers, bordered by the western Atlantic Ocean. Approximately 20% of the Brazilian population lives in towns bordering the sea or banks of estuaries, mainly in the vicinity of the state capitals (CGEE, 2008). The main economic activities or types of occupation in coastal areas are ports, the exploitation of mineral resources, tourism, aquaculture, conservation areas or environmental protection, as well as housing.

An increase in sea levels along the Brazilian coastline has been observed during the last 50 years, with about 4mm per annum (Mesquita, 2005). In Brazil, the areas most geomorfologicaly susceptible to erosion are in the Northeast, in part due to the lack of rivers capable of carrying sediment to the sea (Marengo, 2006) but also because of the retention of marine sand in sand dunes and the low declivity in the continental shelf that increases coastal adjustment to rising sea level.

Widespread depletion of sources of sediment from the inner continental shelf, together with other factors such as natural or induced changes in the balance of sediments, has caused erosion, to varying degrees, along the whole of the Brazilian coast (MMA, 2006). In Pernambuco, one of the most affected states, about six in every ten beaches along 187km of coastline have lost land to the sea. In Recife, for example, the coastline receded 80m between 1915 and 1950 and more than 25m between 1985 and 1995 (Muehe and Neves, 2005).

The Southern and Southeastern Brazilian coast is prone to extra-tropical cyclones, which in exceptional circumstances can reach hurricane force, as did Hurricane Catarina, which struck the Santa Catarina coast in February 2004 (CGEE, 2008). As long as air movement affects rainfall, the hydrological balance in coastal regions will be very sensitive to climate variations (this includes rivers and lagoons, as well as the strips of sand between lagoons and the sea, the dunes that store rainwater, and mangroves). As it is an area that attracts inhabitation and is of great economic value, there is more pressure on the use of water resources, either as sources of fresh water or as areas for dumping waste.

Other factors that could increase vulnerability, such as disorganized land occupation, indiscriminate exploitation of sand deposits in estuaries and inlets, construction of coastal protection works without paying heed to technical engineering criteria, have often triggered rapid erosive processes (for example, Fortaleza (CE), Olinda (PE), Conceião da Barra (ES) and Matinhos (PR)).

As a result of climate change, the anticipated impacts in coastal areas, excluding those that would be common to mainland areas (agriculture, climate etc.), could be the following (CGEE, 2008):

- Coastal erosion;
- Damage to coastal protection works;
- Operational or structural damages to ports and terminals;
- Damage to urban structures in coastal cities;
- Structural or operational damage to the sewage system;
- Exposure of buried pipelines or structural damage to exposed ducts;
- Saline infiltration in estuaries and aquifers;
- Changes in the areas occupied by mangroves;
- Damage to the coral reefs.

As well as the above effects, given the intensity and frequency of storms, consideration should be given to climate changes associated with ocean-atmosphere interaction and its possible consequences on the various forms of occupation of the coastal zones and the Exclusive Economic Zone, including mineral extraction on the continental shelf, and navigation routes in the South Atlantic.

Currently the best recommendation for dealing with the effects of climate change is to establish an action strategy for Integrated Coastal Management which includes (CGEE, 2008):

- To carry out permanent environmental monitoring (long term);
- To propose municipal guidelines for urban occupation;
- To introduce state policies for coastal management;
- To regulate land use;
- To guide the efforts of federal action: legislation, education, monitoring and early warning system;
- To identify sources of funding and resources, their application and forms of control;
- To pre-plan and prioritize studies for accepted forms of response (withdrawal, adaptation and protection).

10.1.8. Urban areas

According to IPCC (IPCC, 2007b) cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. Elderly populations are most at risk. Moreover, poor communities can be especially vulnerable, in particular those concentrated in high-risk areas.

The main part of the Brazilian population is distributed in metropolises, large and medium-sized cities. The urbanization of Brazil is a recent phenomenon in comparison to what occurred in developed countries (CGEE, 2008). Disorganized urbanization, rural exodus and property speculation are some of the aspects that have created areas with high concentrations of low-income populations, which have the only option to live in hazardous situations such as valleys, wetlands, lowlands and steep slopes, or in slums and buildings that have become dilapidated through lack of maintenance. Each of these situations presents particular dangers to its inhabitants.

The temperature increase in Brazilian cities can be attributed to natural factors such as the warming of the South Atlantic, as has been observed since 1950 (Marengo, 2006) or due to anthropogenic factors (e.g. the 'heat island effect', the effect of high-rise buildings and intensive use of cars in large cities), or a combination of both. The highest rate of heating can be found in the metropolis in the Southeast of Brazil (Sao Paulo and Rio de Janeiro), but it is also apparent in cities like Manaus, Cuiaba, Campinas/SP and Pelotas/RS. The 'heat island', often found in cities and large towns results in an increased use of energy to cool buildings, as well as a aggravation of health conditions of people with hypertension which may increase the number of deaths. The increase of global climate temperature could have result in health impacts, principally in big cities.

Another consequence of climate change may be the increased frequency of high-intensity rainfall. Extreme events result in extremely intense localized disruptions, for example road flooding, congestion, degradation of historic buildings, loss of housing for poor people, material destruction and even death, for those living in risk areas (CGEE, 2008). Along the whole of the Northeast coast, in the forest zone, (from part of Rio Grande do Norte, also Recife and Olinda, as far as the Reconcavo Baiano) occurrences of strong rainfall brought by Eastern surges, accompanied by powerful swells, driven by wind, are capable of causing damage and destruction to buildings and infrastructures in the coastal region (Xavier et al, 2008).

Landslides and flooding caused by severe storms are two types of natural disasters responsible for a large number of victims in Brazil, especially in the metropolitan regions of Rio de Janeiro, Recife, Salvador, Horizonte, and the Serra do Mar and Serra da Mantiqueira mountain ranges.

Some cities in the country are already taking measures to mitigate and adapt to climate change, such as Rio de Janeiro, where systems warning of risks of unusually high surf and landslides have been developed (CIM, 2008). Sao Paulo has also implemented a Climate Change Plan which should also help in mitigation and adaptation. At state level, the Climate Change Plan of Sao Paulo was also approved. Moreover, along with Curitiba, these cities are affiliated to C40, a group of large cities worldwide that are committed to tackling climate change. The cities of Sao Paulo, Rio de Janeiro, Porto Alegre, Belo Horizonte and Brasilia signed a statement for the implementation of policies to combat climate change, at the Fourth Municipal Leaders Summit in Montreal, in 2005.

Toxic substances, emitted by industries, cars, thermoelectric plants and other sources, have constantly contaminated the terrestrial atmosphere. These impacts are more evident in the major urban centers like in the city of Sao Paulo, where the atmospheric pollution is being treated as a public health problem (Saldiva, 1992). Air pollution results in an increase of hospitalization – principally of people with respiratory problems and heart deceases – early neonatal mortality, hematological, oftalmological, neurological and dermatological problems. These problems occur principally in dry periods, especially in the winter season, in cities in the Southeast and South regions of Brazil when thermal inversion is more frequent.

Rising sea levels could lead to buildings in low-lying urban areas being abandoned and the displacement of people who live close to the coast and in service centers set up on the beaches (CGEE, 2008). Another difficulty in coastal cities will be the destiny of the untreated sewage that is collected and taken to the sea via underwater outlets. Calculations of the flow of this material were carried out at sea levels lower than those projected for climate change.

Global warming could also cause higher incidences of urban pests. Higher temperatures will produce greater numbers of insects, termites and mosquitoes, amongst others, affecting the quality of life of city-dwellers.

With regard to fuel, it is necessary to discourage the use of fossil fuels, mainly in the transport sector (COPPE, 2008). As the use of biofuels is connected to fossil fuels, measures to reduce their consumption may also mean reducing the consumption of others. Because of the numbers of cars and trucks, the transport sector is responsible for all the energy consumption of anhydrous and hydrated alcohol and more than 80% of the energy consumption of diesel oil. A reduction in the use of fuel for transport will reduce the emission of greenhouse gases and lessen the pressure on the use of renewable sources.

Amongst measures of adaptation to climate change we may highlight the following; the provision of alternative housing for low-income populations in risk areas; the implementation of measures to mitigate temperature increase (planting trees in cities, providing adequate buildings to cope with tropical conditions); reformulation of the road systems and sewage-collection, especially in coastal cities; increasing knowledge and alternative techniques to mitigate climate change and help the population and cities to adapt to it; regulating building works through the Code of Works and a Master Plan, to adapt to the effects of climate change.

10.1.9. Human health

With regard to future effects, the IPCC Health Committee recognized the following possible impacts:

- Changes in the spatial distribution and intensity of transmission of endemic diseases, especially those transmitted by vectors, such as malaria, dengue, leishmaniasis, West Nile fever, etc.;
- An increased risk of diarrhea, especially in children, as a result of the deterioration in access to good-quality water, especially in dry tropical areas;
- A worsened nutritional status in children, with damage to their development, in areas already affected by food shortages and prolonged periods of drought (developing countries);
- An increase in the risk of cardio-respiratory disease due to an increase in pollutants in the troposphere (especially the ozone layer) influenced by higher temperatures;
- An increase in the risk of diseases in population groups considered vulnerable, such as children and the elderly, indigenous people and traditional communities, poor communities in urban areas, coastal populations and populations that depend directly on natural resources that are affected by climate variation.

Due to its size and location, Brazil could be subject to significant climate variations which cause social and environmental impacts. These in turn, favor the increase of infectious endemic climate-sensitive diseases such as malaria, dengue, cholera, leishmaniasis and leptospirosis, amongst other (MCT, 2007). The effect of climatic variables may be direct, such as the persistence of moisture and temperatures favorable for the development and spread of infectious agents and vectors, or indirect, such as the processes of migration of human population triggered by drought (environmental refugees), causing a wider distribution of endemic diseases and increasing the social vulnerability of communities.

For example, Rio de Janeiro has had major outbreaks of leptospirosis. In the period 1975-2006, 4,643 cases were reported, and in 1996 downtown Jacarepaguá experienced a large epidemic with 1,797 confirmed cases (Confalonieri and Marinho, 2007). This was one of the largest epidemics of the disease yet reported in the world. Similar problems are found in other major cities in the country, as a result of poor infrastructure and sanitation and unsuitable use of urban land. With respect to climate change, the most common infectious endemic diseases in Brazil are malaria and dengue fever, incidences of which could increase or decrease regionally.The greater seriousness of these diseases is mainly linked to their high incidence and the difficulties in controlling them, as well as the well-known sensitivity to climatic variations.

The states in the Northeast are the most vulnerable to the impacts of climate on health (MCT, 2007) among which are: water shortage, which could have on the effect on the epidemiological picture of diseases linked to poor hygiene (e.g., infectious diarrhea in infants), and the worsening situations of food shortages that generate malnutrition. Migration - mostly rural-to-urban - may redistribute widespread infectious and chronic diseases such as dengue, calazar, schistosomiasis and Chagas disease (Confalonieri et al, 2008).

In the Amazon, another vulnerable region, the probable impacts of less rainfall and an increase in temperature have four main related aspects (CGEE, 2008); the worsening situation of access to good-quality water; a reduction in the amount of subsistence items available (e.g. fish); an increase in the inhalation of smoke particles from forest fires, changes in the cycles of endemic diseases (malaria, leishmaniasis etc.).

The size of the expected environmental and health impacts can be illustrated using as an example the 2005 drought episode in the central Brazilian Amazon. Small riverside communities remained isolated with insufficient water and were unable to fish as a result of tributary streams drying up (World Bank, 2005).

Urban and particularly marginalized populations are vulnerable to three main risks: landslides on slopes caused by periods of heavy rain; risk of epidemics of leptospirosis in flooded areas with reduced garbage collection during floods; exposure to air pollutants, such as ozone, of which concentrations may increase through the effect of higher temperatures (CGEE, 2008).

Special attention should be given to the coastal metropolitan areas that have historically had the greatest levels of mortality and morbidity, depending on their social, demographic and geographic characteristics (MCT, 2007). The coastal impacts caused by an increased average sea level will be manifest in soil salinization, the loss of cultivable areas and deterioration of drinking-water reservoirs. There may also be damage to infrastructure, sanitation, electricity, etc. due to erosion; the possible effects on health would therefore be indirect.

With a greater occurrence of extreme rainfall in the Southern and Southeastern regions it is estimated that there would be a greater risk of exposure to storms and floods. For example, in the city of Rio de Janeiro, between 1966 and 1996 there were at least 527 victims of fatal accidents caused by rains and floods.

Looking at the current evidence, the following general adaptation measures are recommended for the health sector (CGEE, 2008):

- Improving of programs to control widespread climate-sensitive endemic diseases in Brazil, specially malaria and dengue;
- Reducing the general conditions of social vulnerability of the population most likely to suffer from health problems (mainly diseases and accidents), by introducing economic, education and housing policies;
- Establishing early-warning systems, to combine the prediction of extreme weather events with vulnerability maps and contingency plans which also involve health care.

10.2. Principal initiatives and policies of science, technology and innovation (ST&I) relating to vulnerability, impact and adaptation (VIA)

With the objective of deepening the knowledge on climate change, its vulnerabilities, potential impacts and possible societal responses for adaptation to inevitable changes, the following themes should be strengthened through science, technology and innovation policies. These areas were identified in studies carried out by CGEE and published in *Strategic Partnerships* as well as in a series of five workshops with the participation of specialists in each topic.

It is necessary to deepen the knowledge in the following areas:

a) **Climate and climate change**

Although knowledge in this area has developed a great deal, the projections for the future are still unclear, especially those related to topics such as the volume of precipitation in each region. Brazil must continue to invest in climate science, improve the information base and incorporate new technologies and local models to permit more reliable scenarios for the climate of the future. Events caused by climate variations have occurred throughout history and are still happening today. They may be more acutely felt in the future by reason of climate changes;

b) Economic, social and environmental vulnerability

In principle, all regions and economic and social situations have some type of vulnerability to climate changes and extreme events. We need to increase our knowledge of these vulnerabilities, including from the conceptual point of view, as it is a relatively new subject in specialist literature. Vulnerability represents the degree of susceptibility in a region, a group, an activity or natural resource to climate change such as droughts, rain, temperature highs, a rise in sea level and hurricanes. Understanding of social, economic and environmental vulnerabilities is therefore very important in order to improve the quality of adaptation policies of society and government towards such events.

c) Social, economic and environmental impacts

We need to increase knowledge concerning the impacts of climate variability and climate change and their consequences in terms of material damage, human lives and others. It is necessary to be able to measure these impacts, including the related costs. Different productive sectors will be affected in different ways, with some sector or activity being affected in a positive way in distinct regions.

d) Adaptation to the variability of climate change

Brazil already has a history of policy adaptation to climate variability, as in the case of the droughts in the Semi-arid region of the Northeast. Hundred and fifty years of public policies generated lessons that have not always been used. However, there is still much to do even in the absence of climate change. The country's Civil Defense System also has a history with many lessons. With climate change, there will be an even greater need to formulate social and governmental responses to the risks of extreme weather events. Adaptation measures are important to reduce the vulnerability of regions, ecosystems, populations and activities, and thus reduce the subsequent impacts and losses that may occur.

The following assumptions may also be made:

- The IPCC has projected that, in Latin America by the middle of the century, more intense impacts of climate change will occur in the Amazon and the Northeast of Brazil. Therefore, these areas deserve special attention for actions of S, T & I relating to vulnerability, impact and adaptation (VIA);

- It is clear that the poor communities and the lowland coastal areas are the most vulnerable to the impacts caused by global climate change. The development, improvement and integration of early-warning systems are of critical importance to anticipate the response towards extreme events, reducing the vulnerability of these populations and of production systems;
- While it is imperative to reduce emissions being the only morally acceptable solution in the long term, some degree of climate change is inevitable, reason why emphasis also must be given to the need to adapt to it;
- As a result of climate change there are also potential opportunities to be explored, such as the carbon market, environmental services and possible gains of agricultural productivity as a result of CO_2 fertilization;
- It is necessary to improve institutional and inter-sectoral articulation and to increase and improve the availability of information and databases, especially historical rainfall data;
- It is pivotal to promote institutional and technical capacity and environmental education, through training programs, integrated education for children, young people and adults;
- It is necessary to support scientific research with integration of government bodies, productive sectors, scientific bodies and civil society representatives in order to identify vulnerabilities, to construct Brazilian scenarios for impacts and to identify strategies and policies for adaptation to climate change in the coming decades;
- It is worth to mention the "Brazilian Research Network on Climate Change" (Climate Network) established by the Ministry of Science and Technology and designed to generate scientific; information to help the country meet the challenges of global environmental changes;
- It is also worth to mention the Brazilian Panel on Climate Change, established by the Ministries of Environment and Science and Technology, that will assess and summarize periodically the Brazilian scientific production on this subject;
- Information regarding climate change must be disseminated in a manner that is accessible to the public (e.g. through channels such as the Weather Network and other media). The role of the press is of fundamental importance;
- It is necessary to deepen the knowledge about synergies between mitigation and adaptation practices.

In this way, it is recommended that the S, T & I System will specifically encourage the increasing of knowledge concerning VIA and that the process will be based on the following initiatives:

Forests

- Increasing the quantity and quality of data and information needed for studies on vulnerability, impact and adaptation to climate change and promoting the use of methods and tools to enable a better assessment of regional and local vulnerabilities and the potential impacts of climate change on forest ecosystems;
- Increasing the scientific knowledge on the main vulnerabilities and impacts of climate change on forests and on the productive forest sector in general;
- Identifying the potential for carbon storage in each ecosystem;
- Monitoring the economic and environmental impacts of extractivism, with a particular emphasis on permanent follow up of the direct and indirect environmental impact of logging;
- Dissemination of information on impacts that have already occurred and their locations, as well as a projection of the expected impacts of climate change under various emission scenarios, alerting about irreversible impacts, estimating the different risks and identifying opportunities related to climate change;
- Evaluation of the potential economic value of environmental services in standing tropical forests, using the new REDD (Reduction of Emissions from Deforestation and Degradation) instrument in analysis under the terms of the Climate Convention;
- Preventing forest fragmentation and reducing or annulment of deforestation;
- Defining approaches to identifying and evaluating measures and strategies for adaptation, including measures for making forests more resilient to the impacts of climate change;
- Reviewing of the priorities for the conservation and establishment of ecological corridors.

Agriculture

- Mapping the vulnerabilities for the agricultural sector in the country;
- Establishing and implementing effective S, T & I programs to assess the impacts of climate change on agriculture and possible measures for adaptation, in terms of the major crops and forage, including extreme events that affect agriculture;
- Assessing the geographical distribution of plant diseases based on current climate conditions and estimated regional and global climate changes;
- Implementing agroclimatological and agroecological zoning;
- Development and implementation of technologies for thermal comfort systems for livestock production;
- Integrating production systems with crop-livestock-forestry systems;

- Evaluation of the effects of increasing concentrations of CO_2 in soil-plant systems of existing agricultural ecosystems in the country, combined with predicted increases in temperature, water balance and nutrients;
- Identifying the weakest links in the production chain to develop alternatives;
- Organizing the production chain to meet marketing standards, including family farming;
- Genetic improvement of animals and plants to meet new climate conditions and the potential increase of pests and diseases;
- Rural extension with a view to adequate the productive sector for the effects of climate change, giving guidance on adaptation measures;
- Implementing integrated S, T & I actions on food security in rural areas, especially in the Semi-arid region;
- Implementing public policies using scientific and technological knowledge in modern agriculture that intensify and maximize the use of the areas within biomes that have already been altered, together with policies for adding value to agricultural or primary forest products through industrialization;
- Adopting incentives for the maintenance and expansion of forested areas, forest corridors, integrated crop-forest systems, as well as increasing the legal control of land use;
- Establishing systems to remunerate environmental services on rural properties.

Biodiversity

- Researching issues concerning paleoecology, paleoenvironmentalism and paleoclimate, environmental and ecological history, incorporating knowledge on the current distribution of species and communities, reconstructing migration processes and the growth of endangered flora and fauna communities in each Brazilian state;
- Restructuring and integrating initiatives related to biological inventories (species and genetic variability) and environmental information (assessment of soil and climatic and hydrological data) and implementing a national program that includes the private sector;
- Supporting the consolidation of an organized infrastructure and data sharing (biological and abiotic), through the dynamic integration of distributed information systems that adopt internationally accepted standards and protocols that will facilitate the development of consistent analysis and predictive modeling;
- Improving and developing models that can simulate the synergistic effects associated with ecosystems (climate change, fire, extreme weather events, soil use, socio-economic aspects and ecological niches for species);

- Designing and implementing systems to monitor the impact of climate change on species (native, endemic, endangered and invasive) with the definition of the biological indicators of the impact on species, populations and ecosystems;
- Developing models to recover degraded areas, restore ecosystems and control biological invasions;
- Implementing research programs to study the role of ecological complexity and interactivity in the functioning of ecosystems, including studies related to ecophysiological drought and heat stress;
- Reviewing conservation priorities and establishing ecological corridors, taking into account the impact of climate change on biodiversity;
- Structuring a National Program for Biological Resource Centers (ex-situ conservation, e.g. germplasms);
- Building a financial method to remunerate environmental services provided by forests in conservation units as a strategy to contain deforestation and to mitigate climate change.

The semi-arid region

- Diagnosis (mapping, definition of roles and current status) of the institutions and legal instruments related to environmental and climate change;
- Assessment of the vulnerability of the Semi-arid region to changes in land use, climate change, population increase and the conflict over the use of natural resources, including a map of risks and vulnerability, integrating the various sectoral vulnerabilities;
- Evaluation of the hydrological potential in the river basins and hydrogeological basins of the Semi-arid region;
- Evaluation of the food security in the Semi-arid region;
- Execution of a multi-criteria analysis to map regional vocations and propose appropriate policies for the regional possibilities identified;
- Developing applied research to assess the impacts and map risks of climate change, identifying vulnerable populations, and establishing adaptation measures;
- Assessment of the impacts on biodiversity, especially on the Caatinga vegetation, riparian forests and mountain slopes;
- Establishing policies for sanitation and water supply, principally for small communities;
- Implementation of technological improvements to collect, store and treat water;
- Developing crops and agricultural systems adapted for the Semi-arid region, taking into account variability and climate change;

- Defining at Federal Government and state level, environmental education and awareness programs on climate change and vulnerabilities, their impacts and possible adaptation measures, with emphasis on the Semi-arid region.

Energy and water resources

- Preparing climatic vulnerability maps for each river basin, taking into account the multiple use of water;
- Reducing the vulnerability of the electricity generation system through the integration of energy sources at different scales;
- Developing models for the energy sector that take climate change scenarios into account in order to increase the reliability of simulated results for the sector;
- Developing strategies for integrating – within the planning and operation of generating hydroelectric power and water resources plans – of aspects linked to climate change in order to reduce the vulnerability of the energy and water supply;
- Reviewing operating rules for hydroelectric plants, taking into account the possible impacts of climate change;
- Reviewing the arrangements for the generation of hydroelectricity in existing energy park, principally in terms of multiple uses of water, either during periods of extreme drought and flood, or to ensure better adaptation of water catchments to the needs of a growing population and economy;
- Seeking alternatives for power generation by increasing the production of renewable fuels and other renewable sources;
- Survey of factors that influence the production of alcohol and biodiesel from agricultural crops;
- Production of second-generation biofuels for sustainable regional development;
- Adopting stricter environmental regulations for the generation of energy from fossil fuels, which would benefit the options of generating renewable energy;
- Evaluating ways of compensation for non-renewable energy sources, encouraging the expansion of renewable sources;
- Establishing strategies to encourage better regional and continental integration between hydrographic basins and electrical systems;
- Strengthening and expanding energy-efficient programs for industry;
- Promoting political and economic incentives to reduce consumption and increase energy efficiency in the residential, industrial and service sectors;

- Promoting the National Water Resources Policy, supporting the implementation of its instruments (like Water Resources Plans, classification of water bodies, water right permit, water use fees) and its management system (like River Basin Committees and Water Agencies);
- Promoting the management of the demand for water resources (rational use, multiple use, reuse, economic equipment, control of losses).

Coastal areas

- Mapping and identifying the most susceptible populated areas, and the development of their occupation considering items such as urban areas, port areas, public roads, production facilities and biodiversity;
- Preserving and restoring technical archives of port and coastal engineering, including cartographic information, technical drawings, pictures and reports;
- Developing risk studies for coastal areas taking into account environmental, technical, engineering and socio-economic aspects;
- Implementing a permanent and long-term program of environmental monitoring that includes meteorological, oceanographic, geodesic and geomorphological parameters;
- Implementing an environmental monitoring network for those ecosystems most at risk (mangroves, coral reefs);
- Updating nautical charts for coastal engineering studies, mapping and cartographic alignment (vertical and horizontal datums) between the Brazilian Institute of Geography and Statistics - IBGE maps and nautical charts to construct a Digital Ground Model for the coastal zone, including surface and submerged areas;
- Updating the land map of the coastal strip between an elevation of 0-20m with a vertical resolution of 1m or higher, and vertical datum compatible with those of nautical charts, including the entire width of the coastal plains from the coastline, including the placement of geodesic marks on the coastal strip;
- Developing guidelines and standards for coastal and marine works, including the possible impacts of global climate change on works and buildings;
- Developing techniques for the biological improvement of mangroves with a view to reforestation;
- Promoting Integrated Coastal Management based on the integration of programs and Water Resources Plans and coastal management;

- Supporting the implementation of coastal management programs in coastal municipalities, establishing no-building areas and monitoring coastal segments;

Urban areas

- Assessing the vulnerability of and mapping areas at risk of flooding and landslides in the cites;
- Assessing the economic, social and environmental impacts as a result of natural climate events such as floods and landslides;
- Evaluation of the possibilities for water supplies in major cities (see the map of the National Water Agency - ANA) and alternative water supplies in emergencies and after disasters;
- Identifying alternatives for housing low-income population in areas at risk;
- Reformulation of the road system and sewage collection, especially in coastal cities;
- Regulation of works, through the Work Code and the Master Plan, to scenarios of climate change (increased temperatures, heavy rainfall and rising sea levels);
- Renaturalization (recreating microclimates, re-planting vegetation, revitalizing water courses) of urban areas;
- Implementing policies to adopt construction techniques adapted to higher temperatures such as ecological roofs, buildings with natural ventilation and lighting, etc.);
- Implementing methods and policies to reduce the use of fossil fuels in transport, encouraging the use of public transport and railways, and the integration of trains/trucks/ships to reduce the final energy consumption of anhydrous and hydrated alcohol and diesel oil.

Human health

- Operational research to develop and implement methods for analyzing the vulnerability of the population to the adverse effects of climate on health;
- Analysis of political and institutional vulnerability of the National Civil Defense System and other bodies linked to human health;
- Updating and expanding available studies by incorporating data and information from other sectors that are directly relevant in determining the state of the population's health (quality/availability of water, food security, etc.);
- Research to improve the morbidity and mortality forecast model (Brazilian Climate and Health Model), with the objective to alert precociously society in regard to changes in meteorological and climate conditions;

- Expanding studies on regional climate modeling to produce climate scenarios for the not too distant future in order to make them compatible with socio-economic and health scenarios;
- Identifying the impacts of climate change on human health and their physical and financial extent, including, among others, information on food production, costs for treating endemic infectious diseases and air pollution, mortality-morbidity and material impacts;
- Integrating civil defense databases (at municipality and state levels) with health care organizations to improve the quality of records of health problems caused by extreme climate events;
- Installing systems for environmental, epidemiological and entomological monitoring in selected locations and situations, to detect early signs of biological effects of climate change (e.g. phenology, geographical distribution of species, etc.);
- Improving the effectiveness of programs to control infectious diseases and endemic diseases such as dengue, Kala-azar and schistosomiasis.

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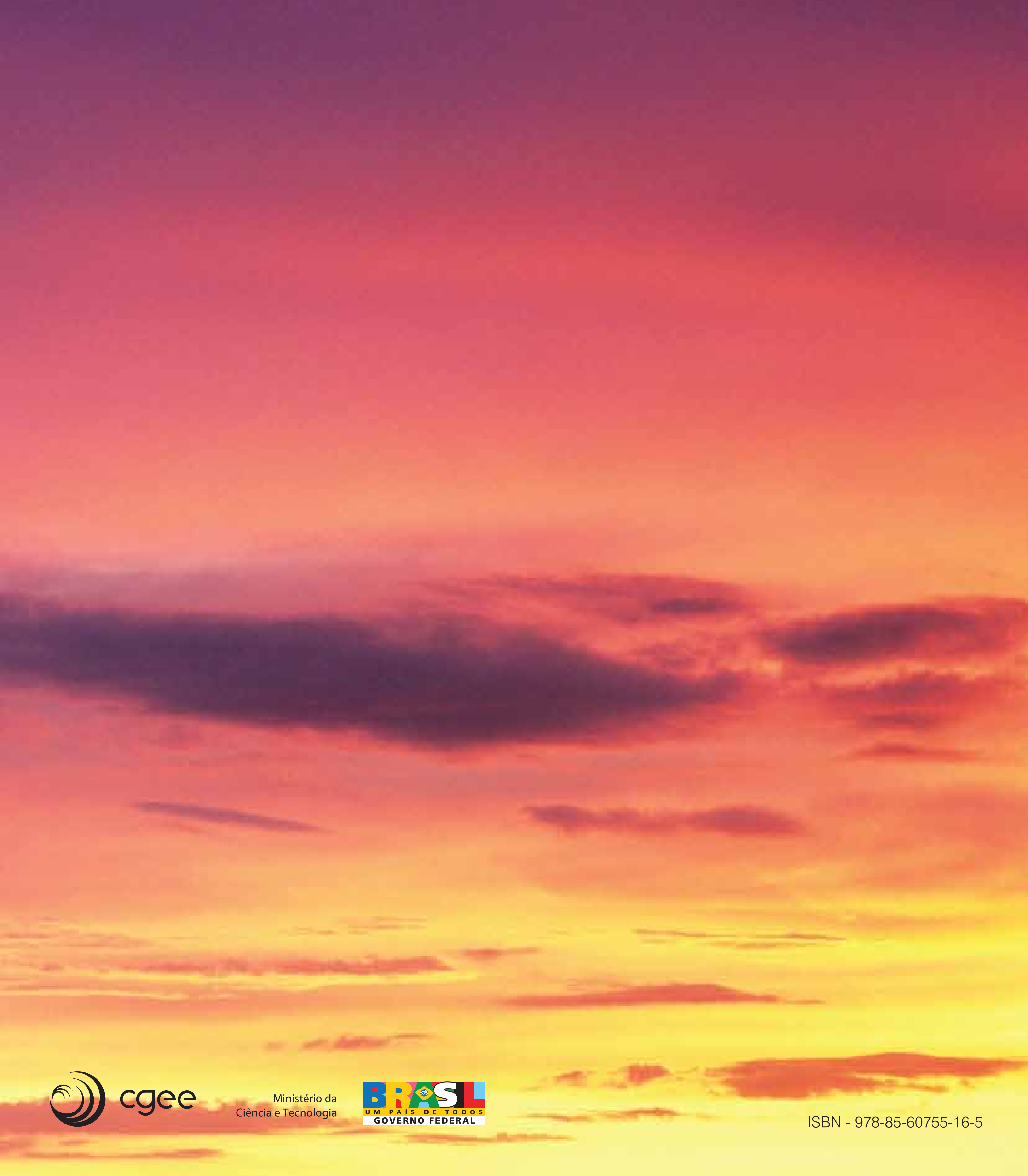

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