Organização do Tratado de
Cooperação Amazônica

Fundo para o
Meio Ambiente Mundial

Programa das Nações Unidas
para o Meio Ambiente

Organização dos Estados Americanos
Departamento de Desenvolvimento Sustentável

PROJETO DE GERENCIAMENTO INTEGRADO E SUSTENTÁVEL DOS RECURSOS HÍDRICOS TRANSFRONTEIRIÇOS NA BACIA DO RIO AMAZONAS CONSIDERANDO A VARIABILIDADE CLIMÁTICA E AS MUDANÇAS CLIMÁTICAS

Bolívia, Brasil, Colômbia, Equador, Guiana, Peru, Suriname, Venezuela

PROJETO GEF AMAZONAS – OTCA/PNUMA/OEA

Atividade Nº. IV. 2. Investigar e avaliar os riscos decorrentes das mudanças nas condições hidrológicas e climáticas sobre as comunidades humanas e ecossistemas vulneráveis, assim como suas repercussões socioeconômicas

Relatório Final

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Contrato CPR/OEA – 18/2006

Dezembro de 2006

CHANGES IN THE HYDROCLIMATOLOGY OF THE AMAZON BASIN AND DERIVED RISKS FOR HUMANS AND VULNERABLE ECOSYSTEMS

MUDANÇAS HIDROCLIMÁTICAS E OS RISCOS DECORRENTES PARA COMUNIDADES HUMANAS E ECOSSISTEMAS VULNERÁVEIS

EXECUTIVE SUMMARY

INTRODUCTION

The Amazon River Basin is the world's largest drainage system. This river provides 16% of annual global river runoff, and 27% of the world water resources are formed by the five largest river systems: Amazon, Ganges with Brahmaputra, Congo, Yangtze, and Orinoco (UNESCO, 2001). In fact, 1,100 rivers make up the Amazon system. The source of the Amazon River is a small river, the Apurimac, located at 17,200 feet above sea level.

The Amazon River flow regime is subject to interannual and long term variability represented as large variations in downstream hydrographs. The flow regime of this river system is relatively un-impacted by humans, and is subject to interannual and long-term variability in tropical precipitation, that ultimately is translated into large variations in downstream hydrographs. This river drains an area of 6.2×10^6 km^2 and discharges an average of 6300 km^3 of water to the Atlantic Ocean annually.

During recent 25-30 years all over the world there is an especially intensive anthropogenic change of hydrologic cycle of rivers and lakes, their water quality, water resources and water budget. The values of water resources, their dynamics with time and distribution over the territory are now determined by not only natural climate variations, as it has been previously, but also the man’s economic activities. In many regions and countries of the world, water resources are quantitatively depleted and much contaminated.

The Amazon region can be categorized as a region at great risk from climate variability and change. The risk is not only due to projected climate change but also through synergistic interactions with existing threats not related to climate change, such as land clearance, forest fragmentation and fire. Over the next several decades there is a risk of an abrupt and irreversible replacement of forests by savannah with large-scale loss of biodiversity and loss of livelihoods for people in the region.

On the basis of what is now known on climate variability in Amazonia, and on the role of the moisture transport in and out of the basin as suggested by observational and modeling studies, a question arises: what would be the possible impacts of regional scale deforestation or of the increase of greenhouse gases concentration in the atmosphere on the climate of the Amazon and neighboring regions?

The recent drought in 2005 that affected large sections of the western Amazon Basin in 2005 has shown how vulnerable is the population to extreme climate events. This drought was the most severe the past 40 years and also one of the most intense of the last 100 years. The drought has evaporated whole lagoons, and kindled forest fires, killed off fish and crops and protected species, stranded boasts and the villagers, who travel by them, brought disease and wreaked economic havoc.

Therefore, the main purpose of this report is to investigate and assess the risk associated with climate variability and climate change in the hydroclimatology of the Amazon region, as its impact on natural ecosystems and society.

Some specific objectives are listed below, and are discussed on the upcoming sections

(a) To provide a historical review in the evolution of studies of the climatic variability and change in the Amazon basin,
(b) To provide historical evidences of extreme hydroclimatic events in the region,
(c) To investigate and document the impacts of climate variability and change in all the Amazon countries,
(d) To discuss future climate change scenarios produced by global and regional models in the basin,
(e) To assess impacts derived of climate change in the Amazon countries and how population natural ecosystems would be vulnerable.

A final objective will be to assess the degree of vulnerability of the Amazon basin to climate change in order to provide basis for vulnerability assessments and adaptation measurements. The document is organized in chapters that discuss climate variability and change and their risks, their impacts on the region at the level of country and basin wide, the vulnerability of society and natural ecosystems to climate change, and finally we provide recommendations

1. CLIMATE CHANGE AND DERIVED RISKS

Climate variability and change, due to both natural climate variability or to the increase in the concentration of greenhouse gases in the atmosphere of anthropogenic origin may have a potential to accelerate the hydrologic cycle, and the Amazon region would be one of the most affected regions.

Changes in land use patterns due to deforestation might produce changes in latent heat and can ultimately influence Land-use practices, such as deforestation leading to agriculture or urbanization often disrupt the supply of fresh water through changes in the surface water balance and the partitioning of precipitation into evapotranspiration, runoff and groundwater flow. However, trends in long term rainfall or river discharge variability identified in the middle 1970's (Gentry and Lopez Parodi 1980) as possible consequence of deforestation have proven not to be entirely true.

Long term variability of rainfall and river discharge in Amazonia seem to be linked to decadal variability, linked to natural causes and not to land use changes alone. The extremes in the variability have been linked to drought related to El Niño in 1926, 1983, 1998 (Marengo 2004, Ronchail et al 2002), or to warming in the tropical North Atlantic, as in 1963 and 2005 (Marengo et al. 2006).

The pioneer studies by Salati et al (1979) suggested the important role of the Amazon forest in the local rainfall and discussed the fact that Amazon Basin's abundant vegetation releases large amounts of water vapor by transpiration, which together with evaporation equals *50%* to *60%* of the total rainfall in the basin (Salati et al. 1979, Salati and Nobre, 1991).

In fact, part of this rainfall is sustained locally by evapotranspiration, induced by a precipitation recycling, and another part comes from atmospheric moisture transported from the tropical Atlantic by the trade winds, especially during the summer rainy season, and another part is due to intense regional water vapor recycling.

These early findings by Salati and collaborators have brought the scientific community to realize the important role of Amazonia in the regional and global climate, and that large scale deforestation could in fact affect the hydrological cycle of the region, impacting the climate at various geographical scales.

A recent study by Marengo (2006b) shows that even though all models project warming for the region until 2100, reaching up to 8 °C in the HadCM3 model for the A2 extreme scenario. On the other hand, there is not a clear tendency for rainfall anomalies and while some models shows a wetter Amazon basin, other shows drying. The difference among models reaches up to 5 °C and 2.5 mm/day up to 2100 time slice (Fig. 1).

Projections for future climate change from the Hadley Centre model have shown that an increase in the concentration of greenhouse gases in the atmosphere will produce changes in vegetation such that Amazonia will become a savanna by 2050's, and the region will become drier, warmer and most of the moisture coming from the tropical Atlantic, that normally produced rainfall in the region, will not find the adequate environment to condensate above the savanna vegetation by 2050, and the moist air stream will move to southeastern South America producing more rainfall in those regions.

Therefore, after 2050, the Amazon Basin would behave as a "source of carbon" for the regional water balance rather than a sink as in present day's climate (Cox et al., 2000, 2004; Betts et al., 2004). Fig. 3 shows that for the 2090-2100 period the Amazon basin becomes warm and dry, resembles the patterns of an intense El Niño-like situation, with large SST anomalies in the tropical Pacific are large (+3 to +4 °C above normal), drying conditions in the Amazon Basin and increase risk of fire on this region. However, those results still show some degree of uncertainty since are based solely on the coupled model of the UK Hadley Centre for Climate Research.

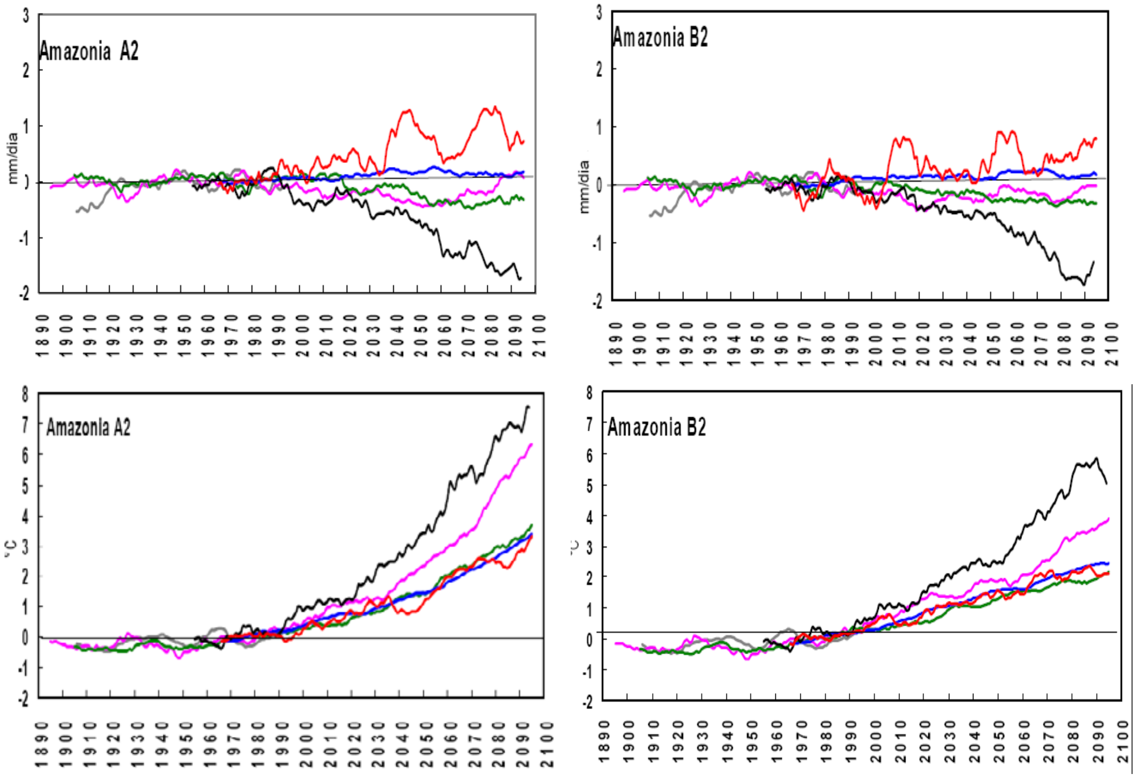

Figure. 1. Time series of rainfall and air temperatures anomalies for the Amazon region from 1980 to 2100. The anomalies are calculated based on the 1961-90 climatology from five IPCC TAR models (CCCMA, CCSR/NIES, CSIRO, GFDL and HadCM3) and observations from the CRU. Scenarios are A2 (high) and B2 (low) emission scenarios. The lines represent the 11-year moving average of each time series. Color lines indicate the different models used (Marengo 2006b).

The projected climate change shown in Fig. 2 could trigger a collapse of the Amazon with savanna replacing the forests with a global mean warming in the range of 2-3°C above preindustrial as predicted by one climate model. The probability of this dangerous event is not clear. Synergistic interactions with the effects of forest clearing and fragmentation could flip the ecosystems of this region from forest to savannah and to desert in parts of North-eastern Brazil. Biodiversity, human livelihoods, and economic development consequence would be enormous.

A variety of human activities can act to modify various aspects of climate and the surface hydrologic systems. Historically, land-surface changes in Amazonia got intensified in the mid and early 1970's, when strategic governmental plans first attempted to promote the economic development of the region. Those plans included the construction of extensive roads throughout the basin and the implementation of fiscal incentives for new settlers, triggering a massive migration of landless people into the region.

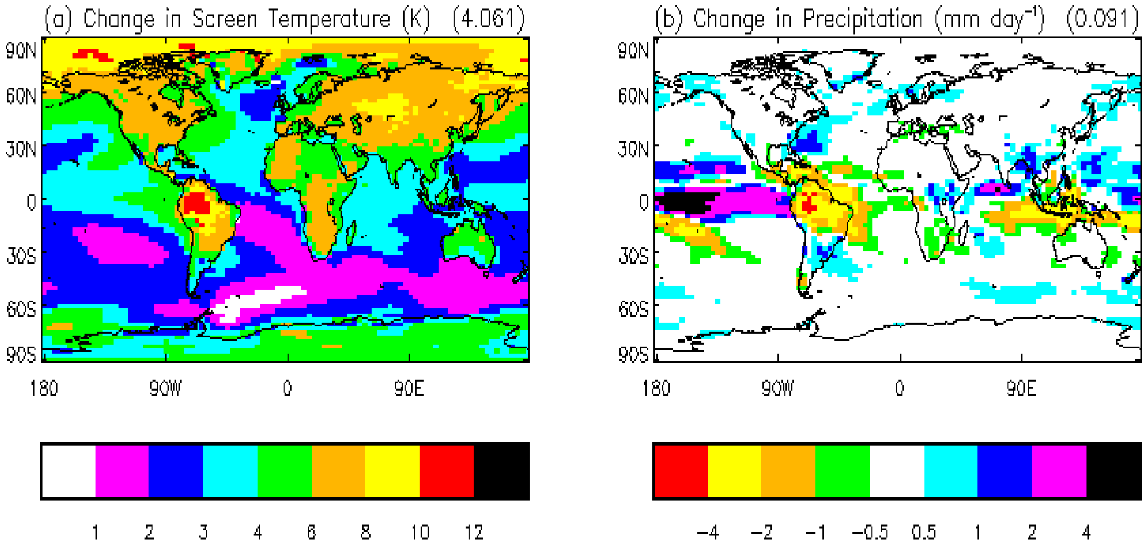

Figure. 2. Change in Global Climate in HadCM3LC Interactive CO$_2$ and Dynamic Vegetation, for surface temperature (left, in °C) and rainfall (right, in mm/day). Maps show the difference between 2090-2100 and 1980-1990. (Cox et al 2000, 2004)

Changes in land cover can significantly affect the surface water and energy balance through changes in net radiation, evapotranspiration, and runoff. However, because of the intricate relationships between the atmosphere, terrestrial ecosystems, and surface hydrological systems, it is still difficult to gauge the importance of human activities in the Amazonian hydrologic cycle.

The construction of reservoirs for hydroelectric generation in Amazonia has some impacts in the hydrological regime as well as on the biodiversity and on the water quality (Tundisi et al., 2002), depending on the size and inundated area of the tropical rain forests. Brazil has five reservoirs operating for hydroelectricity generation (Coaracy Nunes, Curua-Una, Tucurui, Balbina and Samuel) and six other planned to be built (Manso, Cachoeira, Ji-Parana, Karanaô, Barra do Peixe, and Couto Magalhães). Land use changes have also been reported near the site of the reservoir due to human settlements in the region.

In an attempt to investigate the possible impact of Amazon deforestation in the regional and global climate and hydrology, global climate model simulations of land use changes where forest are replaced by grassland in the whole basin have been started since the late 1970's, using models that vary from empirical to global climate models.

The results have suggested a possible change in the regional and global climate as a consequence of tropical deforestation (see reviews in Salati and Nobre, 1991; Marengo and Nobre 2001). The predicted change in tropical circulation determines the change, if any, in atmospheric moisture convergence, which is equivalent to the change in run-off.

All these changes expected from deforestation in Amazonia may have climatic, ecological and environmental implications for the region, the continent and for the globe. A sound knowledge of how the natural system functions is thus a prerequisite to defining optimal development strategies. The complex interactions between the soil, vegetation, and climate must be measured and analyzed so that the limiting factors to vegetation growth and soil conservation can be established.

New knowledge and improved understanding of the functioning of the Amazonian system as an integrated entity and of its interaction with the Earth system will support development of national and regional policies to prevent the exploitation trends from bringing about irreversible changes in the Amazonian ecosystem. Such knowledge, in combination with enhancement of the research capacities and networks between the Amazonian countries will stimulate land managers and decision makers to devise sustainable alternative land use strategies along with forest preservation strategies.

Table 1 shows some of the forcing (natural and anthropogenic) that have impacts on the water resources availability and quality, and the impacts on the population, biodiversity, generation of hydroelectricity. This table is more comprehensive than

The major climatic forcing (El Niño, variations in the tropical Atlantic SST gradient or the release of greenhouse gases due to human or natural causes) have a direct impact on the water and energy cycles, that translates in regional scale reductions in rainfall, evaporation, streamflow and increase in air temperature, generating drought, high risk of fires, impacts on ecosystems and biodiversity, impacts on water and air quality, impacts on availability of water resources for irrigation, electric generation and safe water for population.

All Amazon countries are sensitive to climate variability and change and their impacts on biodiversity and natural ecosystems, and the situation may be even more complicated for the Andean-Amazon countries where erosion and river channel sedimentation is an additional problem.

Table 1. Natural and anthropogenic forcing, climatic tendencies and human and ecosystem dynamics in Amazon countries.

Forcing(natural or anthropogenic)	Impacts on water resources	Consequences
El Niño and Tropical Atlantic sea surface temperature anomalies	Changes in the rainfall distribution in the Amazon Region	Drought in Northern Amazon Region; problems in transportation due to low river water levels; high risk of forest fires at seasonal level; impacts on natural river ecosystems; impacts on agriculture; impacts water storage for hydroelectric generation

Continues

continuation

Climate change due to increase in concentration of GHG	Possible changes in the hydrological cycle; changes in the energy balance and warming; changes in biodiversity and natural ecosystems	Dynamics of vegetation affected; Amazon forest die and become savanna; drying of the Amazon region; floods or extremely low water levels likely to occur; more frequent forest fires; impacts on water storage for hydroelectric generation
Deforestation and land use change	Possible changes in the hydrological and energy cycles. Changes in water quality and chemistry due to deforestation in the east flank Andes (Upper-Amazon countries)	Regional rainfall reduction; regional warming; erosion; sedimentation along the main channel and accumulation of sediments in reservoirs; water quality and biodiversity may be affected.
Biomass burning (natural and man-made)	Changes in the water and energy cycles; changes in the air quality	Impacts on the onset of the rainy season and physics of rainfall; impacts on the air quality and sensitivity to warming due to release of large amounts of GHG and aerosols.
Agriculture	Possible changes in the hydrological and energy cycles; introduction of exotic species;	Erosion; changes in regional microclimates; impacts of groundwater
Constructions of highways and reservoirs	Changes in regional circulation and rainfall patterns; decomposition or organic matter	Erosion; changes in regional microclimate; increase in methane release to the atmosphere; changes in cloudiness
Mining and related activities	Pollution of rivers and streams; erosion; chemical spills	Deterioration of water quality; impacts on fishery and natural river ecosystems; erosion and floods in flatlands; social problems
Oil exploration	Pollution of rivers and streams; destruction of forest for oil pipelines; chemical spills	Deterioration of water quality; impacts on fishery and natural river ecosystems; erosion and risk of land slides.
Cattle and ranching; human settlement and urbanization	Changes in regional circulation and microclimate; possible changes in the energy and water cycles;	Impacts on natural ecosystems; erosion; increase of biomass burning; impacts on groundwater

Amazon Rivers have a natural vocation for transportation. Almost 18,300 km of rivers are potentially suited for navigation. The Amazon River main channel and the upstream section called Solimões (Rio Amazonas in the Peruvian, Colombian, Bolivian and Ecuadorian Amazonia) are suitable for navigation as well as its tributaries Ica, Branco, Negro and Trombetas on the left margin and the Juruá, Mamore-Madeira, Tapajos e Xingu on the right margin. The Amazonas/Solimões has an extension of about 6,500 km, with 3,100 km in Brazilian territory.

The Lower Amazonas, between Belem and Manaus has an extension of 1500 km and can be as wide as 150 km, and allows for navigation of big cargo ships. The Solimões River between Manaus and Tabatinga has 1,600 km of extension and allows for the navigation of middle size ships, and a third section is located almost the border with Peru, with 250 km length. So, prospects of reductions in the river level and discharge in the Amazon Rivers may have large impacts on the regional economy, as it was observed during the drought of 2005.

Perhaps the most important hydroclimate feature that affects Amazonia is drought, rather than flooding. Drought favors fires that affect population and biodiversity due to the smoke, as well as human activities. Smoke also affects the onset of the rainy season as well as the extension of the dry season, as well as the moisture content all year around. The drought also affects the availability of water in the form of reductions in river level discharge, affecting transportation, safe water availability and human health, as well as hydroelectricity generation. This implies that the Amazon is more vulnerable to drought than to floods.

There is evidence of extensive droughts, and perhaps widespread fires, linked to paleo El Nino Southern Oscillation ENSO events occurred in the Amazon basin in 1,500, 1000, 700 and 400 BP, and these events might have been substantially more severe than the 1982-83 -and 1997-98 ones (Meggers 1994). The best documented case of an earlier drought event in Amazonia linked to El Niño event was during 1925-26 (Sternberg 1968; 1987, and Williams et al. 2005). Rainfall anomalies in the central-northern Brazilian Amazonia and southern Venezuela in 1926 were about 50% lower than normal.

During the last 103 years, 10 events of intense drought have been identified. The evidences for the dry years in 1911-12, 1918-19 and 1925-26 are also apparent in the Rio Negro water level record in Fig. 1 as the minimum discharge prior to 1926. The first two were El Niño years, while the third was a La Niña event. The impacts of the 1925-26 El Niño were somewhat different from those observed on a “typical” El Niño event.

During this particular drought, extensive fires prevailed in Venezuela and the upper Negro River basin. Unusually high air temperature anomalies were recorded in various Venezuelan and northern Brazilian Amazonian towns for both 1925 and 1926, and it is plausible that the dryness in the northern portion of the Negro River basin in 1925 also contributed to the major drought in 1926 by a depletion of soil moisture (Fig. 8).

In Amazonia, the 1997/98 El Niño produced a drought situation that extended over most of the region and large parts of Amazonia did get rainfall below normal since September 1997. River levels in there were about 9 m below normal, and this determined problems with the generation of hydroelectricity since the reservoirs showed values much lower than normal. Impacts of the drought were also observed in the form of fires.

In 2005, large sections of the western Amazon Basin experienced the most severe drought in the past 40 years and also one of the most intense of the last 100 years. During this event, the worsening drought has forced the Brazilian government to extend emergency warnings across the Amazonas state. The military has been called in to distribute supplies and medicine to tens of thousands of people. This drought provoked extensive forest fires in the State of Acre, although the area has yet to be estimated (Brown et al. 2006).

Navigation along sections of the Madeira and upper and central Amazon River (known in Brazil as the Solimões River), had to be suspended because the water levels fell to extremely low levels, which led various countries of the Amazon region to declare state of public calamity in September 2005. The drought left thousands of people short of food, caused problems to river transportation, agriculture, generation of hydroelectricity and also affected directly and indirectly the populations living along the Amazon River streams.

An observational study of the causes of this drought by Marengo et al. (2006) suggest that causes of the drought were not related to El Niño but to (a) the anomalously warm tropical North Atlantic, (b) the reduced intensity in northeast trade wind moisture transport into southern Amazonia during the peak summertime season, and (c) the weakened upward motion over this section of Amazonia, resulting in reduced convective development and rainfall.

The difference in the spatial features of these drought years and the 2005 and perhaps the 1963-64 droughts was that the later two struck hardest western and southern Amazonia, a feature not associated with a typical El Niño but probably with tropical North Atlantic warmer and more active than normal.

Contrary to the above droughts, the droughts of 2005 as well as those in 1963-64 and in 1979-81 did not occur associated with El Niño events. While several studies analyze the droughts of 1982-83 (Aceituno 1988, Marengo et al. 1998) and 1997-98 (Nepstad et al. 1999) and their impacts in climate, hydrology and fires in Amazonia, there are only casual references to the drought event of 1963-64.

This is suggestive of future warmer climate change scenarios due to the increase in the concentration the greenhouse gases and aerosols, where by the end of the 21st Century the probability of events like this may increase as simulated by the UK Hadley Centre global coupled model. In addition, land use changes and biomass burning due to the increased fires and the subsequent injection of aerosols to the atmosphere have the potential to affect the onset and the amount of rainfall in the region (Andreae et al, 2004).

However, this does not imply changes in the large scale circulation leading to this drought in 2005 may be consequence of regional deforestation or of global warming and climate change.

2. IMPACTS OF CLIMATE CHANGE IN THE AMAZON BASIN

Based on the evidence shown in previous sections, as well as in the reviews by IPCC (2001a, b), Marengo and Silva Dias (2006), Marengo (2006a, b), Salati et al (2005), Hiller (2003) among others summarize possible impacts of climate change in Amazonia:

- In Amazonia there is an observed positive air temperature trend of the order of + 0.63 °C over the last 100 years until 1997 (Victoria et al. 1998), that has been updated to +0.81 °C until 2002 (Marengo 2003).

- Increased air temperatures affect the surface water balance diminishing the soil moisture storage and increasing the probability of forest fires. The best examples are the drought of Amazonia during El Niño 1998 and the recent drught of 2005..

-Considering the recent drought of Amazonia in 2005, Fearnside (2006) has linked this episode to climate change due to the increase in the concentration of greenhouse gases and to deforestation in Amazonia. It is almost impossible to assure that a phenomenon that lasted less than 2 years can be ascribed to climate change.

-The implications that future warmer climates may be analogous to a year like during the very strong El Niño 1997-98 are out of place, since there are drought years in Amazonia (as in 1963-64 and 2005) that were not linked to El Niño but to climate variability in the tropical North Atlantic sector.

-Model simulations for future climate in Amazonia (Cox et al. 2004, Betts et al. 2004) suggest that drought conditions would prevail in Amazonia after 2050 in an “extended El Niño like mode” do not imply that changes in El Niño would result as a consequence of climate change.

- Low water levels in the Amazon River and tributaries consequence of rainfall reductions would affect transportation along the main channel, and this situation was clearly observed during the drought of 2005 (Marengo et al. 2006, Brown et al 2006).

-Model projections show some long term reductions of streamflow in the Amazon region during the second half of the XXI Century (Milly et al 2005, UK Met office 2005), even though current climate trends do not show any significant unidirectional trend in Amazon River and tributaries streamflow

- As the rainforest becomes increasingly dry, damaging wildfires broke out in the region, damaging hundreds of thousands of hectares of forest and injecting into the atmosphere large amounts of smoke and aerosols that polluted the air in many towns affecting population.

-These ecological impacts of forest fires include the feasibility of sustainable forest management in the region, which is currently advanced as a promising basis for the regional economy (Brown et al., 2006). Previously, in 1997-98, fires associated with an exceptional drought caused by El Niño devastated large areas of tropical rain forests in northern and eastern Amazonia (Nepstad et al. 1999).

- Climate change will threaten human health in the Amazon. Contagious diseases and viruses such as cholera,- which killed 159 people from 1991 to 1998 - the Rotavirus (latent in the south of the state of Roraima, with 11 deaths in Ipixuna), Severe Diarrheic Diseases, Hepatitis A and Typhoid Fever could proliferate, in function of an increased concentration of these pathogens caused by the drastic decrease in the volume of water in the rivers and lakes and due to the scarcity of potable water, which has already begun to be confirmed in the state's rural areas.

- Recreational and commercial fisheries are particularly at risk of climate extremes and increased variability because fish populations are notoriously variable, and fisheries yields are often heavily dependent on the occasional strong year class (Pitcher and Hart, 1982).

-Deforestation also provokes great biodiversity loss in Amazonia, estimated between 8,000 to 34,000 species, considering that deforestation raises 1% per year (Salati et al. 2006).

-Warming water temperatures because of global warming will impact temperature dependent species. Temperature tolerances often govern both the local and biogeographic distribution limits of freshwater fishes (Carpenter et al., 1992).

-Distributions of aquatic species will likely change as some species invade more high altitude habitats or disappear from the low altitudinal limits of their distribution. Elevated temperatures may also result in reduced water dissolved oxygen concentrations, which may have immediate adverse effects on eggs and larvae, which rely on dissolved oxygen for survival (Carpenter et al., 1992).

- Increased water temperatures and reduced precipitation may also reduce suitable habitat during dry, warm summer months and potentially lead to increased exotic species. Exotic fish species often out-compete native species for habitat and food resources and lead to declines in native populations and decreased species diversity (Latini and Petrere Jr, 2004).

- Decreased precipitation during dry months will affect many Amazonian streams and freshwater systems. Small, shallow habitats (ponds, headwater streams, marshes, and small lakes) will likely experience the first effects of reduced precipitation (Carpenter et al., 1992).

-Even short-lived stresses such as temporary climatic extremes can cascade throughout the tropic network for extended periods. Fish adapted to cooler water temperatures are most vulnerable to climatic extremes such as warm water conditions because they rely on constant temperatures.

- Extreme climatic events, such droughts induced both by natural climate variability of human activities can fragment the Amazon Forest and transform an area of approximately 600,000 square kilometers in a savanna.

Fig. 3 shows the annual rainfall and temperature anomalies from the A2 and B2 scenarios foe the future, as represented by the ensemble of the three regional models used for CREAS.

The figure shows that changes in A2 are more radical and regionally comprehensive as compared to those of B2. While the drier region (between 1 and 2 mm/day) in B2 cover mostly northern Amazonia, the die region in A2 extends into eastern Amazonia and the entire state of Para, with the larges reductions nearby the mouth of the Amazon River.

In relation to annual temperature changes, in the scenario A2 the entire tropical South American region may become 4-6 °C warmer, and up to 8 °C warmer than normal in central equatorial Amazonia. In the B2 scenario the warming all across Amazonia varies between 2-4 °C with the warmest in central equatorial Amazonia by 4-5 °C. The possible impacts on these changes are shown in Fig. 4, with the more intense impacts on the A2 scenario

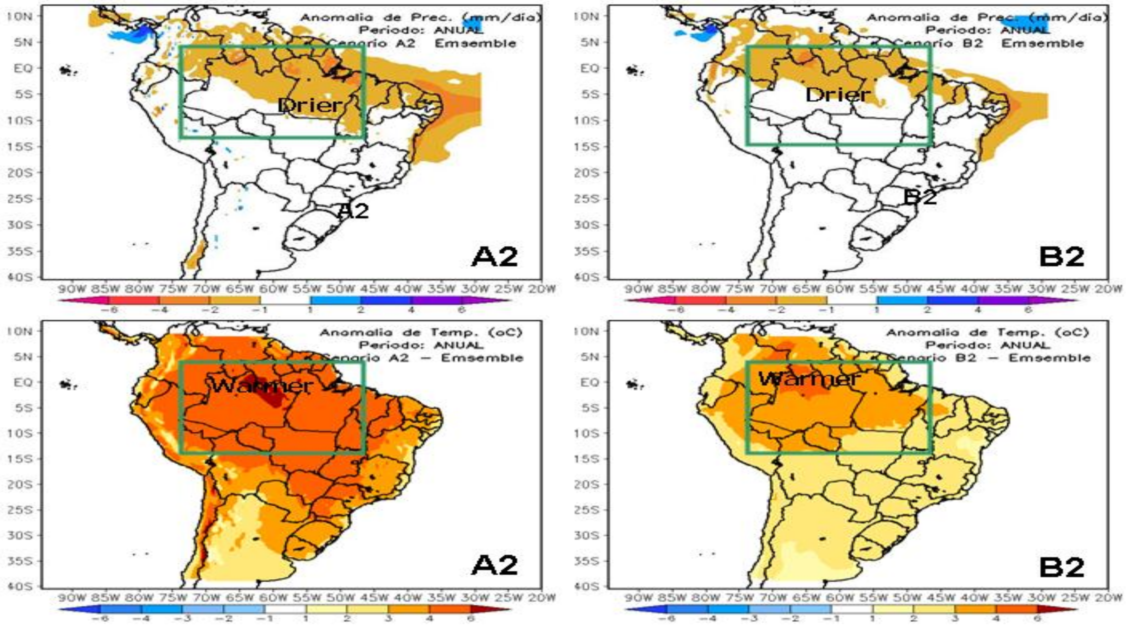

Figure. 3. Projected changes in annual rainfall and air temperature anomalies for the Scenarios A2 (Left) and B2 (right). Units are mm/day (rainfall) and (°C) for temperatures. Results are the ensemble of 3 regional models (Eta/CPTEC, RegCM3 and HadRM3P) for the period 2071-2100 relative to 1961-90. Green square represents the Amazon region (Source: Ambrizzi et al. 2006).

A2 scenario (High emissions)

Amazonia: 4-8 ºC warmer and 15-20% less rainfall and possible delay in the onset of the rainy season, and afecting most of northern and central Amazonia. Possible effects in biodiversity and natural ecosystems. Lower river levels affecting transportation and commerce and the generation of hydroelectricity. Drier atmosphere that favors the onset and spread of forest fires. Smoke from fires can affect population. Possible increase in the frequency and intensity of waather and climate extremes

B2 scenario (Low emissions)

Amazonia: 3-5 ºC warmer and 5-15% drier. The impacts are less regionally extended than in A2. Changes can affect population and biodiversity but in less degree than the A2 Scenario. Impacts on river levels and the onset of forest fires may be less intense than in A2. Warming and drying is more intense in northern Amazonia.

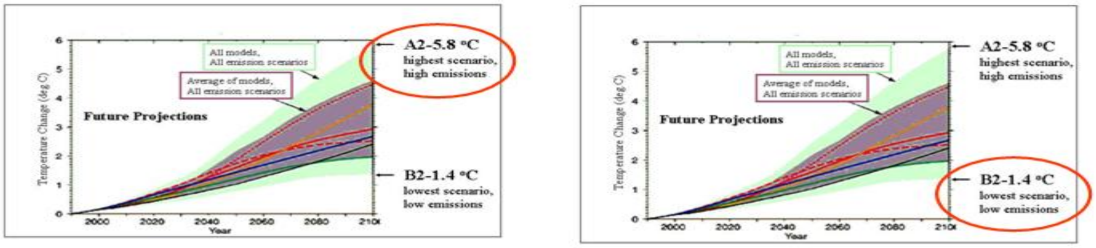

Figure. 4. Summary of projected changes in regional annual rainfall and air temperature anomalies for the Scenarios A2 (Left) and B2 (right) and their expected impacts

International initiatives and programs such as LBA project (Brazil-European Union-US-Some Amazon countries), HYBAM (IRD France and Peru, Ecuador, French Guiana, Bolivia and

Brazil), and TROPENBOS (The Netherlands and Colombia, Guyana and Surinam) were able to solve this problem at least partially since they have a life span of few years. However, these projects were more concerned with climate and natural climate variability in the short term and impacts on ecology and not on climate change.

There is an imbalance among countries, Brazil leads the studies, research and hydrological and climatic monitoring activity in the whole basin and the LBA project is one example. Technical, logistic, financial and sometimes politic constraints preclude the Amazon countries to joint efforts in studies on variability of climate and water resources, especially considering the hydroelectric generation potential of the basin, and the possibilities of deforestation in the Amazon and global warming affecting negatively this potential.

In fact, one common thing in most of the Amazon countries is that there are assessments of possible changes in water availability (rainfall, streamflow) in agriculture, hydroelectric generation and other activities as a consequence of climate change at a country level, as shown in their respective National Communications the UNFCCC. With the different methodologies used it is almost impossible to integrate all of these in one representative of the entire Amazon region.

3. COMMUNITIES IN RISK AND VULNERABLE ECOSYSTEMS IN AMAZONIA

Despite world concerns and international efforts to conserve natural resources, tropical forests continue to disappear at unprecedented rates. In establishing systems for the sustainable management and exploitation of tropical forests, issues relating to the way in which human activity affects the basic ability of forests to self-regenerate are vitally important; so is the preservation of basic ecological processes such as biological productivity and recycling of water and nutrients.

It can be presumed that changes to the cycles of water, energy, carbon and nutrients that result from replacement of Amazonian vegetation will have consequences for climate and the environment at local, regional and global scales. The conversion of primary tropical forest to agricultural areas or secondary vegetation represents one of the most profound changes to the natural environment of the present age.

Population growth in Amazonia from 3,5 million in 1970, up to 20 million in 2000, though 65% living in large and mid-size cities and towns, and colonization projects have produced rush of landless people to small scale, low tech agriculture with subsidized cattle ranching. During the last 20 years the land use change is causing an unprecedented imbalance in Amazonia, and possible consequences are biodiversity losses of unknown magnitude and significant alterations on natural cycles of water, carbon, trace gases, aerosols, and nutrients.

The knowledge of the variations if the infectious diseases cycles at regional levels is still incomplete in Amazonia, mainly due to the large extent of the region and its environmental heterogeneity. It is also important to know seasonal or interannual climate variability modulate the intensity of diseases. Historically, research in epidemiology has been limited to specific risk situations (frequency of cases during some periods of epidemic) without worrying about its links to environmental variability.

With the advance of forest clearance and the establishment of agriculture, ranching, and urban development, malaria transmission is substantially reduced, and risks of new infection are largely driven by human behavioral factors. Malaria mitigation strategies for frontier settlements require a combination of preventive and curative methods and close collaboration between the health and agricultural sectors.

Forest fires have significant sanitary, economic and environmental effects. Climate change is likely to affect the risk of forest fires, which in some countries, such as Brazil, have been associated with the increase risk of outpatient visits for respiratory disease (Haines and Patz, 2004), and increased risk of respiratory disease, eye problems, injuries and fatalities (Haines *et al*., 2000; Patz, 2004).

As far as natural ecosystems are concerned, tropical forests of Latin America, particularly those of Amazonia, are increasingly susceptible to fire occurrences due to increased El Niño-related droughts and to land use change (deforestation, selective logging, forest fragmentation) (Nepstad *et al*, 1999, Fearnside, 2001). One of the most important losses due to climate change in Amazonia is biodiversity given its ecological and economical importance High risk of forest loss due to global warming is shown by Schloze et al. (2006) for Amazonia, with more frequent wildfires. The current levels of biodiversity are still unknown.

Burning in Amazonia has been almost entirely restricted to areas where trees have been felled and allowed to dry before being set alight. Fire normally stops burning when it reaches the edge of a clearing rather than continuing into unfilled forest. Archaeological evidence suggests that catastrophic fires have occurred in Amazonia during major El Niño events four times over the past 2,000 years: 1,500, 1,000, 700, and 400 BP (Meggers, 1994). Human action could now turn less intensive El Niño events, which are much more frequent than major ones, into catastrophes.

Subsistence farming in the Amazon is particularly threatened by warming and drying during critical seasons. In northeastern Brazil, people have been suffering from decreased agricultural yields that are among the most severe in the world. More than 45 million people live in this region, which is prone to periodic droughts and famines. Slight climate changes in this region will likely have major consequences for human populations.

4. CONCLUSIONS

This report shows a review if what us known on terms of climate and hydrology variability in the Amazon basin in the present, and also provides some information on what could be the future climate in the region as a consequence of the increase in the concentration of greenhouse gases and from land use changes due to deforestation.

The document constitutes an state-of-the art in the review on climate and hydrological variability in the basin, considering the evolution of the knowledge of the hydrological cycle in the basin since the late 1970´s, when the papers by Salati showed the importance of the forest in the moisture recycling in the basin, and on the results of deforestation in the Amazon in the regional and global climate as suggested by early experiments using climate models and scenarios of deforestation.

The report exhibits a comprehensive review of climate variability and change and impacts in the Amazon basin, and well as on climate variability, with examples of some extreme events as the droughts and their impacts in the society and ecosystems. This provides the basis for analysis of model simulations and projections of climate change.

Currently, the models used by the IPCC TAR and AR4 have allowed for a more sophisticated and complex representation of climate processes and feedbacks, including the role of the ocean and vegetation dynamics. Future climates for the Amazonia simulated by those models have suggested, with some degree of uncertainty, that in for the high emission scenario A2, temperatures in the Amazon basin would show warming of up to 8 °C, with reductions of rainfall by about 20%.

These changes due to an increase of greenhouse gases concentration would may results in a warmer and drier Amazonia, with conditions that would allow for the propagation of forest fires, and the tropical forest can collapse, varying from a sink of carbon to a source of carbon, and becoming savanna type vegetation by the years 2040-2060. The drier climate in the region would also impact levels of rivers in the region, and also moisture export for other regions outside Amazonia, thus affecting the hydrological cycle in the region.

Most of the knowledge we have on extreme hydroclimatic events in the Amazonia are mainly based on studies of extreme droughts, such as those related to El Nino in 1926, 1983, 1998 and those non related to El Nino but to warming in the tropical North Atlantic as in 1964 and 2005. Rainfall and river anomalies observed during those events have been considered as a sample on what could be expected in the future under global warming, still the uncertainties are high.

We have learned about impacts on the population, biodiversity and local and regional economies by studying the 2005 drought in Amazonia. The impacts on the local economy were mainly reflected in the closing of the airports due to the large amounts of smoke and the closing of ports due to the extremely low levels in river that did not allow the navigation of ships. To this we should add the problems of the population due to the collapse of local agriculture, the number of people treated at hospitals due thermal stress and respiratory and intestinal diseased from smoke from forest fires and polluted water showed that people in Amazonia is vulnerable to drought, and this vulnerability could be aggravated in warmer-drier climates in the future as suggested by some models. The costs are high, but it will be more expensive if the governments do not come with measures to cope with climate change.

The lack and the difficult access to hydrometeorological data, as well as the poor network of climatic stations in large sections of the basin do not allow for a detailed analyses of tendencies and characteristics of extreme weather and climate events in the basin. Models show for the future that heat waves and intense rainfall events, as well as intense dry spells could occur in the Amazonia. However, the lack of climatic and hydrological data with an adequate time and space resolution do not allow for an detailed knowledge of weather and climate extremes in the Amazon region.

The suggestion that the OATC should somewhat work with the meteorological and hydrological services in the basin to allow for access to data is something that this institution should consider carefully. Problems in data access are common in all countries. May be the implementation of a regional climatic and hydrological data should be the solution. Data access and availability is a major problem in South America in general, and any action from OATC with the National Meteorological Services to allow for data access or for an implementation of a regional data bank is welcome.

Some regional experiments and programs such s LBA and GEOMA have helped on the improvement of the knowledge of the functioning of the Amazon region in present climates, but most of the scientists and participant institutions are mainly from Brazil. Some of the observational networks developed in the Brazilian Amazonia, such as SIPAM, could be extended to other Amazon countries with the help of the OATC as mediator among governments so the SIPAM could be extended to the entire Amazonia.

It is here believed that there is an imbalance in research and operational activities Among Amazon countries regarding studies on climate change and impacts in society, biodiversity and population.. Brazil is developing since 2004 programs and studies directed to the development of climate change scenarios, and to assessments of vulnerability of society, biodiversity and water resources due to climate change. Other countries still have not developed this technology and depend on whatever they can get from international office or from Brazil. In that sense, there are a set of recommendations (see next section) directed to an implementation of training and capacity building activities linked to various aspects of climate change, such as modeling, detection techniques, downscaling and vulnerability assessments, and the assessments of impacts and mitigation and adaptation measurements.

Brazil is leading efforts on regional modeling of climate change with the CREAS project, and Amazon countries are more than welcome to access future climate change projections for their own countries. May be a coordination of methods and techniques for impacts and vulnerability and impacts assessments common to the entire basin is needed, so integration of regional results would be less complicated.

Finally, we noticed that the Amazon countries that still need some help in terms of detection of climate change and impacts assessments are Suriname and Guyana that seem a bit isolated from the other Spanish or Portuguese speaking Amazon countries. Venezuela and Bolivia are doing some studies on impacts and vulnerability but they still do not show a major integration with Brazil, Peru and Colombia.

5. RECOMMENDATIONS

The OATC Secretary is trying to integrate and to establish science and technology policy that includes the "extension" and application of the SIPAM (Sistema de Proteção da Amazônia) Brazilian developed technology to all Amazon countries. A recent Project introduced by the Núcleo de Assuntos Estratégicos (NAE) from Brazil is directed to the implementation of the largest data bank in the Amazon region. The goal of this initiative is to make available different studies relevant to the Amazon rain Forest developed in the past, as well as to encourage and integrate research activities in the Amazon Basin in the most democratic way.

This is a big challenge, since only 10% of research focused in Amazonia has been developed inside the Amazon countries (From Brazil International Gazeta, 2006).

The LBA project has developed since 1996 it Phase I, and as a consequence of this an extensive research agenda has been implemented in the Amazon countries, mainly the Brazilian Amazonia, in the fields of ecology, hydrology, climatology, human dimensions and economy, and they have implemented the LBA-Data Information System), and the archive include thousands of studies and reports and also different levels of environmental data that area available to all Amazon scientists and governments.

The LBA Phase II looks for an integration of data sets and studies and Pan Amazonian levels, and we expect that the OATC would help to make LBA Phase II the most democratic possible at the different levels of society, science community and government.

The Rede Temática de Pesquisa em Modelagem da Amazônia (GEOMA) is an initiative funded by the Brazilian government, and has as a major objective the development of models and methodologies able to simulate the dynamics of ecological and soci-economic systems at different geographical scales, within the context of sustainability and in support of decision making at the local, regional and national levels. The GEOMA Network is based on an interdisciplinary approach, teaming experts in mathematical and computational modeling, economy, geographical information systems remote sensing, ecology, demography, meteorology, hydrology among other sciences.

The GEF-Amazonas OATC/PNUMA/OEA relevant to current efforts and projects associated with the LBA project, as well as with new initiatives on studies about climate change assessments and their impacts in key regions of South America, including Amazonia, developed by CPTEC/INPE, funded by the GEF/MMA-PROBIO from the Ministry of Environment in Brazil and the GOF-FCO of the British Government. This is the CREAS (Cenarios REgionalizados de Clima para America do Sul) project.
Current studies being done for regional projects in South America, such as CREAS (Marengo and Ambrizzi 2006) have been hampered by the very weak evidence of regional observed climate variability in present times, especially for climate extremes consequence of the absence of good quality climatic data needed for studies on climate extremes in the basin.

One important aspect of these projects is the application to vulnerability assessments of key sectors of society, with the objective to influence policy makers and governments in an effort to cope with climate change.

Some of climate change studies and projects have produced results at the catchments level in individual countries that can not be up-scaled for the whole basin, and in other the methods used and the treatment for data are not compatible and it is hard to inter-compare results and estimates among different Amazon countries.

Water and climate are “strategic resources”, and there is a need to quantify their variability and change, as well as to project its availability in the future. The idea of an integrated network of hydrometeorological observations, with data sharing among all Amazon countries should be considered as the main solution to this lack of integration and would reduce the uncertainties in the water balance and hydrometeorological studies on the region.

The monitoring of the meteorological and hydrological network is a real problem, since large sections of the basin are without data coverage and the number of stations is decaying since the late 1970's, being replaced by automatic weather and hydrological stations that provide data but only from recent years.

After the analysis at country level, it has been observed major differences in the availability of climatic and hydrological observed data. Since these data are a fundamental part of the studies on long term climate variability (a first step towards the study o climate and hydrological change), it is noted a lack of integrated assessments of studies on climate variability and change in Amazon´s water balance, as well as on climate trends and water resources variability for the whole Amazon Basin, with the participation of all Amazon countries and with common methodologies and strategies that would allow for a regional integration.

In the past, some international initiatives and programs such as LBA (Brazil-European Union-USA-Some Amazon countries), HYBAM (IRD France and Peru, Ecuador, French Guiana, Bolivia and Brazil), and TROPENBOS (The Netherlands and Colombia, Guyana and Surinam) have been able to solve this problem at least partially during their life span of few years. Something more permanent is needed.

We believe that an effort lead by the OATC, via the GEF-Amazonas could result on the establishment of a common framework for studies on climate variability and change in climate and water resources at a regional level. This effort can involve the major players listed in Section 5, including major water agencies in the Amazon countries, the NMHS (from civilian and military activities), universities, NGOs and research institutes.

The OATC should assume an integrator role given the current sometimes disarticulated coordination among different countries. It is firmly believed that the OATC has the political potential as a regional articulation mechanism to promote the integration of Amazon countries and its institutions to joint experiences, knowledge and resources within the context of sustainable use of its water resources.

Specifically, we propose a partnership sponsored by the OATC on the scientific-environmental-political framework, towards the integration of studies, monitoring activities, and future planning of the water resources in all countries in the region.

To accomplish this, we suggest these lines of action coordinated by the OATC:

a) An implementation of a Regional Climatic and Hydrological Archive for the Amazon region, with the contributions from the NMHS (that are the main responsible for data collection), and other agencies that collect hydrological and climatic data in Amazon countries, such as the National Water agency in Brazil (ANA), and the Navy in Peru (DHN).

b) An implementation of a Regional Archive of future climate and hydrological change global and regional model projections for the Amazon region, where climate and hydrological fields, including statistics of mean and extreme, and uncertainty estimates could be made available for scientists working on climate change and impacts in Amazonia.

c) The SIPAM program also could be extended to all Amazon countries. It is clear that data collected from SIPAM in every country will be shared among scientists working in Amazonia, may be under the umbrella of OATC. This will help a lot on the monitoring of extreme conditions, as it was the case of the drought of Amazonia in 2005.

These three actions certainly will depend from the governments of all the Amazon countries, and certainly the role of the OATC as facilitator will help on the negotiations for access to data or at least limited sets of data for Amazonia, both from observations and from the climate change projections.

We propose some specific activities, and information on time lines and estimated costs can be found in the final report:

a) Data archaeology, including the search of climatic and hydrological data for all Amazon countries, searching the archives of the NMHS, regional civil and military data banks and others sources of data

b) Search and compilation of references, studies and other documents (including internal reports and unpublished material) relevant to climate change in Amazonia, and to its impacts on society and natural ecosystems. This is a continuous work, free of cost and may take all the period of the project. At the end, we expect to implement a documentation center that will hold of this information, and can be updated and on permanent basis.

c) Identification of variables that can be considered for studies on impacts of climate and hydrological change. These variables can be defined according to the needs of the scientists that will study the impacts.

d) Assessments of strategies for model assessments, as well as definition of the global and regional models to be used. It is advisable to choose the wide variety of models available from the IPCC AR4 at the IPCC Data Distribution Centre, and then analyze the individual global models and an ensemble of them for mean and extremes of climate simulations for the present.

e) Assessments of future regional climate change scenarios using the climate change scenarios derived from CREAS. This is an ongoing activity and the proposed time line is for refinements for the Amazon region. The analyses will include means and extremes, as well as uncertainty assessments for the entire Amazon region. This work can be done by a consultant during 6 months. The final product will be thematic maps of climate change scenarios in the region, usable in GIS format, and accompanied by comprehensive reports.

f) Training courses and workshops (2) for scientists in Amazon countries on the analyses and assessments of future climate change scenarios, including the preparation of maps and the statistical analyses of the scenarios. Two 1-week hands-on courses are being proposed, to take place in 2 Amazon countries hosted by institutions that have computer equipments suitable for the analyses of climate change projections, for about 30 people for course

g) A 4-day Workshop on vulnerability to climate change in Amazonia, directed for scientists working on climate change and impacts in Amazonia. This workshop could be planned for the first quarter of 2008, hosted by an Amazonian institution either from Bolivia (Santa Cruz) or

Colombia (Leticia). The GEF-Amazonas can fund the participation of about 30 participants and 5 speakers, as well as the logistic aspects in the host city. We expect that the host institution can provide some in kind contribution, and that local and regional governments and NGOs can send participants at their own expenses for about 30 participants. We can ask IAI for additional support (may be for 3 or 4 additional participants and 1-2 speakers). We expect a total of about 70 people.

h) Implementation of progress reports indicating how the project is going on, press releases, scientific documents and papers all along the duration of the project.

The following is a proposal for timetable for these activities and costs. We assume that year 1 of the project is 2007.

Year	2007												2008											
Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
4.a	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	x	x	x
4.b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	x	x	
4.c										x	x	x	x	x	x									
4.d															x	x	x	X						
4.e																			x	x	x	x	x	x
4.f																					x			
4.g																								
4.h			x			x			x			x			x			X			x			x

Year	2009												2010											
Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
4.a	x	x	x	x	x	x	x	x	x	x	x	x												
4.b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	x	x	x
4.c																								
4.d																								
4.e																								
4.f										x														
4.g																				x				
4.h			x			x			x			x			x			X			x			x

This is a proposed budget for these activities during the 4 years of the project, in US $ Dollars

Activity	Year 2007	Year 2008	Year 2009	Year 2010	Total
4.a	2,000.00	2,000.00	2,000.00	2,000.00	8,000.00
4.b		8,000.00			8,000.00
4.c	6,000.00	2,000.00			8,000.00
4.d		9,000.00			9,000.00
4.e					
4.f		60,000.00	60,000.00		120,000.00
4.g				60,000.00	60,000.00
4.h	2,000.00	2,000.00	2,000.00	2,000.00	8,000.00
Total	10,000.00	83,000.00	64,000.00	64,000.00	221,000.00

6. MAIN ACTORS

This is a list of institutions that develop monitoring and climate change activities, as well as impacts in various sectors of society in each country. Some of these institutions are the focal point at the government level, such as Ministries of Environment, National Meteorological Services, as well as other institutions linked to the governments. Other institutions are science oriented, such universities and research centers, and also NOGs, such as Greenpeace, WWF at each country. For a complete list of these institutions (including web sites) and others per country, as well as international institutes and projects/programs, please refer to Appendix I.

The OATC should assume an integrator role given the current sometimes disarticulated measurements among different countries. It is firmly believed that the OATC has the political potential as a regional articulation mechanism to promote the integration of Amazon countries and its institutions to joint experiences, knowledge and resources within the context of sustainable use of its water resources. Specifically, we propose a partnership sponsored by the OACT on the scientific-environmental-political framework, towards the integration of studies, monitoring activities, and future planning of the water resources in all countries in the region.

Colombia

-Instituto de Hidrología, Meteorología y Estudios Ambientales, IDEAM, Bogotá
-Instituto del Medio Ambiente-Universidad Nacional de Colombia, Bogotá
-Alexander von Humboldt Biological Resources Institute, Bogotá
-Amazon Scientific Research Institute –SINCHI, Bogotá
-Instituto del Agua-Programa de Postgrado en Aprovechamiento de Recursos Hidraúlicos, Universidad Nacional de Colombia, Medellín
-Instituto de Ciencias Naturales- Universidad Nacional de Colombia, Bogotá
-TROPENBOS International, Bogota

Peru

-Servicio Nacional de Meteorología e Hidrología SENAMHI, Lima
-Consejo Nacional del Medio Ambiente, CONAM, Lima
-HIBAM-IRD (Hidrogeodinámica de la Cuenca Amazónica) Project that includes Brazil, Perú, Bolivia, Ecuador and France, Lima
-Instituto de Investigaciones de la Amazonía Peruana IIAP, Iquitos
-Instituto Nacional de Recursos Naturales INRENA, Lima
-SIAMAZONIA -Sistema de Información de la Diversidad Biológica y Ambiental de la Amazonia Peruana, Lima
-Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú, Lima, Iquitos.

Venezuela

-Ministerio del Ambiente, Caracas
-Servicio Meteorologico Nacional-MARN, Caracas
-Instituto Venezolano de Investigación Científicas (IVIC), Caracas,

Bolivia

-Servicio Nacional de Meteorología e Hidrología SENAMHI, La Paz
-HYBAM-IRD, La Paz
-Universidad Mayor de San Andrés UMSA, La Paz
-Programa Nacional de Cambio Climático-Ministerio de Desarrollo Sostenible y Planificación, La Paz, Bolivia

Ecuador

-Instituto Nacional de Meteorología e Hidrología INAMHI, Quito
-Ministerio del Medio Ambiente, Quito
-Comité de Cambio Climático del Ecuador (parte del Ministerio del Medio Ambiente), Quito
-HIBAM-IRD, Quito
- National Water Resources Council, CNRH,
-Committee for Nature Defense and Environment CEDENMA

Guyana

-Hydrometeorological Service-Ministry of Agriculture, Georgetown
-National Climate Committee (NCC), Georgetown
-Environmental Protection Agency EPA, Georgetown
-Iwokrama, Georgetown
-TROPENBOS, Georgetown

Suriname

-National Institute for Environment and Development of Suriname (NIMOS), Paramaribo
-TROPENBOS, Paramaribo

-Department of Natural Resources and Environmental Assessment NARENA, Paramaribo
-CELOS - Centre for Agricultural Research in Suriname, Paramaribo

Brazil

-Centro de Previsão de Tempo e Estudos Climáticos CPTEC/INPE, São Paulo
-Instituto Nacional de Meteorologia INMET, Brasília.
-Programa Nacional de Mudanças Climáticas, Ministério da Ciência e Tecnologia, Brasília
-Núcleo de Assuntos Estratégicos, Brasília
-Instituto Nacional de Pesquisas da Amazonia INPA, Manaus.
-Agencia Nacional de Águas (ANA), Brasília.
-Fundação Brasileira de Desenvolvimento Sustentável, Rio e Janeiro
-HYBAM-IRD, Brasília
-Universidade de São Paulo USP-IAG, Departamento de Ciências da Atmosfera, São Paulo.
-Universidade Federal do Para UFPa, Belém.
-Empresa Brasileira de Pesquisas Agropecuárias EMBRAPA-Oriente, Belém
-Universidade de São Paulo-CENA, Piracicaba.
-Instituto de Pesquisa Ambiental da Amazônia – IPAM, Belém, Santarém, Brasília.
-Instituto do Homem e Médio Ambiente da Amazônia-IMAZON, Belém.
-PROBIO, Ministério do Meio Ambiente, Brasília.
-Instituto de Pesquisas Econômicas Aplicadas IPEA, São Paulo.

CHANGES IN THE HYDROCLIMATOLOGY OF THE AMAZON BASIN AND DERIVED RISKS FOR HUMANS AND VULNERABLE ECOSYSTEMS

SUMMARY

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ACRONYMS

AR4	IPCC Fourth Assessment Report
CEDENMA	Committee for Nature Defense and Environment of Ecuador
CNRH	National Water Resources Council of Ecuador
COLA	Center for Ocean, Land and Atmosphere
CONAM	Consejo Nacional del Médio Ambiente, Perú
CPTEC	Centro de Previsão de Tempo e Estudos Climáticos, Brazil
CREAS	Cenários Regionalizados de Mudanças de Clima para América do Sul
CRU	Climate Research Unit, UK
ENSO	El Niño Southern Oscillation
FCO	Foreign Commonwealth Office, UK
GEOMA	Rede Temática de Pesquisa em Modelagem da Amazônia
GPCC	Global Precipitation Climatology Center
GCM	General Circulation Model
GEF	Global Environmental Facility
GHG	Greenhouse Gases
GOF	Global Opportunity Fund, UK
GISS	Goddard Institute for Space Studies
INPE	Instituto Nacional de Pesquisas Espaciais, Brazil
IPCC	Intergovernmental Panel on Climate Change
LBA	Large-Scale biosphere Atmosphere Experiment in the Amazon Basin
LLJ	Low Level Jet east of the Andes
NCC	National Commission on Climate Change of Ecuador
NMHS	National Meteorological and Hydrological Services
ACTO	Amazon Cooperation Treaty Organization
OEA	Organización de los Estados Americanos

PNUMA	Programa de la Naciones Unidas para el Medio Ambiente
PNCC	Programa Nacional de Cambio Climático, Bolivia
PROBIO	Projeto de Conservação e Utilização Sustentável da Diversidade Biológica Brasileira, Brazil
SIPAM	Sistema de Proteção Amazônica, Brazil
SRES	IPCC Special Report on Emission Scenarios
SST	Sea Surface Temperature
TAR	IPCC Third Assessment Report
UK	United Kingdom
UNESCO	United Nations Education, Science and Culture Organization
UNFCCC	United Nations Framework of Climate Change Convention
WWF	World Wildlife Fund for Nature

INTRODUCTION

The Amazon River Basin is the world's largest drainage system. This river provides 16% of annual global river runoff, and 27% of the world water resources are formed by the five largest river' systems: Amazon, Ganges with Brahmaputra, Congo, Yangtze, and Orinoco (UNESCO, 2001). In fact, 1,100 rivers make up the Amazon system. The source of the Amazon River is a small river, the Apurimac, located at 17,200 feet above sea level.

The 1,100 tributaries flow through nine of the South American countries: Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname and French Guiana (Table 1). The Amazon River and its tributaries drain most of the area of heavy rainfall. The area is called Amazonia and most of it is a sparsely populated rainforest. Most of the Amazon Basin is in Brazil (Amazonia Legal). The Amazon River represents 16% of annual global river runoff

Table 1. Amazon Basin by countries. Area is in Km^2.

Country	Area	Area Amazonia	% of country's area	% of Amazonia per country
Brazil	8511.9	4982.0	58.5	63.4
Bolivia	1098.5	824.0	75.0	10.5
Peru	1285.2	651.0	51.0	8.3
Venezuela	912.0	419.0	46.0	5.3
Colombia	138.3	406.0	36.0	5.1
Guyana	214.9	214.9	100.0	2.7
Suriname	142.8	142.8	100.0	1.8
Ecuador	270.6	123.0	45.0	1.6
French Guiana	91.0	91.0	100.0	1.2
Total	13665.2	7853.7	67.9	100.0

Source: OATC

The Amazon River flow regime is subject to interannual and long term variability represented as large variations in downstream hydrographs. The flow regime of this river system is relatively un-impacted by humans, and is subject to interannual and long-term variability in tropical precipitation, that ultimately is translated into large variations in downstream hydrographs. This river drains an area of 6.2×10^6 km^2 and discharges an average of 6300 km^3 of water to the Atlantic Ocean annually.

During recent 25-30 years all over the world there is an especially intensive anthropogenic change of hydrologic cycle of rivers and lakes, their water quality, water resources and water budget. The values of water resources, their dynamics with time and distribution over the territory are now determined by not only natural climate variations, as it has been previously, but also the man's economic activities. In many regions and countries of the world, water resources are quantitatively depleted and much contaminated.

Of vital importance in developing sustainable management and exploitation systems for tropical forests are the questions as to how far human intervention affects the forests' basic capacities to renew themselves and how to safeguard the basic ecological processes such as biological productivity and nutrient and water cycling. Altered cycles of water, energy, carbon and nutrients, resulting from the changes in Amazonian vegetation cover, are expected to have climatic and environmental consequences at local, regional and global scales.

Even though the Amazon region can be considered as a closed system, the region constitutes a source of atmospheric moisture for other regions in the continent. Moisture transport in and out of the Amazon basin has also been studied since the 1990's using a variety of data sets. The regional circulation features responsible for this transport and its variability in time and space have been detected and studied using observations collected during short-term field experiments.

This feature is the South American Low Level Jet east of the Andes (LLJ, Fig. 1) and represents a regional circulation pattern in South America that could be described as a moisture corridor that brings moisture from the Amazon Basin to the southern Brazil-Northern Argentina region of the Paraná-La Plata Basin, especially during the warm rainy season (Marengo et al., 2004; Vera et al., 2006). Concerns are great regarding the possible role of climate change (warming and drying) in the Amazon on the climate of the Paraná-La Plata Basin.

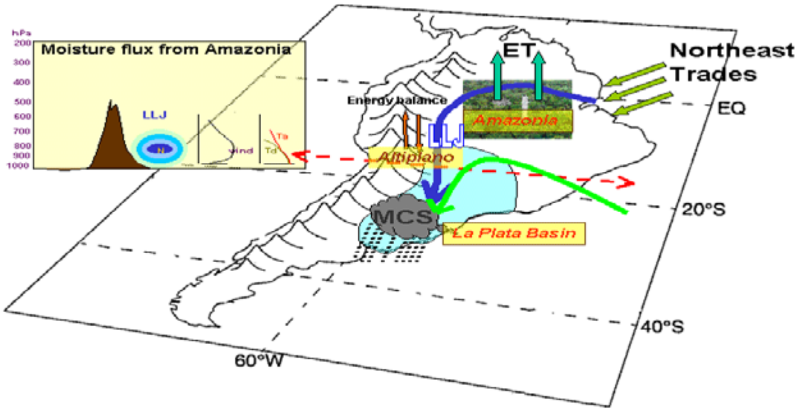

Figure 1. Conceptual model of the South America Low Level Jet east of the Andes (LLJ) transporting atmospheric moisture from the Amazon into the Piranha-La Plata Basin (Marengo et al. 2004).

The Amazon region can be categorized as a region at great risk from climate variability and climate change. The risk is not only due to projected climate change but also through synergistic interactions with existing threats not related to climate change, such as land clearance, forest fragmentation and fire. Over the next several decades there is a risk of an abrupt and irreversible replacement of forests by savannah with large-scale loss of biodiversity and loss of livelihoods for people in the region.

On the basis of what is now known on climate variability in Amazonia, and on the role of the moisture transport in and out of the basin as suggested by observational and modeling studies, a question arises: what would be the possible impacts of regional scale deforestation or of the increase of greenhouse gases concentration in the atmosphere on the climate of the Amazon and neighboring regions?.

The recent drought in 2005 that affected large sections of the western Amazon Basin in 2005 has shown how vulnerable is the population to extreme climate events. This drought was the most severe the past 40 years and also one of the most intense of the last 100 years. The drought has evaporated whole lagoons, and kindled forest fires, killed off fish and crops and protected species, stranded boasts and the villagers, who travel by them, brought disease and wreaked economic havoc.

Therefore, the main purpose of this report is to investigate and assess the risk associated with climate variability and climate change in the hydroclimatology of the Amazon region, as its impact on natural ecosystems and society.

Some specific objectives are listed below, and are discussed on the upcoming sections

(a) To provide a historical review in the evolution of studies of the climatic variability and change in the Amazon basin,
(b) To provide historical evidences of extreme hydroclimatic events in the region,
(c) To investigate and document the impacts of climate variability and change in all the Amazon countries,
(d) To discuss future climate change scenarios produced by global and regional models in the basin,
(e) To assess impacts derived of climate change in the Amazon countries and how population natural ecosystems would be vulnerable.

A final objective will be to assess the degree of vulnerability of the Amazon basin to climate change in order to provide basis for vulnerability assessments and adaptation measurements. The document is organized in chapters that discuss climate variability and change and their risks, their impacts on the region at the level of country and basin wide, the vulnerability of society and natural ecosystems to climate change, and finally we provide recommendations

The present document represents a contribution to the **Projeto Gerenciamento Integrado e Sustentável dos Recursos Hídricos Transfronteiriços na Bacia do rio Amazonas – Projeto GEF Amazonas OATC/PNUMA/OEA.** The GEF-Amazonas OATC/PNUMA/OEA

The OATC has as a goal the reinforcement of the institutional framework to plan and execute, in a coordinated effort activities of protection and sustainable management of water and soil in the Amazon Basin to cope with the impacts associated with climate change due no natural and anthropogenic causes.

This activity is linked to current efforts and projects associated with the LBA project, as well as with new initiatives on studies about climate change assessments and their impacts in key regions of South America, including Amazonia, developed by CPTEC/INPE, funded by the **GEF/MMA-PROBIO** from the Ministry of Environment in Brazil and the **GOF-FCO** of the British Government.

One important aspect of these two projects is the application to vulnerability assessments of key sectors of society, with the objective to influence policy makers and governments in an effort to cope with climate change.

1. CLIMATE CHANGE AND DERIVED RISKS

1.1 Climate change and impacts in the Amazon region

1.1.1 Climate variability and change in the Amazon Basin: A review

Climate variability and change, due to both natural climate variability or to the increase in the concentration of greenhouse gases in the atmosphere of anthropogenic origin may have a potential to accelerate the hydrologic cycle, and the Amazon region would be one of the most affected regions.

Changes in land use patterns due to deforestation might produce changes in latent heat and can ultimately influence Land-use practices, such as deforestation leading to agriculture or urbanization often disrupt the supply of fresh water through changes in the surface water balance and the partitioning of precipitation into evapotranspiration, runoff and groundwater flow. However, trends in long term rainfall or river discharge variability identified in the middle 1970's (Gentry and Lopez Parodi 1980) as possible consequence of deforestation have proven not to be entirely true.

Long term variability of rainfall and river discharge in Amazonia seem to be linked to decadal variability, linked to natural causes and not to land use changes alone. The extremes in the variability have been linked to drought related to El Niño in 1926, 1983, 1998 (Marengo 2004, Ronchail et al 2002), or to warming in the tropical North Atlantic, as in 1963 and 2005 (Marengo et al. 2006).

Costa et al., (2003) have identified increases in the annual mean and the high flow season discharge of the Tocantins Rivers basin (176,000 km^2 area) in eastern Amazonia since the late 1970's, even though rainfall has not increased. They suggest that changes in the land cover in the basin for agricultural purposes and urban development have altered the hydrological cycle of the basin. For instance, the Tocantins River showed a ~25% increase in river discharge between 1960 and 1995, coincident with increasing deforestation but no significant changes in precipitation.

Callede et al., (2004) suggest that increases in the mean annual discharge of the reconstructed series of the Amazon River at Óbidos during 1945-98 could be the consequence of Amazon deforestation. Same tendency was found for the Mamore River in the Bolivian Amazonia (Ronchail et al. 2004).

They also found a break in 1970, for the mean annual discharges as well as for the floods, that agrees with the decadal variability in Amazon rainfall as identified by Marengo (2004) in northern and southern Amazonia, attributed to natural decadal scale climate variability. So far, it is hard to say that any change in the tendencies in streamflow in the Amazon River or its main tributaries could be consequence of regional deforestation.

Previously, the increasing trends in discharge and precipitation were observed at all but the eastern parts of the Amazon Basin between the late 1950s and the early 1980s and despite contentions that these trends were associated with upstream deforestation (Gentry and Lopez-Parodi, 1980).

The pioneer studies by Salati et al (1979) suggested the important role of the Amazon forest in the local rainfall and discussed the fact that Amazon Basin's abundant vegetation releases large amounts of water vapor by transpiration, which together with evaporation equals 50% to 60% of the total rainfall in the basin (Salati et al. 1979, Salati and Nobre, 1991).

In fact, part of this rainfall is sustained locally by evapotranspiration, induced by a precipitation recycling, and another part comes from atmospheric moisture transported from the tropical Atlantic by the trade winds, especially during the summer rainy season, and another part is due to intense regional water vapor recycling.

These early findings by Salati and collaborators have brought the scientific community to realize the important role of Amazonia in the regional and global climate, and that large scale deforestation could in fact affect the hydrological cycle of the region, impacting the climate at various geographical scales.

Deforestation experiments started to be developed in the early 1980's and by the early 2000's new developments in dynamics vegetation and greenhouse gases have provide more inside information on the important role of the Amazon region in the functioning and variability of the global climate.

A recent study by Marengo (2006b) shows that even though all models project warming for the region until 2100, reaching up to 8 °C in the HadCM3 model for the A2 extreme scenario. On the other hand, there is not a clear tendency for rainfall anomalies and while some models shows a wetter Amazon basin, other shows drying. The difference among models reaches up to 5 °C and 2.5 mm/day up to 2100 time slice (Fig. 2).

Projections for future climate change from the Hadley Centre model have shown that an increase in the concentration of greenhouse gases in the atmosphere will produce changes in vegetation such that Amazonia will become a savanna by 2050's, and the region will become drier, warmer and most of the moisture coming from the tropical Atlantic, that normally produced rainfall in the region, will not find the adequate environment to condensate above the savanna vegetation by 2050, and the moist air stream will move to southeastern South America producing more rainfall in those regions.

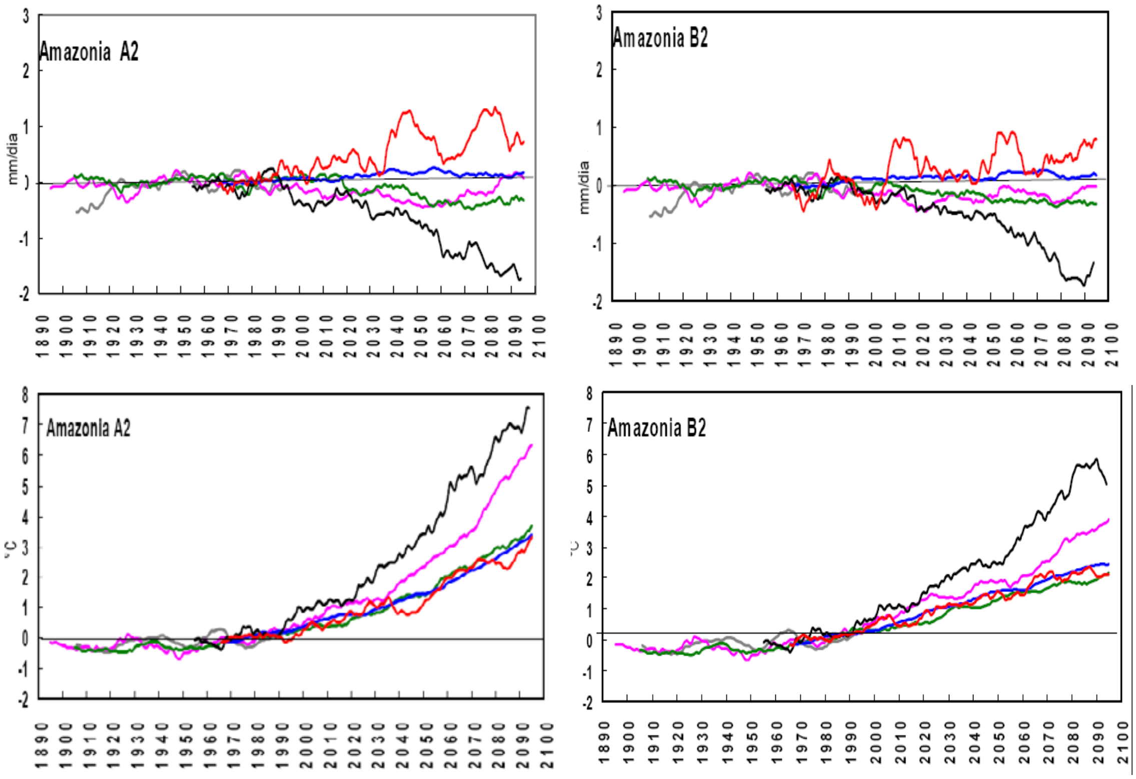

Figure 2. Time series of rainfall and air temperatures anomalies for the Amazon region from 1980 to 2100. The anomalies are calculated based on the 1961-90 climatology from five IPCC TAR models (CCCMA, CCSR/NIES, CSIRO, GFDL and HadCM3) and observations from the CRU. Scenarios are A2 (high) and B2 (low) emission scenarios. The lines represent the 11-year moving average of each time series. Color lines indicate the different models used (Marengo 2006b).

Therefore, after 2050, the Amazon Basin would behave as a "source of moisture" for the regional water balance rather than a sink as in present day's climate (Cox et al., 2000, 2004; Betts et al., 2004). Fig. 3 shows that for the 2090-2100 period the Amazon basin becomes warm and dry, resembles the patterns of an intense El Niño-like situation, with large SST anomalies in the tropical Pacific are large (+3 to +4 °C above normal), drying conditions in the Amazon Basin and increase risk of fire on this region. However, those results still show some degree of uncertainty since are based solely on the coupled model of the UK Hadley Centre for Climate Research.

The projected climate change shown in Fig. 3 could trigger a collapse of the Amazon with savanna replacing the forests with a global mean warming in the range of 2-3°C above preindustrial as predicted by one climate model. The probability of this dangerous event is not clear. Synergistic interactions with the effects of forest clearing and fragmentation could flip the ecosystems of this region from forest to savannah and to desert in parts of North-eastern Brazil. Biodiversity, human livelihoods, and economic development consequence would be enormous.

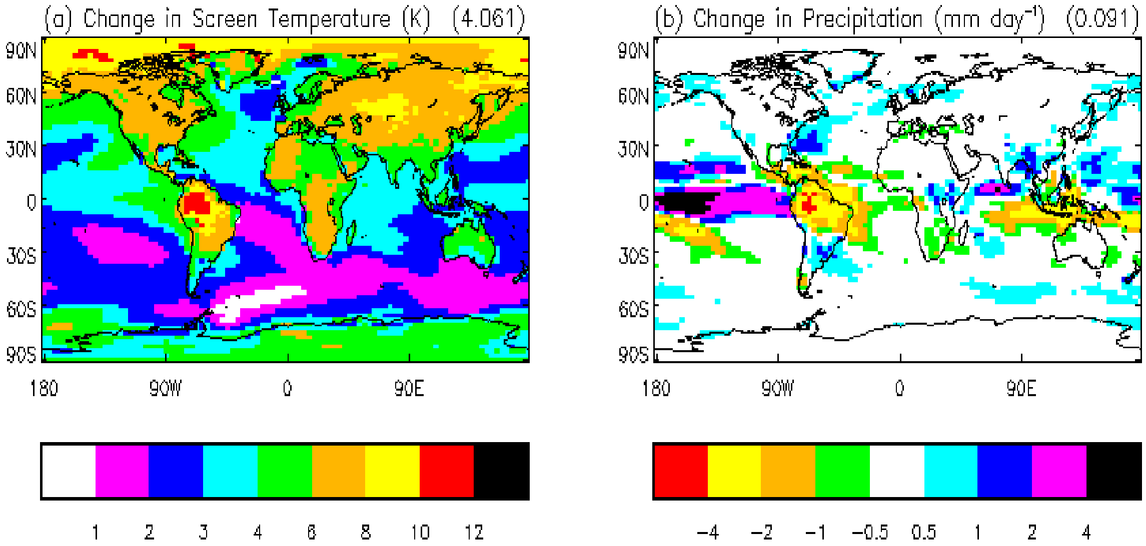

Figure 3. Change in Global Climate in HadCM3LC Interactive CO_2 and Dynamic Vegetation, for surface temperature (left, in °C) and rainfall (right, in mm/day). Maps show the difference between 2090-2100 and 1980-1990. (Cox et al 2000, 2004)

1.1.2 Changes in land use and impacts on Amazon hydrological cycle

A variety of human activities can act to modify various aspects of climate and the surface hydrologic systems. Historically, land-surface changes in Amazonia got intensified in the mid and early 1970's, when strategic governmental plans first attempted to promote the economic development of the region. Those plans included the construction of extensive roads throughout the basin and the implementation of fiscal incentives for new settlers, triggering a massive migration of landless people into the region.

Land-surface changes are accompanied by alterations in climate and consequently, on the hydrological cycle. Water flux anomalies associated with these changes have already occurred in the Amazon and Tocantins River basins (Marengo and Nobre, 2001; Costa et al. 2003), Recently, major land-surface changes have been observed in various parts of the tropics (Aldhous, 1993), and Amazonia, which holds more than 40% of all remaining tropical rainforests in the world and it has been the focus of many studies about the impact of these changes on hydrological dynamics.

Changes in land cover can significantly affect the surface water and energy balance through changes in net radiation, evapotranspiration, and runoff. However, because of the intricate relationships between the atmosphere, terrestrial ecosystems, and surface hydrological systems, it is still difficult to gauge the importance of human activities in the Amazonian hydrologic cycle.

Between May 2000 and August 2005, Brazil lost more than 132,000 square kilometers of forest and since 1970; over 600,000 square kilometers (232,000 square miles) of Amazon rainforest have been destroyed. About 60-70 % of deforestation in the Amazon results from cattle ranches while the rest mostly results from small-scale subsistence agriculture. Despite the widespread press attention, large-scale farming (i.e. soybean) currently contributes relatively little to total deforestation in the Amazon.

Most soybean cultivation takes place outside the rainforest in the neighboring grassland ecosystem and in areas that have already been cleared. Logging results in forest degradation but rarely direct deforestation. However, studies have showed a close correlation between logging and future clearing for settlement and farming. In many tropical countries, the majority of deforestation results from the actions of poor subsistence cultivators. However, in Brazil only about one-third of recent deforestation can be linked to "shifted" cultivators.

A large portion of deforestation in Brazil can be attributed to land clearing for pastureland by commercial and speculative interests, misguided government policies, inappropriate World Bank projects, and commercial exploitation of forest resources.

The INPE´s deforestation monitoring program provides the most reliable estimate of the areal extent of forest conversion to agriculture and ranchland in the Brazilian Amazon, which is the most extreme form of forest conversion (Fig. 4). However, these estimates do not include alterations of the forest through selective timber harvest and forest ground fire. These land-use activities impoverish the forest by killing trees and animals, by releasing CO_2 to the atmosphere, and by rendering the forest more vulnerable to fire. Studies conducted in the field indicate that the area of forest altered by timber harvest and ground fire may be similar in size to the area that is deforested during some years.

Virtually all forest clearing, by small farmer and plantation owner alike, is done by fire. Though these fires are intended to burn only limited areas, they frequently escape agricultural plots and pastures and char pristine rainforest, especially in dry years like 2005. Many of the fires set for clearing forest for these purposes are set during the three-month burning season and the smoke produced creates widespread problems across the region, including airport closings and hospitalizations from smoke inhalation.

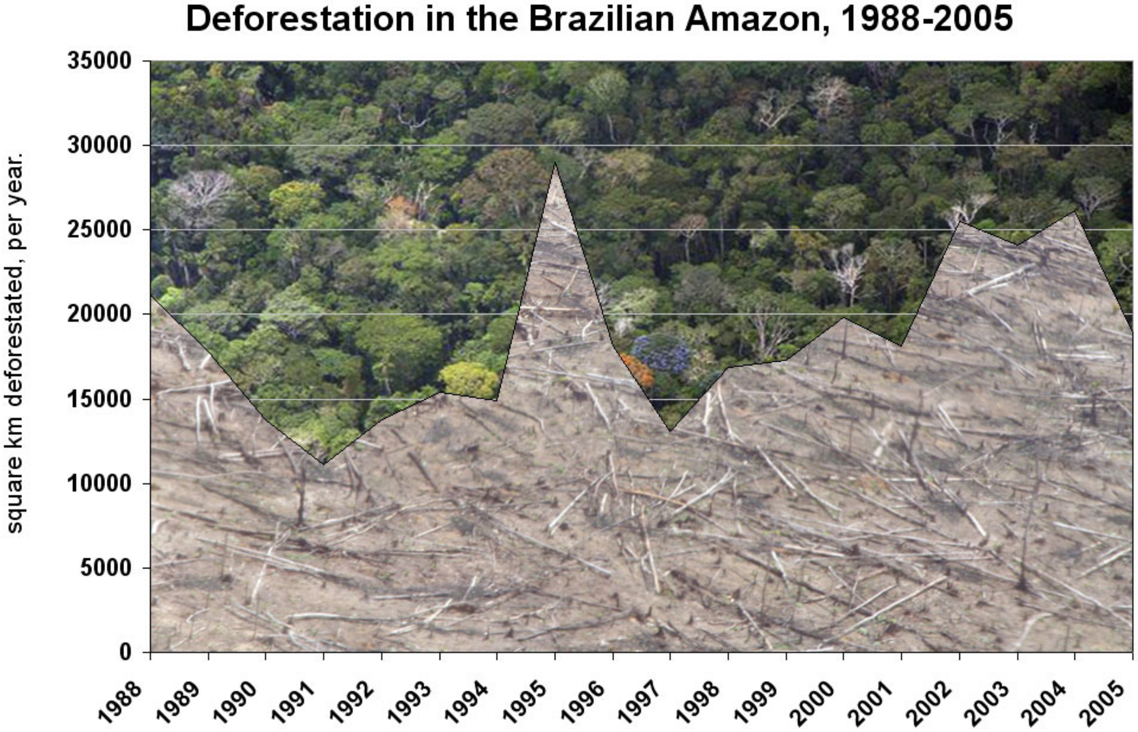

Figure 4. Deforestation rates in Brazilian Amazonia (INPE).

These fires cover a vast area of forest. In 1987 during a four-month period (July-October), about 19,300 square miles (50,000 sq. km) of Brazilian Amazon were burned in the states of Parà, Rondonia, Mato Grosso, and Acre. The burning produced carbon dioxide containing more than 500 million tons of carbon, 44 million tons of carbon monoxide, and millions of tons of other particles and nitrogen oxides.

Fires and climate change are having a dramatic impact on the Amazon. The aerosols and smoke from the biomass burning during the dry season in Amazonia seems to have an impact on the onset of the rainy season in southern Amazonia, and ultimately increase in the concentration of greenhouse gases and aerosols could affect the energy balance and thus climate of the region.

Historically, hydroelectric projects have flooded vast areas of Amazon rainforest. The Balbina dam flooded some 2,400 square kilometers (920 square miles) of rainforest when it was completed. Fearnside (personal communication) calculated that in the first three years of its existence, the Balbina Reservoir emitted 23,750,000 tons of carbon dioxide and 140,000 tons of methane, both potent greenhouse gases which contribute to global climate change.

The construction of reservoirs for hydroelectric generation in Amazonia has some impacts in the hydrological regime as well as on the biodiversity and on the water quality (Tundisi et al., 2002), depending on the size and inundated area of the tropical rain forests. Brazil has five reservoirs operating for hydroelectricity generation (Coaracy Nunes, Curua-Una, Tucurui, Balbina and Samuel) and six other planned to be built (Manso, Cachoeira, Ji-Parana, Karanaô, Barra do Peixe, and Couto Magalhães). Land use changes have also been reported near the site of the reservoir due to human settlements in the region.

Mining has impacted some parts of the Amazon Basin. During the 1980s, over 100,000 prospectors invaded the state of Para when a large gold deposit was discovered, while wildcat miners are still active in the state of Roraima near the Venezuelan border. Typically, miners clear forest for building material, fuel wood collection, and subsistence agriculture.

In an attempt to investigate the possible impact of Amazon deforestation and land use changes in the regional and global climate and hydrology, global climate model simulations of land use changes where forest are replaced by grassland in the whole basin have been started since the late 1970's, using models that vary from empirical to global atmospheric models.

The results have suggested a possible change in the regional and global climate as a consequence of tropical deforestation (see reviews in Salati and Nobre, 1991; Marengo and Nobre 2001). The predicted change in tropical circulation determines the change, if any, in atmospheric moisture convergence, which is equivalent to the change in run-off.

Typically, the climatic impacts of tropical deforestation have been evaluated using a global climate model, linked to a biophysical land surface model that explicitly represents the characteristics of changing vegetation cover (changes in canopy height, leaf density, or rooting depth).

It is suggested that the impact of large-scale deforestation on the circulation of the tropical atmosphere consists of two components: the response of the tropical circulation to the negative change in precipitation (heating), and the response of the same circulation to the positive change in surface temperature.

Under a hypothesized Amazon basin deforestation scenario, almost all models show a significant reduction in precipitation and evapotranspiration (Table 2), and most found a decrease in streamflow, precipitation, evaporation and increases in air temperature. The predicted change in tropical circulation determines the change, if any, in atmospheric moisture convergence, which is equivalent to the change in run-off.

Costa and Foley (2000) suggested that the increases in temperature associated with deforestation in the Amazon basin may be around 1.4 °C, compared to a warming of approximately 2.0 °C that would be expected from a doubling of atmospheric CO_2 combined with deforestation. Zhang et al., (2001) show that the joint climate change over the Amazon region features a warming of 4.0 °C, while warming due to deforestation only reached +3.0 °C.

However, such predictions disagree with the results encountered by mesoscale models, which have been consistently predicting the establishment of enhanced convection – and potentially rainfall – above sites of fragmented deforestation. In general, the effects of deforestation on climate are likely to depend on the scale of the deforested area (Avissar and Liu, 1996). In some cases, the thermal circulation induced may get as intense as a sea-breeze circulation convergence, like for example, over domains with extended areas of unstressed dense vegetation bordering areas of bare soil.

Table 2. Comparison of climate simulation experiments of Amazon deforestation from global climate models. Results show the differences between deforested minus control run. ΔE is change in evapotranspiration (mm d^{-1}), ΔT is the change in surface air temperature (°K), ΔP is the change in precipitation (mm d^{-1}), ΔR is runoff, calculated as the difference of ΔP and ΔE ($\Delta R=\Delta P-\Delta E$)

Experiment	ΔE	ΔT	ΔP	ΔR
Dickinson and Henderson-Sellers (1988)	-0.5	+3.0	0.0	+0.5
Dickinson and Kennedy (1992)	-0.7	+0.6	-1.4	-0.7
Henderson-Sellers et al., (1993)	-0.6	+0.5	-1.6	-1.0
Hahman and Dickinson (1995)	-0.4	+0.8	-0.8	-0.4
Zeng et al., (1996)	-2.0		-3.1	-1.1
Hahmann and Dickinson (1997)	-0.4	+1.0	-1.0	-0.6
Costa and Foley* (2000)	-0.6	+1.4	-0.7	-0.1
Costa and Foley** (2000)	-0.4	+3.5	-0.4	-0.1
Lean and Warrilow (1989)	-0.9	+2.4	-1.4	-0.5
Lean and Warrilow (1991)	-0.6	+2.0	-1.3	-0.7
Lean and Rowntree (1993)	-0.6	+1.9	-0.8	-0.3
Lean, Rowntree (1997)	-0.8	+2.3	-0.3	+0.5
Lean et al., (1996)	-0.8	+2.3	-0.4	+0.4
Manzi and Planton (1996)	-0.3	-0.5	-0.4	-0.1
Nobre et al., (1991)	-1.4	+2.5	-1.8	-0.4
Shukla et al., (1990), Nobre et al., (1991)	-1.4	+2.5	-1.8	-0.4
Dirmeyer and Shukla (1994)	-0.4		-0.7	-0.3
Sud et al., (1990)	-1.2	+2.0	-1.5	-0.3
Sud et al., (1996b)	-1.0	+3.0	-0.7	+0.3
Walker et al., (1995)	-1.2		-1.5	-0.3
Polcher and Laval (1994a)	-2.7	+3.8	+1.0	+3.7
Polcher and Laval (1994b)	-0.4	+0.1	-0.5	-0.1
Zhang et al.,(2001)	-0.4	+0.3	-1.1	-0.0
Zhang et al. * (2001)	-0.6	+3.0	-1.1	-0.5
Zhang et al. ** (2001)	-0.6	+4.0	-1.1	-0.5
Voldoire and Royer (2004)	-0.6	-0.1	-0.4	

(*) Deforestation only

(**) Deforestation combined with 2xCO_2

Source: Marengo (2006a).

Furthermore, since the early 2000's new developments in atmosphere-ocean-biosphere coupled models have been accomplished by the Hadley Centre for Climate Research and Prediction in the UK, the Institute Pierre and Simon Laplace-University of Paris in France, the Frontier Research Center for Global Change in Japan, and the National Centre for Atmospheric Research in the US. The new models include interactive vegetation schemes that more realistically represent the water vapor, carbon, and other gas exchange between the vegetation and the atmosphere allowing a more realistic representation of processes and feedbacks in the simulation of future climate change.

At the biome level, GCMs of potential future climates project that evergreen forests are succeeded by mixed forest, savanna and grassland in eastern Amazonia and savanna expand into parts of western Amazonia (Cramer et al. 2004). Other modeling experiments project an expansion of savanna, grasslands and desert ecosystems into north-eastern Amazonia (White et al. 1999). Large-scale modeling shows widespread forest loss over most of the Amazon, accelerated by positive feedback between warming, forest dieback, and emissions of carbon from soil and vegetation (White et al., 1999; Cox et al., 2000, 2004, Jones et al. 2003).

Fig. 4 shows that the increase in the concentration on greenhouse gases produce drying and warming conditions that led to the collapse of the forest site becoming savanna, and what is called the Amazon die back (Cox et al 2000). This scenarios, even though uncertainty since it is generated by the HadCM3 model only can not be neglected. Brazil is one of the most vulnerable countries to climate changes in the world because of its invaluable biodiversity. If the Amazon loses more than 40% of its forest cover, we will reach a turning point from where we cannot reverse the savannization process of the world's largest forest.

Amazon forests are also threatened by secondary effects of climate change, such as a potential increase in the frequency and perhaps in intensity of fires. It is suggested that fire poses the greatest threat to Amazon forests and numerous studies have shown a well established link between forest fires, habitat fragmentation, climate change, and drought induced by extreme El Niño events in the Amazon or by anomalously warm surface waters in the tropical North Atlantic (Nepstad et al., 2001; Laurance and Williamson, 2001, Marengo et al 2006, Brown et al 2006).

All these changes shown in Table 2 in Amazonia may have climatic, ecological and environmental implications for the region, the continent and for the globe. A sound knowledge of how the natural system functions is thus a prerequisite to defining optimal development strategies. The complex interactions between the soil, vegetation, and climate must be measured and analyzed so that the limiting factors to vegetation growth and soil conservation can be established.

New knowledge and improved understanding of the functioning of the Amazonian system as an integrated entity and of its interaction with the Earth system will support development of national and regional policies to prevent the exploitation trends from bringing about irreversible changes in the Amazonian ecosystem. Such knowledge, in combination with enhancement of the research capacities and networks between the Amazonian countries will stimulate land managers and decision makers to devise sustainable alternative land use strategies along with forest preservation strategies.

Table 3 shows some of the forcing (natural and anthropogenic) that have impacts on the water resources availability and quality, and the impacts on the population, biodiversity, generation of hydroelectricity. This table is more comprehensive than

The major climatic forcing (El Niño, variations in the tropical Atlantic SST gradient or the release of greenhouse gases due to human or natural causes) have a direct impact on the water and energy cycles, that translates in regional scale reductions in rainfall, evaporation, streamflow and increase in air temperature, generating drought, high risk of fires, impacts on ecosystems and biodiversity, impacts on water and air quality, impacts on availability of water resources for irrigation, electric generation and safe water for population.

All Amazon countries are sensitive to climate variability and change and their impacts on biodiversity and natural ecosystems, and the situation may be even more complicated for the Andean-Amazon countries where erosion and river channel sedimentation is an additional problem.

Table 3. Natural and anthropogenic forcing, climatic tendencies and human and ecosystem dynamics in Amazon countries.

Forcing(natural or anthropogenic)	Impacts on water resources	Consequences
El Niño and Tropical Atlantic sea surface temperature anomalies	Changes in the rainfall distribution in the Amazon Region	Drought in Northern Amazon Region; problems in transportation due to low river water levels; high risk of forest fires at seasonal level; impacts on natural river ecosystems; impacts on agriculture; impacts water storage for hydroelectric generation
Climate change due to increase in concentration of GHG	Possible changes in the hydrological cycle; changes in the energy balance and warming; changes in biodiversity and natural ecosystems	Dynamics of vegetation affected; Amazon forest die and become savanna; drying of the Amazon region; floods or extremely low water levels likely to occur; more frequent forest fires; impacts on water storage for hydroelectric generation
Deforestation and land use change	Possible changes in the hydrological and energy cycles. Changes in water quality and chemistry due to deforestation in the east flank Andes (Upper-Amazon countries)	Regional rainfall reduction; regional warming; erosion; sedimentation along the main channel and accumulation of sediments in reservoirs; water quality and biodiversity may be affected.
Biomass burning (natural and man-made)	Changes in the water and energy cycles; changes in the air quality	Impacts on the onset of the rainy season and physics of rainfall; impacts on the air quality and sensitivity to warming due to release of large amounts of GHG and aerosols.
Agriculture	Possible changes in the hydrological and energy cycles; introduction of exotic	Erosion; changes in regional microclimates; impacts of groundwater

	species;	
Constructions of highways and reservoirs	Changes in regional circulation and rainfall patterns; decomposition or organic matter	Erosion; changes in regional microclimate; increase in methane release to the atmosphere; changes in cloudiness
Mining and related activities	Pollution of rivers and streams; erosion; chemical spills	Deterioration of water quality; impacts on fishery and natural river ecosystems; erosion and floods in flatlands; social problems
Oil exploration	Pollution of rivers and streams; destruction of forest for oil pipelines; chemical spills	Deterioration of water quality; impacts on fishery and natural river ecosystems; erosion and risk of land slides.
Cattle and ranching; human settlement and urbanization	Changes in regional circulation and microclimate; possible changes in the energy and water cycles;	Impacts on natural ecosystems; erosion; increase of biomass burning; impacts on groundwater

1.1.3 Changes in the hydrology of the Amazon River Basin

Macroscale hydrological models, which model the land surface hydrological dynamics of continental scale river basins, have rapidly developed during the last decade (Russell and Miller, 1990; Miller et al., 1994; Marengo et al., 1994; Nijssen et al., 1997, 2001). These models can act as links between global climate models and water resources systems on large spatial scales and long term time scales.

Predictions of changes in river discharges in the Amazon basin for present climates and 2xCO_2 future scenarios have been calculated by Russell and Miller (1990) and Nijseen et al., (2001) using global models, and some problems in parameters of the model or perhaps the availability of suitability of runoff data for validations indicate that in most of the models the rainfall and runoff in Amazonia are underestimated. This underestimation in rainfall and runoff in the Amazon has also been detected in various global climate models: GISS, HadCM3, CPTEC/COLA (Marengo et al., 1994, 2003).

This also generates an uncertainty in the projected values of runoff in the future, forced either by increase in greenhouse gases concentration (GHG) or in changes in land use and land cover. Simulations by Coe et al., (2002) using a terrestrial ecosystem model have been successful to simulate interannual and seasonal runoff variability in Amazonia, and even though the discharge is consistently underestimated, the model captures climate variability and the impacts of El Niño since the early 1950's.

Amazon Rivers have a natural vocation for transportation. Almost 18,300 km of rivers are potentially suited for navigation. The Amazon River main channel and the upstream section called Solimões (called as Rio Amazonas in the Peruvian, Colombian, Bolivian and Ecuadorian Amazonia) are suitable for navigation as well as its tributaries Ica, Branco, Negro and Trombetas on the left margin and the Juruá, Mamore-Madeira, Tapajos e Xingu on the right margin. The Amazonas/Solimões has an extension of about 6,500 km, with 3,100 km in Brazilian territory.

The Lower Amazonas, between Belem and Manaus has an extension of 1500 km and can be as wide as 150 km, and allows for navigation of big cargo ships. The Solimões River between Manaus and Tabatinga has 1,600 km of extension and allows for the navigation of middle size ships, and a third section is located almost the border with Peru, with 250 km length. So, prospects of reductions in the river level and discharge in the Amazon Rivers may have large impacts on the regional economy, as it was observed during the drought of 2005.

Two studies recently published in the context of the IPCC AR4 model analyses have suggested that climate change due to natural and anthropogenic causes are already impacting the hydrology of major rivers, including Amazonia. The report from the UK Met Office indicates that during 2061-2100 river discharges worldwide should increase by 2% until 2020. This increase would aggravate the possibility of landslides and floods in various parts of the planet. The report considers the HadGEM1 (scenario A1B) that account for the CO2 concentration in plants.

In Brazil, the HADGEM1 suggest that in Amazonia and Pantanal the discharge would decrease between 25% e 50%, and that is consistent with the rainfall reduction projected by the HadCM3 model, a previous version of the HadGEM1 (Fig. 5) .

Another study by Milly et al. (2005) considers an ensemble of 16 IPCC AR4 models (CCSM3, CGCM3.1 (T63), ECHAM5/MPI-OM, ECHO-G, FGOALS-g1.0, GFDL-CM2.0, GFDL-CM2.1, GISS-AOM, MIROC3.2 (hires), MRI-CGCM2.3.2, UKMO-HadCM3 e UKMO-HadGEM1) for the period 2041-2060, related to the preset climate 1900-1970. Fig. 6 shows reductions of about 10-15% in Amazonia and in Northeast Milly et al (2005), being the changes on the same direction as in the UK report.

A possible reduction in the discharges of the Amazon Rivers and its major tributaries may have large impacts in the biodiversity, as well as in transportation and hydroelectric generation that affect directly the population. Perhaps the best example is the was the drought of 2005, where transportation along the Solimões e Madeiras rivers was reduced or impossible, while the airports in the states in western Amazonia were closed due to the smoke from the many fires that were set as a consequence of the drought conditions (Brown et al 2006).

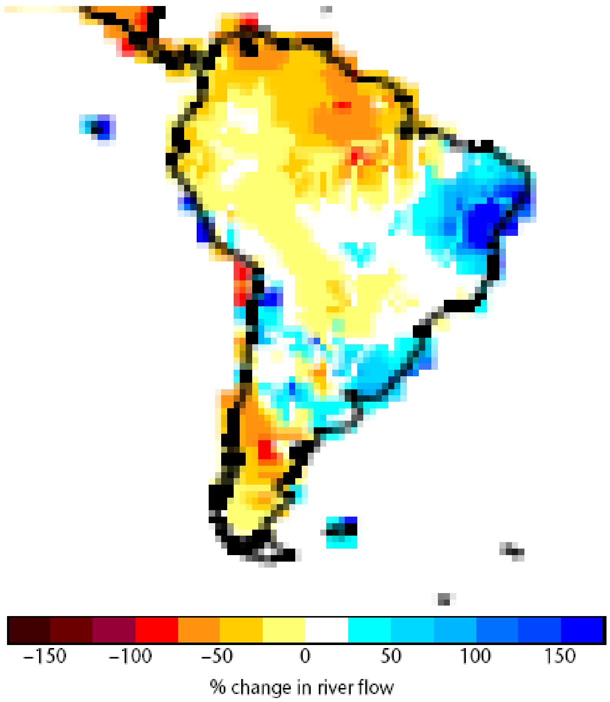

Figure 5. River flow changes (%) in South America for 2061-2100 relative to 1901-1998. Scenario A1B, HadGEM1 model (UK Met Office 2005).

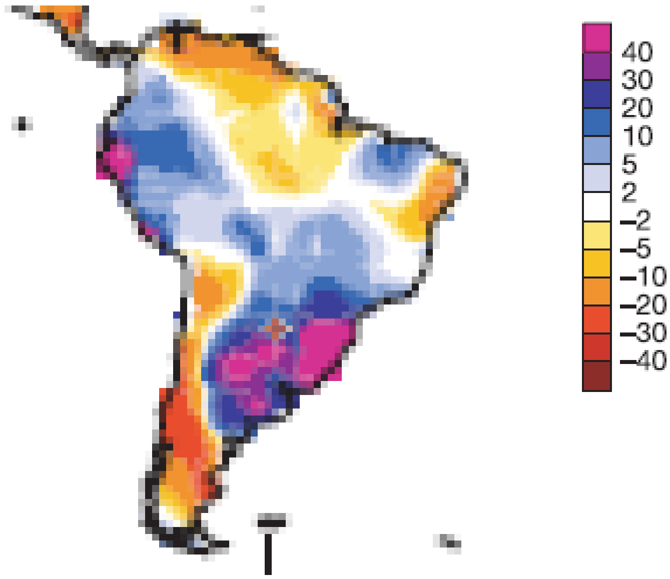

Figure 6. Change in river flow (%) for 2041-2060 relative to 1900-1970. The figure shows the ensemble 12 IPCC AR4 models for the A1B scenario (Milly et al. 2005).

1.2 Social and economical cost of impacts of change in extreme hydrometeorological events

Aquatic resources and water provides many essential services to the people of the Amazon. The region’s native fisheries provide a large proportion of animal protein consumed by inhabitants. Fish are also a valuable source of income to fishermen. River and lake water satisfies nearly all of the water supply needs of Amazonian peoples, including drinking, cooking, bathing, and waste removal. While little water is used for irrigation, river channels and lakes are important avenues of transportation and shipping and provide opportunities for recreation (McClain, 2001).

The most impacting meteorological phenomenon in Amazonia is drought. During the 2005 drought, the worsening drought has forced the Brazilian government to extend emergency warnings across the Amazonas state. The military has been called in to distribute supplies and medicine to tens of thousands of people. The drought is now also affecting towns and cities further downstream. Large areas of sand and mud have been exposed as rivers and lakes have dried up in the worst conditions for 40 years. This drought provoked extensive forest fires in the State of Acre, although the area has yet to be estimated (Brown et al. 2006).

The lakes and rivers' tributaries were being isolated, with an enormous fish mortality (and risk of contamination for persons that nourish themselves with these fish). Navigation along sections of the Madeira, Acre and the upper and central Amazon River (known in Brazil as the Solimões River and Amazonas in the other Amazon countries), had to be suspended because the water levels fell to extremely low levels, which led various countries of the Amazon region to declare state of public calamity in September 2005. The drought left thousands of people short of food, caused problems to river transportation, agriculture, generation of hydroelectricity and also affected directly and indirectly the populations living along the Amazon River streams.

Airports and schools were closed due to the smoke produced by the numerous fires in the region that were about 300% superior in number as compared to 2004 (Marengo et al. 2006). The risks of having more events like this in a warmer climate have raised concerns and government on the sensitivity of the population and natural ecosystems to climate change.

More people, particularly poor people, were affected by the Amazon drought of 2005 than in any previous episode. In many areas, local fisheries collapsed or were severely depleted, worsening rural poverty. The drought increased a number of human health risks, including malaria, possibly cholera and other waterborne diseases, due to the decline in waste drainage functions that the river provides for many poor communities.

So far, the estimates of the drought of Amazonia in 2005 have not been yet estimated. Considering the mitigation effects of the drought by the government in terms of food and supplied for people living in the affected area, unofficial estimates provide by Brazilian newspapers indicate that about US $ 20 million dollars have been spent by the government by sending food and medical supplied to cities and villages in the Brazilian western Amazonia. There is no doubt that considering the effects of the drought and derived forest fires in river and air transportation, as well as in fishery, agriculture and human health, the economical losses could reach up to US $ 60 million dollars or even more.

1.3 Review of hydroclimatic hazards and disasters in the Amazon Basin

Perhaps the most important hydroclimate feature that affects Amazonia is drought, rather than flooding. A shown in Fig. 7 drought favor fires that affect population and biodiversity due to the smoke, as well as human activities. Smoke also affects the onset of the rainy season as well as the extension of the dry season, as well as the moisture content all year around. The drought also affects the availability of water in the form of reductions in river level discharge, affecting transportation, safe water availability and human health, as well as hydroelectricity generation. This implies that the Amazon is more vulnerable to drought than to floods.

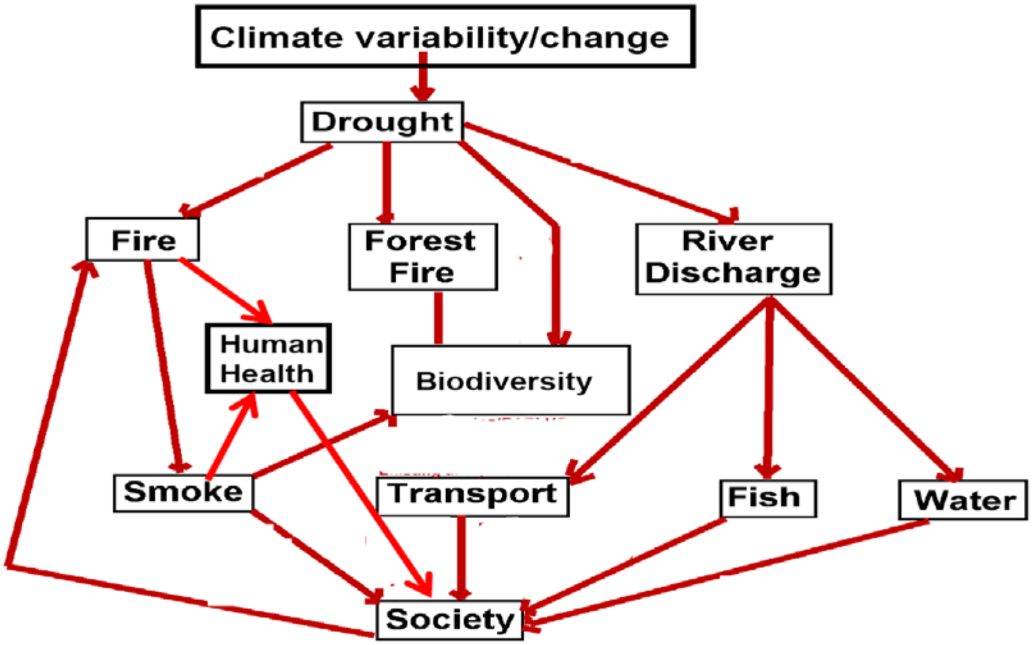

Figure 7. Cascade effects of climate variability and change in the Amazon Basin, that affect society and biodiversity (Source: D. Nepstad, WHRC).

Forest ecosystems throughout Latin America are vulnerable to fires. In particular, the tropical forests of Amazonia have been increasingly susceptible to fire due to increased occurrence of droughts (El Niño and non-El Niño related) and primarily land use change (clear-cut deforestation, forest fragmentation, selective logging) (Nepstad *et al*, 1999; , Fearnside, 2001). During the severe drought related to the 1997-98 El Niño, an area of 40,000km2 of tropical forest has been estimated to have been burned in the Brazilian Amazonia alone (Nepstad et al; 2004). Population is also sensitivity to fires.

Forest fires that burn beneath forest canopies are one of the most important types of forest impoverishment in the Amazon causing large emissions of carbon to the atmosphere. The occurrence and the damage intensity of these fire events are related to the synergetic influence of selective logging, forest fragmentation and severe droughts especially such as that associated with El Niño Southern Oscillation (ENSO) episodes or to the variability of tropical Atlantic SST anomalies. In addition, forest fires occurrence also depends on landscape variables and forest structure.

During the last 103 years, 10 events of intense drought have been identified. The evidences for the dry years in 1911-12, 1918-19 and 1925-26 are also apparent in the Rio Negro water level record in Fig. 1 as the minimum discharge prior to 1926. The first two were El Niño years, while the third was a La Niña event. The impacts of the 1925-26 El Niño were somewhat different from those observed on a “typical” El Niño event.

Furthermore, while rainfall anomalies in the summer of 1925-26 in the northern coast of Peru were well above the normal, Northeast Brazil region did not experienced the expected drought characteristic of an intense El Niño, and Williams et al. (2005) reported that rainfall in Northeast Brazil during 1926 was about 20% above normal. Other drought years in Amazonia were 1948-49, 1963-64, 1979-81, 1982-83, 1993-94 and 1997-98, being two of them El Niño years.

The difference in the spatial features of these drought years and the 2005 and perhaps the 1963-64 droughts was that the later two struck hardest western and southern Amazonia, a feature not associated with a typical El Niño but probably with tropical North Atlantic warmer and more active than normal.

There is evidence of extensive droughts, and perhaps widespread fires, linked to paleo ENSO events occurred in the Amazon basin in 1,500, 1000, 700 and 400 BP, and these events might have been substantially more severe than the 1982-83 -and 1997-98 ones (Meggers 1994). The best documented case of an earlier drought event in Amazonia linked to El Niño event was during 1925-26 (Sternberg 1968; 1987, and Williams et al. 2005). Rainfall anomalies in the central-northern Brazilian Amazonia and southern Venezuela in 1926 were about 50% lower than normal.

During this particular drought, extensive fires prevailed in Venezuela and the upper Negro River basin. Unusually high air temperature anomalies were recorded in various Venezuelan and northern Brazilian Amazonian towns for both 1925 and 1926, and it is plausible that the dryness in the northern portion of the Negro River basin in 1925 also contributed to the major drought in 1926 by a depletion of soil moisture (Fig. 8).

Contrary to the above droughts, the droughts of 2005 as well as those in 1963-64 and in 1979-81 did not occur associated with El Niño events. While several studies analyze the droughts of 1982-83 (Aceituno 1988, Marengo et al. 1998) and 1997-98 (Nepstad et al. 1999) and their impacts in climate, hydrology and fires in Amazonia, there are only casual references to the drought event of 1963-64.

The variability of SST anomalies in the tropical Pacific is responsible for less than 40% of rainfall variability in the Amazon basin (Marengo 1992, Uvo et al. 1998), suggesting that the effect of other sources of variability, such as the meridional SST gradient in the inter-tropical Atlantic (that affects mostly northern and central Amazonia), or land surface processes and large frequency of transients from the South Atlantic (important for southern Amazonia) may be also important in the inter-annual rainfall variability in the region (Marengo et al. 2003, Ronchail et al. 2002).

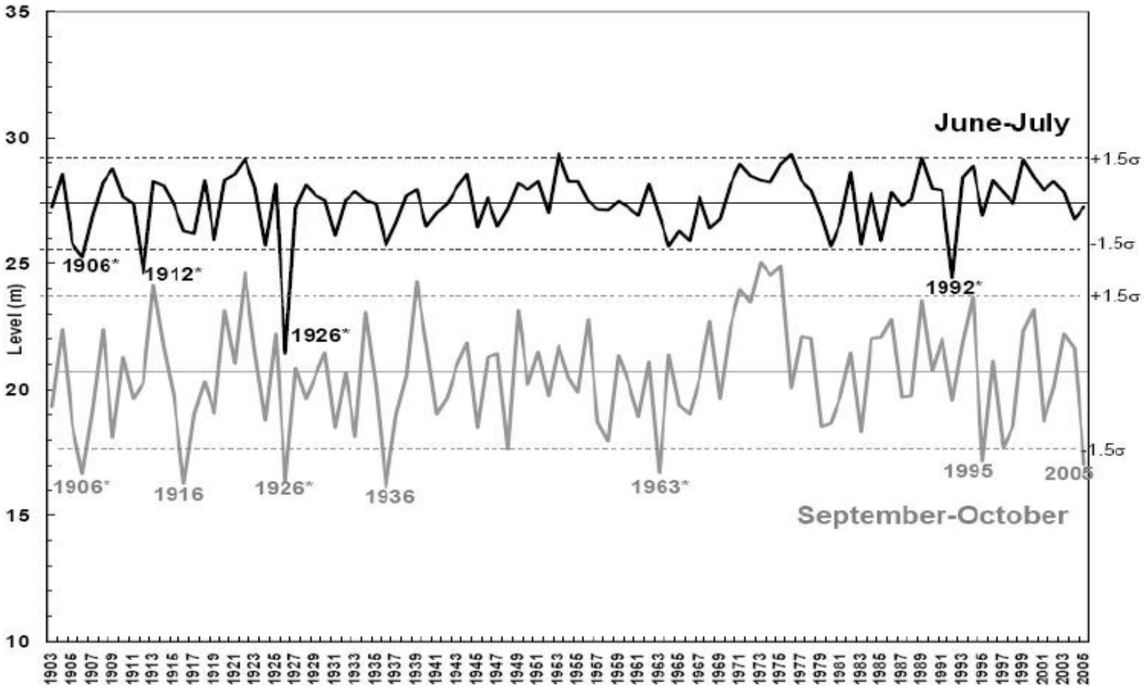

Figure 8. Negro River water levels at Manaus (in m) in the Manaus station, Brazil, during the peak water level season in June-July (black lines) and the low water level season in September-October (grey lines). Full/thin broken lines represent the mean/+ 1.5 σ. The number indicates years where the levels reached values lower than 1.5 σ. Asterisks depict El Niño years (Marengo et al. 2006).

1.3.1 The drought of Amazonia in 1926

The best documented case of a past drought event in Amazonia linked to ENSO event was during 1925-26 (Sternberg 1968, 1987 and Williams et al. 2005).

During this event extensive fires that prevailed in Venezuela and the Rio Negro basins of the upper Amazon during that drought year. Knoche (1937) and later on Williams et al (2005) documents the unusually high air temperature anomalies in various Venezuelan and Brazilian Amazonian cities for both 1925 and 1926, and it is plausible that the dryness in the northern portion of the Rio Negro basin in 1925 also contributed to the major drought in 1926, by a depletion of soil moisture.

Williams et al. (2005) used river stage observations at Manaus, and in annual rainfall records to document the characteristics of this drought event. The annual rainfall anomaly shows an east-west dipole over tropical South America, with drought to the west over the Amazon basin whose discharge is documented at Manaus, and with a surplus to the east and including the Nordeste region of Brazil.

The 1926 drought year has been verified as the most extreme dry period in the century-long record of discharge from the western sub-basin of the Amazon.

The regional rainfall anomaly for 1926 is negative over this sub-basin and positive further east. The magnitude of the rainfall deficit is broadly consistent with the annual deficit in discharge from that sub-basin (30-40%). The enhanced rainfall in the Nordeste in this pronounced El Niño year is attributed to an anomalously warm South Atlantic Ocean, consistent with earlier studies. Aerosol effects may have been contributed significantly to the magnitude of the negative rainfall anomaly.

Fig. 9 summarizes the annual rainfall anomalies for the low-discharge year 1926 for all stations for which data are available in this study over South America. In general, the station climatology was based on the decadal period 1920-1930.

In general, negative rainfall anomalies are found in the sub-basin contributing discharge of the Amazon near Manaus (with a single exception), and positive anomalies are found further to the east, and including the Nordeste region (Hastenrath et al, 1984, Marengo 1992). The overall rainfall anomaly is therefore a dipole with approximate east-west extent.

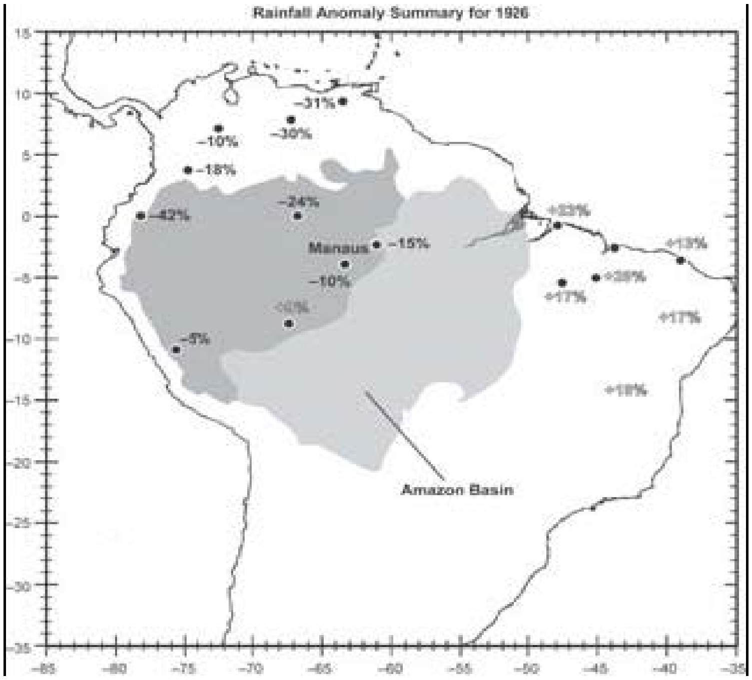

Figure 9 - Summary of the annual (January-December) rainfall anomaly for the dry year of 1926 over South America for all stations available in this study. An east-west dipole is apparent, with reduced rainfall upstream from Manaus and enhanced rainfall further east and extending to the Nordeste region (Williams et al. 2005).

1.3.2 The drought of Amazonia in 1998

In Amazonia, the 1997/98 El Niño produced a drought situation that extended over most of the region and large parts of Amazonia did get rainfall below normal since September 1997. River levels in there were about 9 m below normal, and this determined problems with the generation of hydroelectricity since the reservoirs showed values much lower than normal. Impacts of the drought were also observed in the form of fires.

Rainfall in Boa Vista-Roraima was about 8% of the normal value, with an accumulated rainfall value from September 1997 to March 1998 of about 30.6 mm (where the mean was 397.1 mm). Due to the low precipitation values and the dryness of the air, conditions were favorable for the spread of fires, and the smoke produced by the fires affected population by mean of respiratory disease, as occurred in 1983. This drought has been studied in various papers (See reviews in Marengo 2006).

According to the Instituto de Pesquisa Econômica Aplicada (IPEA), the economical impacts of El Niño 1997-98 in the Amazon basin have been very high. The lost on pasture production due to forest fires was about US$ 54 millions, while the lost in the timber industry during the fires was about $ 7 millions. This represents about 0.1% of the Amazon Gross Product.

Respiratory diseases were responsible for about US$ 6 millions, by means of about 4000-13000 entries to the public hospitals in the region. In total, the economical losses associated with the 1997-98 El Niño varied from US$ 102 millions to US$ 5 billions, that represents about 0.2% to 9.3% pf the Amazon regional Gross Product. This does not account for the losses on biodiversity and erosion in the small streams inside the Amazon region.

1.3.3. The drought of Amazonia of 2005

Beyond ENSO events, droughts in the Amazon can occur through other climatic processes, such as the great drought of 2005. In 2005, large sections of the western Amazon Basin experienced the most severe drought in the past 40 years and also one of the most intense of the last 100 years.

The international section of the 11 December 2005 issue of *The New York Times* reported that "*The drought has evaporated whole lagoons, and kindled forest fires, killed off fish and crops, stranded boasts and the villagers who travel by them, brought disease and wreaked economic havoc*".

Navigation along sections of the Madeira and upper and central Amazon River (known in Brazil as the Solimões River), had to be suspended because the water levels fell to extremely low levels, which led various countries of the Amazon region to declare state of public calamity in September 2005. The drought left thousands of people short of food, caused problems to river transportation, agriculture, generation of hydroelectricity and also affected directly and indirectly the populations living along the Amazon River streams.

Along the Madeira and Purús Rivers, transportation is very difficult with frequent running aground of barges and enormous prejudices for producers and transporters of soybean to the Itacoatiara Port. Heading towards Acre state, the Purús River can only be navigated by very small boats. In the Upper Solimões River, between Tefe and Tabatinga, 1000km from Manaus, the river's level reached 2 m, historically the lowest in the region (during normal droughts the lowest it has reached was 4.5 m), forcing boats to navigate only during the daytime and Tabatinga to move its port´s place.

The minimum levels of the Acre River reached very low values during 2005, with some recovery during 2006 (Fig. 10)

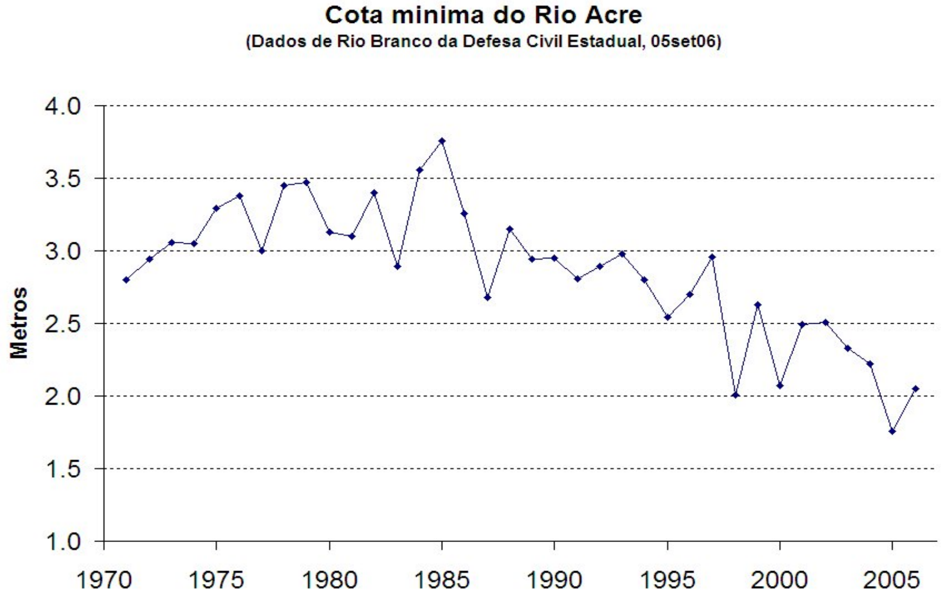

Figure 10. Minimum levels (July-October) of the Rio Acre in Rio Branco from 1967 to 2006 (Source: F. Brown).

Fig. 11 shows the levels of the Rio Negro at Manaus and the levels of the Rio Amazonas in Iquitos. The levels at Manaus are shown for 2005 and other drought years while the Iquitos levels are shown for 2005, both compared to the long term means. In Manaus, the lowest levels were detected during the drought of 1925, while in 2005 reductions in the levels were detected since June 2005 reaching the lowest values in August.

The drought of 1964 was detected all year long, while the drought in 2005 appears only after August 2005, and the levels before May 2005 were above the normal.

In Iquitos, the levels were below normal since January 2005, reaching the lowest levels in September 2005. Similar situation was observed in the Solimões River levels in Fonte Boa and Tabatinga, and in the levels of the Rio Amazonas in Leticia (Colombia). In 2006, the levels went back to normal until May 2006, and after that the levels have been about 3-4 below normal until the end of October 2006. However, the situation in 2006 was not that of the drought in 2005.

This indicates that the drought of 2005 affected western Amazonia, different from El Niño induced droughts that affect central and eastern Amazonia. After October 2006 rainfall started and alleviated the situation, and by February 2006 rainfall was above the normal producing floods.

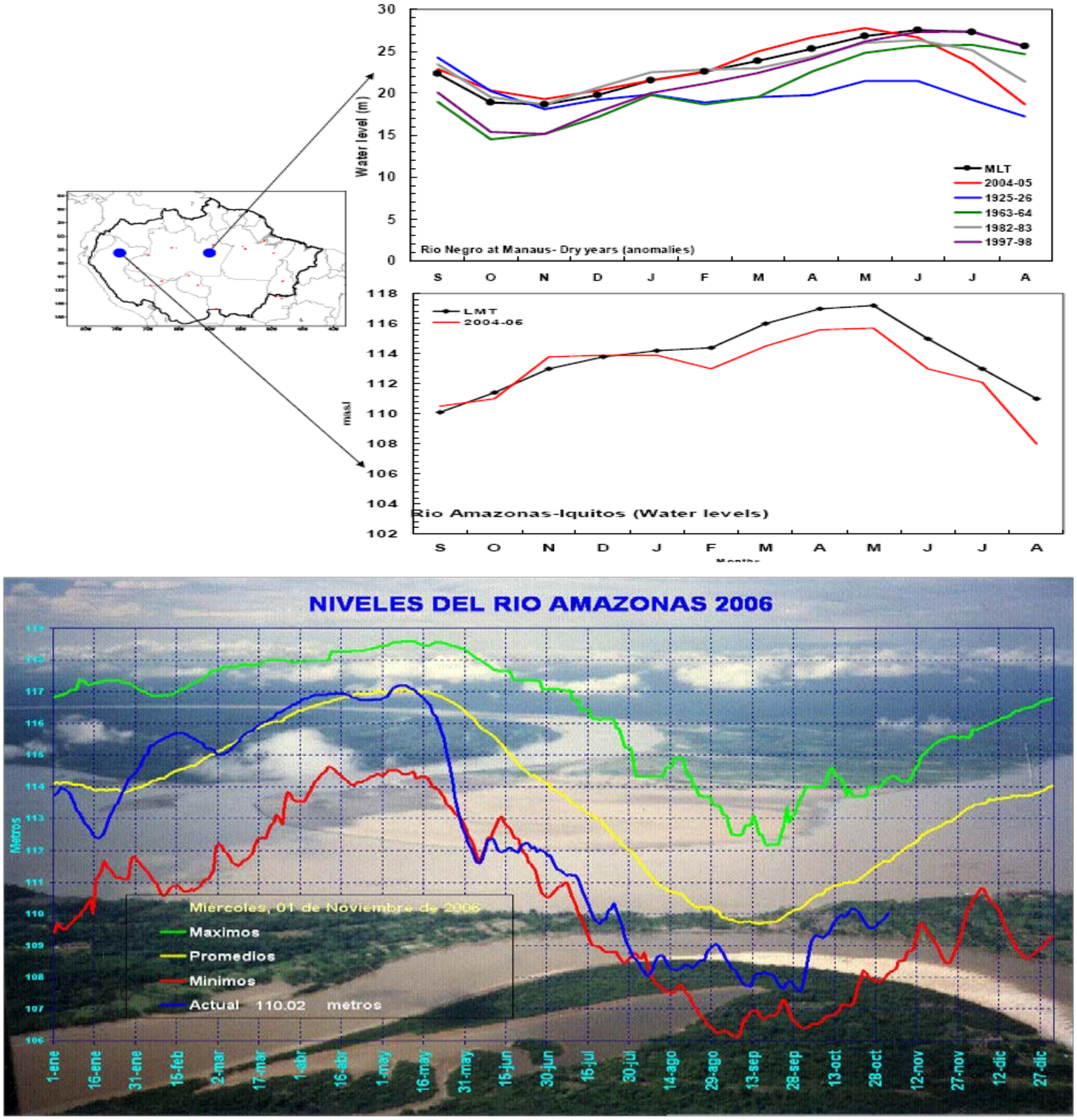

Figure 11. Upper panel: Levels of the Rio Negro at Manaus during some drought years in Amazonia (2004-2005, 1925-26, 1963-64, 1982-83, 1997-98) and of the Rio Amazonas in Iquitos during 2005 (Marengo et al. 2006). Lower panel: Levels of the Amazon River at Iquitos during 2006 (source: www.dhn.mil.pe)

An observational study of the causes of this drought by Marengo et al. (2006) suggest that causes of the drought were not related to El Niño but to (a) the anomalously warm tropical North Atlantic, (b) the reduced intensity in northeast trade wind moisture transport into southern Amazonia during the peak summertime season, and (c) the weakened upward motion over this section of Amazonia, resulting in reduced convective development and rainfall.

The drought conditions were intensified during the dry season until September 2005 when humidity was lower than normal and air temperatures 3-5 °C warmer than normal. Due to the extended dry season in the region, forest fires affected part of southwestern Amazonia. Rains returned in October 2005 and generated flooding after February 2006.

Based on available knowledge about decadal trends in rainfall in Amazonia, it is not clear if this drought is related to the impact of land use changes (deforestation, biomass burning and aerosols release into the atmosphere), to global warming or to a trend linked to hurricanes in the tropical North Atlantic.

This pattern suggests decadal scale variations in SST anomalies in this region, superimposed on a warming trend also detected in surface temperature worldwide and it would be at least partially responsible for circulation changes leading to the drought of 2005 in Amazonia. Fig. 12 shows seasonal rainfall anomalies during both the 1998 and 2005 droughts.

The features of the 1998 El Niño are drought in Amazonia and Northeast Brazil, and abundant rainfall in southern Brazil and Northwest Peru and Ecuador during December-February DJF and March-May MAM.

The extension of the drought of 1998 was much larger than in 2005 covering most of the Amazon region from December 1997 through May 1998. In 2005, reduced rainfall began to affect southwestern Amazonia during the period DJF 2004–2005 while in MAM rainfall was above normal in central Amazonia, in contrast with the drought in the same season during 1998 (Fig. 12).

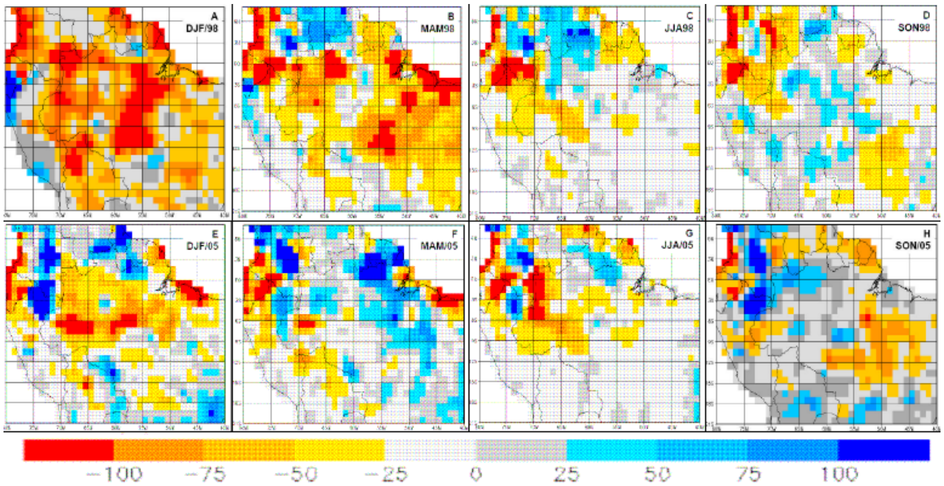

Figure 12. Seasonal rainfall maps for tropical South America during two drought events: 1998 (upper panels), and 2005 (lower panel). Values are shown as deviations from the 1961-1990 long-term mean. Data is from GPCC. Units are in mm/month (Marengo et al. 2006)

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Based on available knowledge about decadal trends in rainfall in Amazonia, it is not clear if this drought is related to the impact of land use changes (deforestation, biomass burning and aerosols release into the atmosphere), to global warming or to a trend linked to hurricanes in the tropical North Atlantic.

Some of these phenomena, as well as the rainfall in Amazonia, have been linked to decadal scale variability and a warming of about 0.5 °C in the tropical North Atlantic during the last 30 years, where SST anomalies have had in the relatively warmer 1990's and 2000's could have the same impact as larger SST anomalies during the relatively colder 1960's.

The warm SSTs in the North Atlantic have been also linked to a very active hurricane season in 2005 that possibly started in the late 1990's, preceded by another active season from the middle 1940's to the middle 1960's (Trenberth and Shea 2006).

This is suggestive of future warmer climate change scenarios due to the increase in the concentration the greenhouse gases and aerosols, where by the end of the 21st Century the probability of events like this may increase as simulated by the UK Hadley Centre global coupled model (P. Cox, personal communication). In addition, land use changes and biomass burning due to the increased fires and the subsequent injection of aerosols to the atmosphere have the potential to affect the onset and the amount of rainfall in the region (Andreae et al, 2004).

However, this does not imply changes in the large scale circulation leading to this drought in 2005 may be consequence of regional deforestation or of global warming and climate change.

2. IMPACTS OF CLIMATE CHANGE IN THE AMAZON BASIN

The GEF-Amazonas Project has, among others, the objective to strength the coordinated planning and execution of strategic actions for the protection and sustainable management of soil and water resources in the Amazon Basin, considering their impacts and vulnerability to climate variability and change.

Therefore, the upcoming analysis includes an assessment of observed and projected climate variability and change in Amazonia, at basin and regional levels,

2.1 Observed and expected impacts of observed and projected climate variability and change basin-wide: State-of-the-art of current knowledge

In the Amazon Basin, the rain forest is 85% intact across this geographic and geopolitical landscape, and it represents an amazing 60% of the world's tropical rain forest. The Amazon and the Tropical Andes harbor the greatest terrestrial and freshwater diversity known on the planet while providing 15% of Earth's freshwater. The principal threats to this massive region include:

- Road development and associated land use changes for urbanization purposes and hydroelectric reservoirs construction
- Agricultural colonization from plantations, ranching, and soy farming
- Commercial logging and mining, and associated hunting
- Loss of biodiversity and natural ecosystems
- Impacts on the hydroelectricity generation potential in the basin
- Rapid climate change and impacts of extremes

Changes in climate and hydrology as explained before threatens the Amazon's water regime and freshwater ecosystems because warming temperatures will result in greater evaporation from water surfaces and greater transpiration by plants, which will result in a more vigorous water cycle. If projected declines in precipitation during dry months occur, climate change impacts to the Amazonian water regime may be exacerbated (Nijssen et al., 2001).

Based on the evidence shown in previous sections, as well as in the reviews by IPCC (2001a, b), Marengo and Silva Dias (2006), Marengo (2006a, b), Salati et al (2005), Hiller (2003) among others summarize possible impacts of climate change in Amazonia:

2.1.1 Observed variability and change in hydroclimatic conditions in Amazonia

- In Amazonia there is an observed positive air temperature trend of the order of + 0.63 °C over the last 100 years until 1997 (Victoria et al. 1998), that has been updated to +0.81 °C until 2002 (Marengo 2003). There are serious consequences to these changes. Projected increases of temperatures and decreased rainfall during already dry months could result in longer and perhaps more severe droughts, along with substantial changes in seasonality.

- Increased air temperatures affect the surface water balance diminishing the soil moisture storage and increasing the probability of forest fires. The best example is the drought of Amazonia during El Niño 1998. There are indications that these events are getting more frequent and intense in the region which increases the concern of scientists on evaluating the response of the forest to consecutive and closer El Niño episodes and which may increase forest fire occurrence (Nepstad *et al*., 2004, Alencar et al., 2004).

-Considering the recent drought of Amazonia in 2005, Fearnside (2006) has linked this episode to climate change due to the increase in the concentration of greenhouse gases and to deforestation in Amazonia. It is almost impossible to assure that a phenomenon that lasted less than 2 years can be ascribed to climate change. As indicated in various studies (Marengo et al 2006), this drought was not related to El Niño but due to anomalously warming in an already warm tropical North Atlantic.

-The implications that future warmer climates may be analogous to a year like during the very strong El Niño 1997-98 are out of place, since there are drought years in Amazonia (as in 1963-64 and 2005) that were not linked to El Niño but to climate variability in the tropical North Atlantic sector.

-Model simulations for future climate in Amazonia (Cox et al. 2004, Betts et al. 2004) suggest that drought conditions would prevail in Amazonia after 2050 in an “extended El Niño like mode” do not imply that changes in El Niño would result as a consequence of climate change.

-It is true that some droughts years in Amazonia occurred during El Niño as in 1926, 1983 or 1998, but to say that the drought of Amazonia in 2005 was linked to climate change that would feature more intense and frequent El Niño events is a speculation. Not all climate models show this tendency for drying in Amazonia due to global warming, and the uncertainties are still high in terms on what would happen to El Niño in terms of intensity and frequency on a warmer climate scenario.

2.1.2 Hydrological impacts

- Low water levels in the Amazon River and tributaries consequence of rainfall reductions would affect transportation along the main channel, and this situation was clearly observed during the drought of 2005 (Marengo et al. 2006, Brown et al 2006).

- Increases in the levels of sediments in the Amazon River waters measured at Obidos, due to land use changes in the Andean-Amazon region, affecting possibly the Madeira and Solimões Rivers (M. Freitas, personal communication).

-Model projections show some long term reductions of sreamflow in the Amazon region during the second half of the XXI Century (Milly et al 2005, UK Met office 2005), even though current climate trends do not show any significant unidirectional trend in Amazon River and tributaries streamflow

2.1.3 Forest fires and recycling

- As the rainforest becomes increasingly dry, damaging wildfires broke out in the region, damaging hundreds of thousands of hectares of forest and injecting into the atmosphere large amounts of smoke and aerosols that polluted the air in many towns affecting population.

-These ecological impacts of forest fires include the feasibility of sustainable forest management in the region, which is currently advanced as a promising basis for the regional economy (Brown et al., 2006). Previously, in 1997-98, fires associated with an exceptional drought caused by El Niño devastated large areas of tropical rain forests in northern and eastern Amazonia (Nepstad et al. 1999).

-Changes in nutrient input into streams and rivers because of altered forest productivity can greatly affect aquatic organisms. Forested streams are highly dependent upon inputs of terrestrial organic matter, especially leaf fall, because of their nutrient supply. Shifts in terrestrial vegetation and changes in leaf chemistry will impact stream biota and ecosystems.

2.1.4 Impacts on society and human activities

- Climate change will threaten human health in the Amazon. Contagious diseases and viruses such as cholera,- which killed 159 people from 1991 to 1998 - the Rotavirus (latent in the south of the state of Roraima, with 11 deaths in Ipixuna), Severe Diarrheic Diseases, Hepatitis A and Typhoid Fever could proliferate, in function of an increased concentration of these pathogens caused by the drastic decrease in the volume of water in the rivers and lakes and due to the scarcity of potable water, which has already begun to be confirmed in the state's rural areas.

-Respiratory problems due to smoke from forest fires in 2005 were reported in Acre and many people, and many elder and children entered hospitals for treatment.

- It is argued that the environmental change caused by deforestation has favored the main malaria vector *Anopheles darlingi*, creating numerous sunlit larval habitats and bringing potential blood hosts in the vicinity of the mosquitoes. The continuing environmental change, caused mainly by deforestation, is likely to favor the malaria situation in Brazil as it creates new malarial habitats and affects large numbers of non-immune settlers who are attracted to the Amazon region.

- Recreational and commercial fisheries are particularly at risk of climate extremes and increased variability because fish populations are notoriously variable, and fisheries yields are often heavily dependent on the occasional strong year class (Pitcher and Hart, 1982).

2.1.5 Impacts on biodiversity and ecosystems

-Deforestation also provokes great biodiversity loss in Amazonia, estimated between 8,000 to 34,000 species, considering that deforestation raises 1% per year (Salati et al. 2006).

-By the end of the Century, 43% of 69 tree plant species studied could become extinct in Amazonia (Miles *et al*., 2004). Larger impact would happen over northeast Amazonia and least impact over western Amazonia in terms of species and biome redistributions. Forty percent of the Amazonian forests could react sensibly to a slight reduction of precipitation; this could mean that the tropical vegetation, hydrology and climate system in South America may change very rapidly to another steady state not necessarily producing gradual changes between the actual and the future situation.

-Warming water temperatures because of global warming will impact temperature dependent species. Temperature tolerances often govern both the local and biogeographic distribution limits of freshwater fishes (Carpenter et al., 1992).

-Distributions of aquatic species will likely change as some species invade more high altitude habitats or disappear from the low altitudinal limits of their distribution. Elevated temperatures may also result in reduced water dissolved oxygen concentrations, which may have immediate adverse effects on eggs and larvae, which rely on dissolved oxygen for survival (Carpenter et al., 1992).

- Increased water temperatures and reduced precipitation may also reduce suitable habitat during dry, warm summer months and potentially lead to increased exotic species. Exotic fish species often out-compete native species for habitat and food resources and lead to declines in native populations and decreased species diversity (Latini and Petrere Jr, 2004).

- Decreased precipitation during dry months will affect many Amazonian streams and freshwater systems. Small, shallow habitats (ponds, headwater streams, marshes, and small lakes) will likely experience the first effects of reduced precipitation (Carpenter et al., 1992). While prospects for successful relocation of spawning activities for fishes exist, some may be thwarted by the strong imprinting and homing behavior present in many species.

- Climate models project a future that has a more variable climate and more extremes events (IPCC 2001a, b) and local fish populations will more often experience extreme events such as those that produce lethal conditions for short periods of time. Such disturbances can deplete stocks of adult fish and other biota, disrupt ecological processes, and redistribute resources (Lake et al. 2000).

-Even short-lived stresses such as temporary climatic extremes can cascade throughout the tropic network for extended periods. Fish adapted to cooler water temperatures are most vulnerable to climatic extremes such as warm water conditions because they rely on constant temperatures.

- Extreme climatic events, such droughts induced either by natural climate variability of human activities can fragment the Amazon Forest and transform an area of approximately 600,000 square kilometers in a savanna These results reported by Hutyra et al (2005) were obtained by mapping areas of the forest most sensitive to drought using rainfall records during the last 100 years. The region corresponding approximately to 11% of the forest area extending from Tocantins to Guiana would be the most affected.

- The results from Hutyra et al (2005) agree with model simulations for future climate in Amazonia (Cox et al. 2004, Betts et al. 2004) that suggest a drought regime after 2050, linked to the so called “Amazon die back”. According to the projections of the HadCM3 model, in the future the forest could collapse and became a source instead of s sink of C02 (as it is in the present).

- This change would be due to global warming and the increase in the concentration of greenhouse gases. As a consequence, the forest would be replaced by savanna type vegetation. As in the Hutyra´s work, the work by Cox et al (2004) and Betts et al (2004) suggest that uncertainties are still high.

2.2 Climate change projections for the Amazon region for the XXI Century: Preliminary results from the CREAS project

This section is based on what was discussed in Sections 1.1.1 and 2.1. As results from the CREAS project, model projections for the A2 and B2 emission scenarios were obtained for South America for 2071-2100 in the form of anomalies relative to 1961-90. Fig. 13 shows the annual rainfall and temperature anomalies from the A2 and B2 scenarios foe the future, as represented by the ensemble of the three regional models used for CREAS.

The figure shows that changes in A2 are more radical and regionally comprehensive as compared to those of B2. While the drier region (between 1 and 2 mm/day) in B2 cover mostly northern Amazonia, the die region in A2 extends into eastern Amazonia and the entire state of Para, with the larges reductions nearby the mouth of the Amazon River.

In relation to annual temperature changes, in the scenario A2 the entire tropical South American region may become 4-6 °C warmer, and up to 8 °C warmer than normal in central equatorial Amazonia. In the B2 scenario the warming all across Amazonia varies between 2-4 °C with the warmest in central equatorial Amazonia by 4-5 °C. The possible impacts on these changes are shown in Fig. 14, with the more intense impacts on the A2 scenario

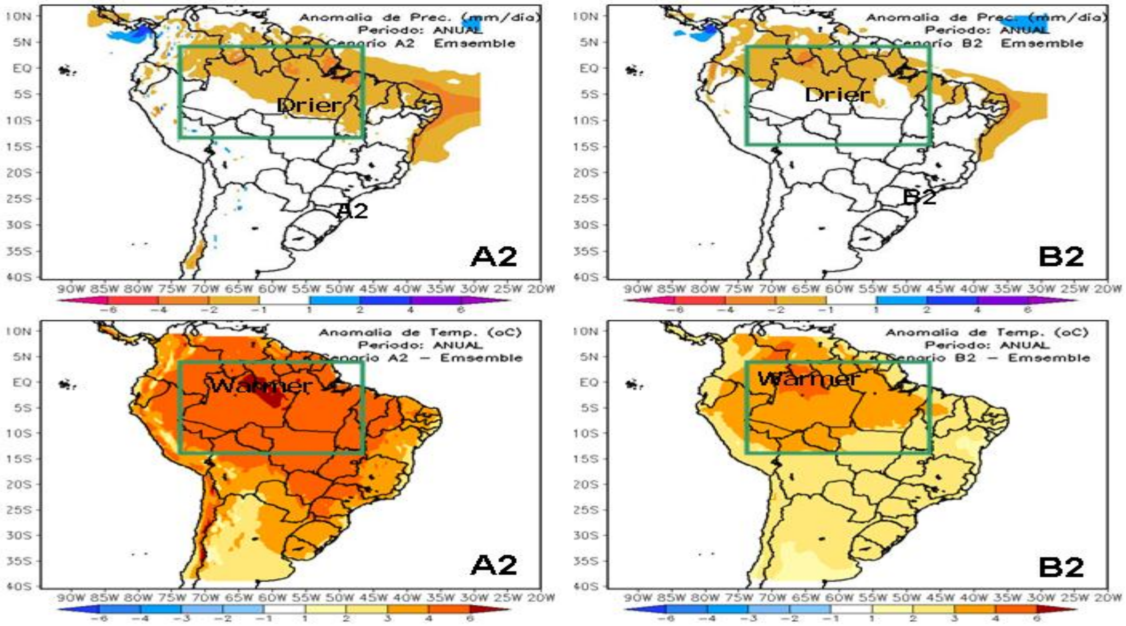
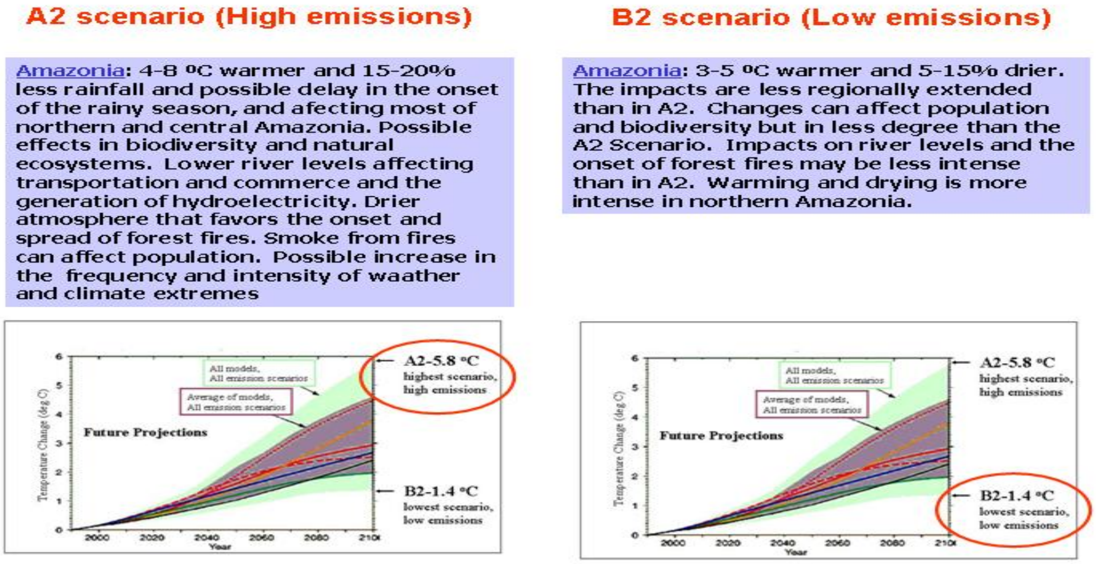


Figure 13. Projected changes in annual rainfall and air temperature anomalies for the Scenarios A2 (Left) and B2 (right). Units are mm/day (rainfall) and (°C) for temperatures. Results are the ensemble of 3 regional models (Eta/CPTEC, RegCM3 and HadRM3P) for the period 2071-2100 relative to 1961-90. Green square represents the Amazon region (Source: Ambrizzi et al. 2006).



A2 scenario (High emissions)

Amazonia: 4-8 ºC warmer and 15-20% less rainfall and possible delay in the onset of the rainy season, and afecting most of northern and central Amazonia. Possible effects in biodiversity and natural ecosystems. Lower river levels affecting transportation and commerce and the generation of hydroelectricity. Drier atmosphere that favors the onset and spread of forest fires. Smoke from fires can affect population. Possible increase in the frequency and intensity of waather and climate extremes

B2 scenario (Low emissions)

Amazonia: 3-5 ºC warmer and 5-15% drier. The impacts are less regionally extended than in A2. Changes can affect population and biodiversity but in less degree than the A2 Scenario. Impacts on river levels and the onset of forest fires may be less intense than in A2. Warming and drying is more intense in northern Amazonia.

Figure 14. Summary of projected changes in regional annual rainfall and air temperature anomalies for the Scenarios A2 (Left) and B2 (right) and their expected impacts

2.3 Experiences on assessment of climate change and impacts at the country level in the Amazon Basin: the National Communications to UNFCCC

At country level, few studies on climate variability and change and their impacts in biodiversity and society have been developed for each one of the Amazon countries. Independent studies have been developed by scientists and institutions and few of them relevant to the Amazon Basin are published in the international literature, while most of them are available in printed form in the form of internal reports. A nice collection of references can be found in Chapter 14 in the IPCC WGII TAR (IPCC 2001b).

At the national level, perhaps the most comprehensive studies have been developed in the form of the National Communications to the UNFCCC, as well as other nation al studies implemented by the National Institutes of Health and the Ministries of Environment or other organizations, funded either by the government or institutions such as the Inter American Institute for Global Change. This is the case of Brazil, Bolivia and Peru, and will be detailed later on.

After the regional and country level analysis, efforts such as data, models and methods sharing must be encouraged, since these are fundamental for the development of integrated studies on climate variability and change, and impacts on society, water resources, and natural ecosystems.

International initiatives and programs such as LBA project (Brazil-European Union-US-Some Amazon countries), HYBAM (IRD France and Peru, Ecuador, French Guiana, Bolivia and Brazil), and TROPENBOS (The Netherlands and Colombia, Guyana and Surinam) were able to solve this problem at least partially since they have a life span of few years. However, these projects were more concerned with climate and natural climate variability in the short term and impacts on ecology and not on climate change.

Most of the private organizations working in Amazonia are interested in biodiversity, conservation, timber, and with few exceptions on hydrology, water quality and water resources. NGOs such as World Wildlife Foundation WWF and Greenpeace have been involved on campaigns about climate change and impacts in Amazonia, in relation to deforestation, global warming, fires and recent extreme events in the region, such as the drought in 2005 (Greenpeace 2006). Sometimes, the approach is not based on scientific evidence or model simulations, and the uncertainties are still high.

There is an imbalance among countries, Brazil leads the studies, research and hydrological and climatic monitoring activity in the whole basin and the LBA project is one example. Technical, logistic, financial and sometimes politic constraints preclude the Amazon countries to joint efforts in studies on variability of climate and water resources, especially considering the hydroelectric generation potential of the basin, and the possibilities of deforestation in the Amazon and global warming affecting negatively this potential.

In fact, one common thing in most of the Amazon countries is that there are assessments of possible changes in water availability (rainfall, streamflow) in agriculture, hydroelectric generation and other activities as a consequence of climate change at a country level, as shown in their respective National Communications the UNFCCC

In relation to the UNFCCC National Communications from Amazon countries, Table 4 shows a list of the Amazon countries that have submitted their First National communications.

Most of the countries have included the analysis of future climate change projections from the IPCC IS92 scenarios and 2CO2 projections for 2010, 2030 and 2100 (Bolivia, Ecuador, Guyana, Venezuela), while some other countries do not include assessments of future climate change (Brazil, Colombia, Peru, Surinam) on their National Communication but that were published as separate books or reports, either at national or regional scale. The most used global models are the GISS, HadCM2, UKTR (1CO2 and 2CO2), GFDL, CCCM, and ECHAM3.

The global models used for each country have been chosen depending on their ability to simulate realistically the present climates of the countries. Colombia used also the A1 SRES scenario, while Venezuela used the A2, B2, A1 and B1 together with the IS92 scenarios. Downscaling was done using MAGIC-SCENGEN (Bolivia, Guyana, and Venezuela) as well as LARS-WG and SDMD. Other models used are the Holdridge Life Zone methods for ecological purposes (Bolivia, Ecuador, Guyana, Colombia), and agricultural models such as DSSAT, CERES and others (Guyana, and Venezuela).

Table 4. Current situation of National Communications to UNFCCC submitted by Amazon countries (Non-Annex I Countries). E=English, S=Spanish, P=Portuguese.

Non Annex I countries	Initial (First) National Communication language	Date of submission	Second National Communication	Date of submission
BOLIVIA	E, S	16/11/00		
BRAZIL	E, S, P	10/12/04		
COLOMBIA	S	18/12/01		
ECUADOR	E, S	10/04/00		
GUYANA	E	03/01/02		
PERU	S	21/08/01		
SURINAME	E	27/03/06		
VENEZUELA	S	13/10/05		

Source: UNFCCC (www.unfccc.int).

In the following we will show results of some national studies and assessments of climate variability and change at the level country. The analysis is based on the national communications to UNFCCC for the assessment of future climate change projections, the Latin American Chapter of IPCC TAR WGII (IPCC 2001b) and on national reports and publications. A relevant comment is that the level of development and progress is totally uneven among countries, while some countries using the IS92 IPCC scenarios for their future assessments, while others are using the IPCC TAR models.

The different methods used at each country's level as well as the various data sets and the scales used because of the country size made comparisons and integrations quite difficult.

2.3.1 Bolivia

Observational studies in the Bolivian Amazonia have shown since 1970 increases of rainfall on the order of +15% in 30 years, thus increasing flooding of the Mamore River (Ronchail *et al.*, 2004), which is agreement with a observed positive trend in southern Amazonian rainfall during the peak season since the late 1920's (Marengo 2004). However, more important than the linear trend is the decadal variability observed in both northern and southern Amazonia.

On the basis of global climate change scenarios and other assumptions, climate scenarios defined for Bolivia on an analysis time horizon until year 2100 (IPCC IS92 scenarios) show: a) all scenarios indicate the same temperature increase trends, b) the temperature increase line is almost parallel to the normal curve and c) in some cases models indicated higher increases.

Concerning precipitation, absolute precipitation increase is higher during the rainy season (September to February), while precipitation variation during the dry-season (May to August) is low in absolute terms. The Amazon basin of the country would present increases of temperature and precipitation reduction in the dry months.

According to the National Program of Climate Changes (MDSMA 1997), an increase of 2 ºC in temperature combined with an increase of 10% in precipitation, would cause an increase of tropical humid forest in 65.27% in detriment to the subtropical humid forest (59.72%). A similar scenario could also cause an increase of the subtropical dry forest in 3.79% (MDSMA 1997). In case of a decrease in precipitation (10%) combined with an increase in temperature (2 ºC), a decrease of the subtropical humid forest is forecast as 81%.

During the last years, vulnerability studies were developed in Bolivia in different topics: agriculture, water resources, forests, cattle rising, pastures and human health. These analyses were accomplished through the elaboration of regional climate and change scenarios based on economic tendencies.

2.3.2 Brazil

Recent studies have identified trends and decadal time scale rainfall and river variability in the Amazon region that are not being included in the Brazilian National Communication to UNFCCC (MCT 2004). A nice review is found in Marengo (2004) and Marengo and Silva Dias (2006), as well on IPCC (2001b). Northern/Southern Amazonia show negative/positive trends since the late 1920's.

Additional observational evidence of changes in the hydrological cycle due to land use change is inconclusive at present, though observations have shown reductions of streamflow and no change of rainfall for a large sub-basin (Tocantins river basin, Costa et al. 2003), highlighting the effect of deforestation on streamflows. Modelling studies of large-scale deforestation indicate a likely drier and warmer post-deforestation climate. Reductions of regional rainfall might lead to atmospheric teleconnections affecting the climate of remote regions.

Recent studies on projections of future climate change in Amazonia have been developed by Milly et al (2005), Marengo (2006a, b), Marengo and Ambrizzi (2006), Salati et al (2006), and while the future scenarios are characterized by warmed trends, that can reach up to 8 C in the A2 scenario by 2100.

The general consensus is that rainfall and river levels in the Amazon region would reduce up to 20% by 2100, affecting thus transportation and commerce along the main river channel, as well as health in the communities living nearby rivers and the river ecosystems. A sample of what could happen in the future was the recent drought of Amazonia in 2005.

Rainforests play a vital role in regulating the global climate and the more trees that are felled, the more unpredictable the climate will become. Tropical deforestation accounts for around 20 percent of global carbon dioxide emissions, a staggering amount that explains why 75 percent of Brazil's own carbon dioxide contribution comes from forest conversion. But with drought plaguing many areas - such as last year's catastrophic event in the Amazon - the forests dry out and become even more susceptible to fire.

This in turn releases more carbon dioxide and smog into the atmosphere, accelerating climate change and the cycle of destruction continues. Brazil is one of the most vulnerable countries to climate change in the world because of its invaluable biodiversity. If the Amazon loses more than 40% of its forest cover, we will reach a turning point from where we cannot reverse the savannization process of the world's largest forest.

2.3.3 Colombia

Among the focal regions of biodiversity in Colombia are the Amazon region to the east (Alto Caqueta basin) and the humid tropical forests of the Choco in the Pacific region. As a consequence of global warming and rainfall decreases, it is possible that 14% of the Amazon basal forest would be affected, along with 30% of the Orinoco basal forest and 7% of Pacific Basal woodland. In terms of human health, the regions susceptible to contagion were defined in terms of climate variables (temperature, rainfall and relative humidity) and the real incidence on the development of malaria and dengue.

The zones most exposed to malaria as a consequence of climate change would include all towns in Choco and Guaviare, some of Putumayo, Caqueta. Amazonas, Meta, Vichada, Vaupes,Guainia and Arauca; the Pacific watersheds of the Departments of Nariño, Cauca and Valle del Cauca; and the watershed of Uraba-Antioquia, southern Guajira, Catatumbo and the Lower Magdalena, Lower Cauca, Nechi, Alto San Jorge and Alto (IDEAM 2001).

2.3.4 Ecuador

The Ministry on Environment from Ecuador hosts a unit for climate change and also is head of the National Climate Change Committee. This committee is formed by the National Meteorological Service INMAHI, the National Water Resources Council CNRH, some other ministries and the Ecuadorian Committee for Nature Defense and Environment CEDENMA, as well as a Non Government Organization OIKOS.

According to the Ecuadorian Environmental Plan and the Environmental Strategy for Sustainable Development (NCC-ME, 2000) the fragile ecosystems that are being threatened include the moorlands of the high sierra, the Amazon region, the Galápagos islands, the agricultural and livestock areas of the sierra, the lake systems, the mangroves and the wetlands.

Current rapid deforestation in the Amazon region has led to the loss of more than 50% of its plant cover, and half of this loss has taken place over the last 22 years. Deforestation, along with pollution, has caused the significant loss of enormous biodiversity in the zone. In addition, there is a rapidly growing process of pollution and resource deterioration. Basic services in general, especially those ensuring basic sanitation, are deficient in the urban sector and absent in the rural sector.

All of these impacts are adversely affecting the living conditions of the indigenous communities and the immigrants (colonizers) and their descendants, preventing sustainable development from being ensured.

The vulnerability to climate change to which Ecuador's water resources are exposed in the watersheds of the rivers of Esmeraldas, Portoviejo, Chone, Jama, Briseño, Pastaza (up to the Agoyán Project), Paute (up to the Daniel Palacios dam), Mira, Carchi, and Napo (lower basin of Quijos River up to the Quijos station in Baeza and the lower basin of the Jatunyacu river up to the hydrometric station of Jatunyacu after it joins the Iloculin River).

The above-mentioned watersheds extend over an area of 50,791 km2 and are located in the provinces of Esmeraldas, Pichincha, Manabí, Cotopaxi, Tungurahua, Chimborazo, Cañar, Azuay, Carchi, Imbabura, and Napo, corresponding to the regions of the coast, sierra, and Amazon region (NCC-ME 2000).

In terms of hydrological and meteorological observations, the INMAHI has a poor observational network in the Amazon region of Ecuador.

2.3.5 Guyana

The National Climate Committee of Guyana (NCC 2002) has implemented the First National Communication. On it they acknowledge the very few studies on climate change and impacts on society and biodiversity, and for the Amazon region the level of knowledge is even lower as compared to the coastal regions. Guyana's greatest vulnerability to climate change however, is the risk of flooding and inundation deriving from sea level rise in the coastal zone.

Most of Guyana's population and economic activities are concentrated in this narrow, fragile, and currently stressed zone. The area is already, for the most part, below the high tide water level. An increase in sea level of about 60 cm then, as projected by GCMs, would further exacerbate the vulnerability of this already fragile zone.

For instance if warmer, wetter and more humid conditions are projected, species that are currently abundant in Central Amazonia, say, may move into regions like Guyana. However, climate variability and change in seasonality will also have to be considered. For instance, if drought conditions occur in the dry season, this may impose severe constraints on forest growth and may be critical in determining species response.

Climate change and sea level rise would also supposedly affect the forestry sector of Guyana. This is one of Guyana's key economic sectors and adaptation policies aimed at its sustainability will have to be implemented. In the short term, adaptation measures may have to be focused on a redefined forest management plan, addressing such concerns as a forest fire protection plan and stricter control of logging practices, under the supposedly drier climate.

In the case of land use, in the short term, cleared forest (from mining/forestry activities) and parts of savannah regions to be used for human settlement instead of clearing more forest for this purpose in response to migration from the coast as a result of sea level rise.

2.3.6 Peru

Agriculture activity is very restricted in the Amazonian region. The most important crops are coffee, cacao, yucca, banana and papaya. Due to its wideness and its environmental repercussions, the illegal cultivation of coca must be mentioned. It is noteworthy that in this region a migratory agriculture is developed, being this, the main reason of the existing deforestation. It is estimated that in 1990 it reached 6 900 000 Ha and the annual deforestation average in the 1985-1990 period was 260 000 Ha.

Forestry is mainly concentrated in the Amazon region and its incipient development is explained by the wide heterogeneity, difficult transportation, safety problems and technological deficiencies.

The BIOFOR Project (CONAM 2001) has supported the development of policy directed towards the conservation of biodiversity and the protection or carbon stocks, as well as to the management of natural and protected areas in the Peruvian forests. This project looks for the institutional strengthening regarding environmental aspects and natural resources conservation.

2.3.7 Suriname

Suriname is particularly vulnerable to the negative impacts of climate change due to its characteristics of low laying coastal zone. This area of Suriname’s most fertile lands is where most of the economic activities are practiced and population is mostly concentrated. Although Suriname barely emits greenhouse gases, because on the low development of industries, sea level rise may inundate large parts of the coastal zone.

The impact of sea level rise is therefore significant, and can be catastrophic for the country. Hence, Surinam most concerning is the vulnerability rate of the coastal zone and not that much the Amazon region (NIMOS 2005).

Average temperature in Suriname has increased over 1 °C in the past 30 year, whilst precipitation in large part of the country shows a decreasing trend. Both changes will have tremendous effect on the climate-dependent economy of the country as well as n the natural ecosystems here, in particular for the coastal zone. The annual floods and droughts superimposed by the El Niño and La Niña events, and change may occur very frequently.

Erosion and sedimentation along the shoreline of the Surinam coast, including mudflats, mud banks and sand beaches, are also determined by sediments supply from the Amazon region. Changes in the Amazon basin may affect the sedimentary budget of the Suriname coast, which on its own turn will have impact on the mangrove forest as they occur at the land-sea interface.

The natural systems of Suriname are vulnerable to many dramatic climate changes, in particular the humid tropical forests. Large-scale deforestation may enhance runoff and erosion of the area resulting in degradation of the soil and consequently poor vegetation growth in the area.

In terms of biodiversity, between the Orinoco and Amazon River mouths, the coast of Suriname shows the highest density of nestling colonies of birds like herons, ibises, spoonbills and storks). Research data shows the Amazon forest, of which Suriname forest is part of, increases in biomass and thus may be interpreted as the CO2 uptake.

The country ranks as the 37th in the world in terms of existing forest area and is one of the Amazon countries containing the highest amount of biomass per hectare of forest undoubtedly will be a country where the forestry sector will play a major role in mitigation of greenhouse gases. For the South American endemic Scarlet Ibis, the coast of Suriname is of critical importance.

2.3.8 Venezuela

Along the XX Century, temperature and precipitation time series exhibited trends in the mean and variance. Maximum temperatures have decreased between 1940 and 2002 at a rate of -0.18 °C/10 years, while the minimum temperatures have increased by +0.37 °C/10 years. The diurnal temperature range has decreased by 3.5 °C during the period. Precipitation has decreased all over the country during 1950 to 1998. In relation to precipitation during the dry and wet periods, it was observed that stations in the Amazon region show any unidirectional trends (MARN 2005).

For the future, it is expected rainfall reductions in most of the country, varying from -5% for the optimistic scenario by 2020 until -25% in 2060 for the pessimistic scenario. Temperature increase vary from +0.3 °C in 2020 for the optimistic scenario to +3.5 °C in 2060 for the pessimistic scenario. Losses by evaporation are to be high due increase in precipitation and temperature increases, which could complicate the levels on reservoirs as well as the water availability for the Caroni River and thus affect hydroelectric generation and human consumption. Due to the rainfall reduction, it is possible that the risk of fires would be high y most of the country.

At the regional level, some international projects have come up in the recent years to monitor indicators of climate change in the country. One of them is the Great Ice Project that measures the recession of glaciers in the Andes, where the Amazon Rivers have their origins.

In addition the HYBAM (Hydrologie du Bassin Amazonien) executed by the Institut de Recherche pour le Développement (IRD) from France that is directed towards the monitoring of climate and hydrology in the Amazon region. HYBAM has regional offices in Brazil, Bolivia, Peru an Ecuador. The work they have done is quite relevant to climate and hydrological variability in the Amazon region, generating plenty of papers. However they have not focused on the possible impacts of climate variability in human activities and natural ecosystems nor on climate change and its impacts.

3. COMMUNITIES IN RISK AND VULNERABLE ECOSYSTEMS IN AMAZONIA

The Amazon's hydrological cycle is a key driver of global climate – and global climate is therefore sensitive to changes in the Amazon. Climate change threatens to substantially affect the Amazon region, which in turn is expected to alter the global climate and increase the risk of biodiversity loss (M. Case, personal communication)

Despite world concerns and international efforts to conserve natural resources, tropical forests continue to disappear at unprecedented rates. In establishing systems for the sustainable management and exploitation of tropical forests, issues relating to the way in which human activity affects the basic ability of forests to self-regenerate are vitally important; so is the preservation of basic ecological processes such as biological productivity and recycling of water and nutrients.

It can be presumed that changes to the cycles of water, energy, carbon and nutrients that result from replacement of Amazonian vegetation will have consequences for climate and the environment at local, regional and global scales. The conversion of primary tropical forest to agricultural areas or secondary vegetation represents one of the most profound changes to the natural environment of the present age.

Population growth in Amazonia from 3,5 million in 1970, up to 20 million in 2000, though 65% living in large and mid-size cities and towns, and colonization projects have produced rush of landless people to small scale, low tech agriculture with subsidized cattle ranching. During the last 20 years the land use change is causing an unprecedented imbalance in Amazonia, and possible consequences are biodiversity losses of unknown magnitude and significant alterations on natural cycles of water, carbon, trace gases, aerosols, and nutrients.

The knowledge of the variations if the infectious diseases cycles at regional levels is still incomplete in Amazonia, mainly due to the large extent of the region and its environmental heterogeneity. It is also important to know seasonal or interannual climate variability modulate the intensity of diseases. Historically, research in epidemiology has been limited to specific risk situations (frequency of cases during some periods of epidemic) without worrying about its links to environmental variability.

In the state of Rondônia, in the southwestern Amazonia, Castro et al (2006) discussed frontier malaria as a biological, ecological, and socio-demographic phenomenon operating over time at three spatial scales (micro-individual, community, and state and national). Spatially explicit analyses reveal that the early stages of frontier settlement are dominated by environmental risks, consequential to ecosystem transformations that promote larval habitats of *Anopheles darlingi*.

With the advance of forest clearance and the establishment of agriculture, ranching, and urban development, malaria transmission is substantially reduced, and risks of new infection are largely driven by human behavioral factors. Malaria mitigation strategies for frontier settlements require a combination of preventive and curative methods and close collaboration between the health and agricultural sectors.

Forest fires have significant sanitary, economic and environmental effects. Climate change is likely to affect the risk of forest fires, which in some countries, such as Brazil, have been associated with the increase risk of outpatient visits for respiratory disease (Haines and Patz, 2004), and increased risk of respiratory disease, eye problems, injuries and fatalities (Haines *et al*., 2000; Patz, 2004).

Climate change and extreme weather events, such as floods, may lead to increased outbreaks of vector-borne diseases such as malaria and dengue, and increased outbreaks of infectious diseases such as cholera and meningitis. Climate change induced droughts will increase the risk of wildfires with direct impacts on human health from loss of property and smoke inhalation. Increased temperature may also lead to an increase in the distribution and growth of allergenic plants in the region.

As far as natural ecosystems are concerned, tropical forests of Latin America, particularly those of Amazonia, are increasingly susceptible to fire occurrences due to increased El Niño-related droughts and to land use change (deforestation, selective logging, forest fragmentation) (Nepstad *et al*, 1999, Fearnside, 2001). One of the most important losses due to climate change in Amazonia is biodiversity given its ecological and economical importance High risk of forest loss due to global warming is shown by Schloze et al. (2006) for Amazonia, with more frequent wildfires. The current levels of biodiversity are still unknown.

The Amazon region represents a major challenge for an inventory of biodiversity, and its quantification at the present is still incomplete, and the number of species varies among different authors. The Amazon Basin contains a staggering portion of the world's biodiversity, and thousands of people support themselves by working its land and forests. It provides everything from building supplies to medicine. The Amazon contains an unknown range of biodiversity: at least 40,000 plant species, 427 mammals, 1294 birds, 378 reptiles, 427 amphibians, 3,000 fish, and over one million insect species identified.

Less rainfall during the dry months could seriously affect many Amazon Rivers and other freshwater systems, and the people that rely on these resources. One possible disastrous impact of reduced rainfall is a change in nutrient input into streams and rivers, which can greatly affect aquatic organisms. A more variable climate and more extreme events will also likely mean that Amazon fish populations will more often experience hot temperatures and potentially lethal environmental conditions. This was observed during the drought of 2005.

Burning in Amazonia has been almost entirely restricted to areas where trees have been felled and allowed to dry before being set alight. Fire normally stops burning when it reaches the edge of a clearing rather than continuing into unfilled forest. Archaeological evidence suggests that catastrophic fires have occurred in Amazonia during major El Niño events four times over the past 2,000 years: 1,500, 1,000, 700, and 400 BP (Meggers, 1994). Human action could now turn less intensive El Niño events, which are much more frequent than major ones, into catastrophes.

Increased fire initiation foci, together with increased forest flammability from logging, already have resulted in substantial incursions of fires into standing forest in eastern and southern Amazonia during dry years. The 1998–1999 fires in Roraima, in the far northern portion of Brazil, reflect the vulnerability of standing forests in Amazonia during El Niño events now that settlement areas in the forest provide permanent opportunities for fire initiation.

It is more probable that forests will be replaced by ecosystems that have more resistance to multiple stresses caused by temperature increase, droughts and fires. In Amazonian rainforests, there are signs of an increase in lianas dominance. This could be a consequence of high water stress and signs of forest degradation.

Subsistence farming in the Amazon is particularly threatened by warming and drying during critical seasons. In northeastern Brazil, people have been suffering from decreased agricultural yields that are among the most severe in the world. More than 45 million people live in this region, which is prone to periodic droughts and famines. Slight climate changes in this region will likely have major consequences for human populations.

In the next we will describe some regional focus on the issues of climate change and its impacts in communities and biodiversity. On human impacts focus will be in water availability and impacts on health on biodiversity discussions will be on the lost of biodiversity in terms of climate change. Fires link both components since fires are related both to health impacts and deforestation and biodiversity lost. We will see that the different Amazon countries have reached different levels of developments, being some of them focusing more on health or on biodiversity loss.

3.1 Bolivia

Recent data from remote sensing show that large areas of Amazonia (mostly the Brazilian Amazonia) have been changed from forest to pasture and agricultural land. Deforestation rates have somewhat stabilized in the early 1990s, mainly in the Brazilian Amazonia, but the underlying pressures to continued land use change are still present: a growing population in the developing nations of Amazonia and plans for a road network criss-crossing the region.

The PNCC (2000) have published a National Assessment of climate change in vulnerability and adaptation of the health sector in various regions of the country. They found that in the Amazon region of Bolivia by 2010 (based on the IPCC IS92 scenarios) it is expected an increase in the occurrence of leishmaniasis due to increments in temperature and humidity, especially during July-September. In relation to malaria, it is expected an intensification and a change of the seasonal patterns of the disease.

3.2 Brazil

Logging practices damage and degrade more than Mha yr-1 of forest in the Brazilian Amazon; surface fires (e.g., those in 1998) may burn large areas of standing forest in these regions (Cochrane *et al.*, 1999; Nepstad *et al.*, 1999, IPCC 2001b). These authors conclude that present estimates of annual deforestation for Brazilian Amazonia capture less than half of the forest area that is impoverished each year—and even less during years of severe drought.

Malaria is endemic in Brazil, affecting mostly the Amazon states. Whereas 50 years ago good progress was made towards its control, since the opening up of the Amazon region for forestry, agriculture and livestock activities, the disease has rapidly increased in incidence, peaking to more than 500,000 cases annually in the 1990s. Rondônia state was particularly hard hit, with thousands of new immigrants suffering malaria attacks. It is argued that the environmental change caused by deforestation has favored the main malaria vector *Anopheles darlingi*, creating numerous sunlit larval habitats and bringing potential blood hosts in the vicinity of the mosquitoes.

The creation of malaria clinics and strengthened control programmes has reduced the malaria situation, but risk is still high, particularly in rural and peri-urban areas where humans and mosquitoes are in close contact. The continuing environmental change, caused mainly by deforestation, is likely to favor the malaria situation in Brazil as it creates new malarial habitats and affects large numbers of non-immune settlers who are attracted to the Amazon region.

As malaria incidence and prevalence is likely to change under climate change and current indications are that malaria remains one of the main diseases affecting public health in the Brazilian Amazon region (PNCM 2003), we may consider the implications of the predicted changes for malaria in the region. Past and current deforestation has caused considerable environmental changes, but the effects of these on malaria are that the disease has become firmly associated with peri-urban settlements and rural development.

The predicted increase in mean temperature, resulting from greenhouse-gas emissions, is unlikely to affect the biology of the mosquito vectors, although higher maximum temperatures may be detrimental to larval and adult-mosquito survival (Clements 1992). Increased precipitation will result in filling up of water reservoirs, but since the annual rainfall is already high in the entire region, it remains to be seen to what extent extra rainfall enhances mosquito breeding. For these reasons the predicted changes are unlikely to affect malaria risk, and the latter is much more affected by environmental change associated with deforestation and urbanization.

3.3 Colombia

The IDEAM has developed the Plano Piloto Nacional Integrado de Adaptación (INAP), that is dedicated to the formulation of adaptation programs to cope with the effects of climate change in high mountain ecosystems, in the island and costal regions o Colombia and on human health. The program has as a major goal to include issues of climate change, vulnerability and adaptation in environmetal policies in the country.

3.4 Ecuador

The Ecuadorian Northeast built a pipeline was built in the 1980’s. The impacts of avalanches and damages to the pipeline have been shown in terms of risks of intense rainfall events and avalanches derived from intense rains. In some cases the avalanches have damaged the pipeline and produced leaking of oil affecting ecosystems, the water streams and the population. In preparing this report, we have not seen much done from the National Climate Change program in terms of assessments of impacts in the society and natural ecosystems. The poor observational network real and lack of observations in the region have hampered studies of climate changes and impacts.

3.5 Guyana

Climate-induced effects on other sectors such as agriculture, fisheries, water and coastal resources, and social and economic conditions might also affect human health. Decreases in food production might result in poorer diets, and rise in sea level and changed precipitation patterns may result in the deterioration of water supplies. Greater numbers of humans could migrate from one area to another, changing the geographic ranges and susceptibility of human populations to many diseases. In general, any event that reduces standards of living will have an adverse impact on human health.

3.6 Peru

Recent data from remote sensing show that large areas of Amazonia have been changed from forest to pasture and agricultural land. Examples are the “Ceja de Selva” or Upper Amazon of Perú. The CONAM has investigated the impacts of climate change and its impacts on the society, but mostly for the highlands or the cities. Some efforts by HYBAM and local universities have discussed impacts of climate change in Amazonia, but there is still a need for some sort of coordination among institutions such as SENAMHI and CONAM , since we believe that the impacts of climate change and impacts on society and ecosystems have not bead dealt yet as good as in Brazil.

3.7 Suriname

The increased mining activity in Suriname has determined that almost all rivers are polluted. Little information on climate change impacts in Suriname are hampered by the lack of long term observations, and the only impacts explored in this country are both due the mining activity and to sea level rise.

3.8 Venezuela

Venezuela is highly vulnerable to climate change, both for the potential consequences of temperature, rainfall and sea level changes as well as for the possible reduction of oil resultant from the adoption o policies and measurements directed to the reduction of GHG emissions. We have not been able to found references on studies about possible impacts of climate change in Venezuela, with the exception of some isolated studies on sea level rise on the Orinoco´s River mouth published by the academic community.

Olivo et al. (2001) assess the impacts of climate change in Venezuela in the form of the potential land loss upon a sea level rise of 0.5m in two Venezuelan coastal sectors: Cabo Codera-Parque Nacional Laguna de Tacarigua and Barcelona-Puerto La Cruz-Guanta. It was estimated that the first one of the two sectors is more vulnerable to land loss due to erosion, while losses due to inundation are not significantly higher for any of the two areas.

Impacts affect mostly urban areas, tourist infrastructure and coastal wetlands. In the vulnerability analysis of sea level impact, the response options evaluated would generate a very high cost for the country. It is proposed that vulnerability analysis to sea level rise be incorporated as part of the coastal zones planning and management process.

4 CONCLUSIONS

This report shows a review if what us known on terms of climate and hydrology variability in the Amazon basin in the present, and also provides some information on what could be the future climate in the region as a consequence of the increase in the concentration of greenhouse gases and from land use changes due to deforestation.

The document constitutes an state-of-the art in the review on climate and hydrological variability in the basin, considering the evolution of the knowledge of the hydrological cycle in the basin since the late 1970´s, when the papers by Salati showed the importance of the forest in the moisture recycling in the basin, and on the results of deforestation in the Amazon in the regional and global climate as suggested by early experiments using climate models and scenarios of deforestation.

The report exhibits a comprehensive review of climate variability and change and impacts in the Amazon basin, and well as on climate variability, with examples of some extreme events as the droughts and their impacts in the society and ecosystems. This provides the basis for analysis of model simulations and projections of climate change.

Currently, the models used by the IPCC TAR and AR4 have allowed for a more sophisticated and complex representation of climate processes and feedbacks, including the role of the ocean and vegetation dynamics. Future climates for the Amazonia simulated by those models have suggested, with some degree of uncertainty, that in for the high emission scenario A2, temperatures in the Amazon basin would show warming of up to 8 C, with reductions of rainfall by about 20%.

These changes due to an increase of greenhouse gases concentration would may results in a warmer and drier Amazonia, with conditions that would allow for the propagation of forest fires, and the tropical forest can collapse, varying from a sink of carbon to a source of carbon, and becoming savanna type vegetation by the years 2040-2060. The drier climate in the region would also impact levels of rivers in the region, and also moisture export for other regions outside Amazonia, thus affecting the hydrological cycle in the region.

Most of the knowledge we have on extreme hydroclimatic events in the Amazonia are mainly based on studies of extreme droughts, such as those related to El Nino in 1926, 1983, 1998 and those non related to El Nino but to warming in the tropical North Atlantic as in 1964 and 2005. Rainfall and river anomalies observed during those events have been considered as a sample on what could be expected in the future under global warming, still the uncertainties are high.

We have learned about impacts on the population, biodiversity and local and regional economies by studying the 2005 drought in Amazonia. The impacts on the local economy were mainly reflected in the closing of the airports due to the large amounts of smoke and the closing of ports due to the extremely low levels in river that did not allow the navigation of ships. To this we should add the problems of the population due to the collapse of local agriculture, the number of people treated at hospitals due thermal stress and respiratory and intestinal diseased from smoke from forest fires and polluted water showed that people in Amazonia is vulnerable to drought, and this vulnerability could be aggravated in warmer-drier climates in the future as suggested by some models. The costs are high, but it will be more expensive if the governments do not come with measures to cope with climate change.

The lack and the difficult access to hydrometeorological data, as well as the poor network of climatic stations in large sections of the basin do not allow for a detailed analysis of tendencies and characteristics of extreme weather and climate events in the basin. Models show for the future that heat waves and intense rainfall events, as well as intense dry spells could occur in the Amazonia. However, the lack of climatic and hydrological data with an adequate time and space resolution do not allow for a comprehensive knowledge of weather and climate extremes in the Amazon region.

The suggestion that the OATC should somewhat work with the meteorological and hydrological services in the basin to allow for access to data is something that this institution should consider carefully. Problems in data access are common in all countries. May be the implementation of a regional climatic and hydrological data should be the solution. Data access and availability is a major problem in South America in general, and any action from OATC with the National Meteorological Services to allow for data access or for an implementation of a regional data bank is welcome.

Some regional experiments and programs such s LBA and GEOMA have helped on the improvement of the knowledge of the functioning of the Amazon region in present climates, but most of the scientists and participant institutions are mainly from Brazil. Some of the observational networks developed in the Brazilian Amazonia, such as SIPAM, could be extended to other Amazon countries with the help of the OATC as mediator among governments so the SIPAM could be extended to the entire Amazonia.

It is here believed that there is an imbalance in research and operational activities Among Amazon countries regarding studies on climate change and impacts in society, biodiversity and population.. Brazil is developing since 2004 programs and studies directed to the development of climate change scenarios, and to assessments of vulnerability of society, biodiversity and water resources due to climate change. Other countries still have not developed this technology and depend on whatever they can get from international office or from Brazil. In that sense, there are a set of recommendations (see next section) directed to an implementation of training and capacity building activities linked to various aspects of climate change, such as modeling, detection techniques, downscaling and vulnerability assessments, and the assessments of impacts and mitigation and adaptation measurements.

Brazil is leading efforts on regional modeling of climate change with the CREAS project, and Amazon countries are more than welcome to access future climate change projections for their own countries. May be a coordination of methods and techniques for impacts and vulnerability and impacts assessments common to the entire basin is needed, so integration of regional results would be less complicate.

Finally, we noticed that the Amazon countries that still need some help in terms of detection of climate change and impacts assessments are Suriname and Guyana, that seem a bit isolated from the the other Spanish or Portuguese speaking Amazon countries. Venezuela and Bolivia are doing some studies on impacts and vulnerability but they still do not show a major integration with Brazil, Peru and Colombia.

5. RECOMMENDATIONS

The OATC Secretary is trying to integrate and to establish science and technology policy that includes the "extension" and application of the SIPAM (Sistema de Proteção da Amazônia) Brazilian developed technology to all Amazon countries. A recent Project introduced by the Núcleo de Assuntos Estratégicos (NAE) from Brazil is directed to the implementation of the largest data bank in the Amazon region. The goal of this initiative is to make available different studies relevant to the Amazon rain Forest developed in the past, as well as to encourage and integrate research activities in the Amazon Basin in the most democratic way.

This is a big challenge, since only 10% of research focused in Amazonia has been developed inside the Amazon countries (From Brazil International Gazeta, 2006).

The LBA project has developed since 1996 it Phase I, and as a consequence of this an extensive research agenda has been implemented in the Amazon countries, mainly the Brazilian Amazonia, in the fields of ecology, hydrology, climatology, human dimensions and economy, and they have implemented the LBA-Data Information System), and the archive include thousands of studies and reports and also different levels of environmental data that area available to all Amazon scientists and governments.

The LBA Phase II looks for an integration of data sets and studies and Pan Amazonian levels, and we expect that the OATC would help to make LBA Phase II the most democratic possible at the different levels of society, science community and government.

The Rede Temática de Pesquisa em Modelagem da Amazônia (GEOMA) is an initiative funded by the Brazilian government, and has as a major objective the development of models and methodologies able to simulate the dynamics of ecological and socio-economic systems at different geographical scales, within the context of sustainability and in support of decision making at the local, regional and national levels. The GEOMA Network is based on an interdisciplinary approach, teaming experts in mathematical and computational modeling, economy, geographical information systems remote sensing, ecology, demography, meteorology, hydrology among other sciences.

The GEF-Amazonas OATC/PNUMA/OEA relevant to current efforts and projects associated with the LBA project, as well as with new initiatives on studies about climate change assessments and their impacts in key regions of South America, including Amazonia, developed by CPTEC/INPE, funded by the GEF/MMA-PROBIO from the Ministry of Environment in Brazil and the GOF-FCO of the British Government. This is the CREAS (Cenarios REgionalizados de Clima para America do Sul) project.

Current studies being done for regional projects in South America, such as CREAS (Marengo and Ambrizzi 2006) have been hampered by the very weak evidence of regional observed climate variability in present times, especially for climate extremes. This is consequence of the non availability of high quality climatic data needed to investigate and quantify climatic extremes and their trends in Amazon countries for the last 50 years or so.

One important aspect of these two projects is the application to vulnerability assessments of key sectors of society, with the objective to influence policy makers and governments in an effort to cope with climate change.

It has become clear for the analyses of extremes, both drought and floods, it is necessary to consider some measurements at the highest level of government. These considerations should include some warning system for floods and droughts, provided by regional and national centers for climate forecast, such as CPTEC and INMET. The implementation of Vulnerability maps for these hydroclimatic extremes and for the entire Amazon basin is some that could be coordinated at the central level by the OATC.

5.1 Projects and activities linked to climate monitoring and climate change projections and impacts

Before considering the impacts of climate change, there is a need to detect and quantify climate change basin and country wide. For this, environmental data with good coverage in time and space, and especially easy access to it is fundamental. So far, results from the different international efforts and projects currently ongoing in the Amazon Region have proven not useful when one can get an integrated picture if the regional Amazon climate variability and change.

Section 4.1 has described all the strategy proposed for the implementation of the proposed IV.2 activity, including the collection of data and previous studies, the collection and analyses of meteorological and hydrological information for the detection o climate trends in the present, the collection and analysis of climate change projections from global IPCC AR4 models and regional downscaled scenarios for South America, and capacity building activities for the analyses and display of climate change projections as well as on vulnerability issues at regional level.

Some of climate change studies and projects have produced results at the catchment level in individual countries that can not be up-scaled for the whole basin, and in other the methods used and the treatment for data are not compatible and it is hard to intercompare results and estimates among different Amazon countries.

The Meteorological and Hydrological Services in the Amazon countries do not open their data banks to scientists (that are mostly at research institutes and universities), and also do not exchange data among services. The situation is particularly grave in the Andean-Amazon countries. Therefore, there is a need for an integration of climatological and hydrological data banks (including public and private archives) in one integrated data bank that could be managed by a "federation" of Amazon meteorological services, supervised and sponsored by OATC.

Water and climate are “strategic resources”, and there is a need to quantify their variability and change, as well as to project its availability in the future. The idea of an integrated network of hydrometeorological observations, with data sharing among all Amazon countries should be considered as the main solution to this lack of integration and would reduce the uncertainties in the water balance and hydrometeorological studies on the region.

The monitoring of the meteorological and hydrological network is a real problem, since large sections of the basin are without data coverage and the number of stations is decaying since the late 1970’s, being replaced by automatic weather and hydrological stations that provide data but only from recent years.

The SIPAM (Sistema de Proteçao da Amazonia) was developed during the 1990´s as a Brazilian initiative to monitor the Brazilian Amazon region, at a cost of US$ 1.4 billions. SIPAM was implemented to integrate information as well as to generate knowledge in order to help with the planning and management activities by the federal and Amazon regional governments in the Brazilian Amazonia. The focus is on the protection of natural resources, social inclusion and sustainable development using the state-of-the-art of radars, meteorological and hydrological stations, integrated with remote sensing operations all across the Brazilian Amazonia.

With this SIPAM is able to provide and promote a complete monitoring of the region in real time. The monitoring also includes extreme meteorological and hydrological events. Currently, there are some negotiations with the governments of Peru and Venezuela to implement a system similar to SIPAM in their countries, with transfer of technology from Brazil to these countries so all the national SIPAM programs can interact with each other. The sharing of the data would improve the extension of the SIPAM coverage to the Amazon of other countries.

5.2 Proposed activities in the context of Activity II.2 of GEF-Amazonas

This section discusses a set of proposed recommendations in the context of what is already know in the Amazon countries, and what has been detected as major problems from this report in relation to climate and hydrological changes and their impacts in human society and natural ecosystems.

The objective of this section is to provide a set of general recommendations, that are presented in two parts: one more general that is related to a philosophy of what needs to be done as a major goal for an integration of Amazon countries about an common issue as climate change, without budgets or deadlines, and a second more specific part with a set of proposed activities, with descriptions, budgets, time tables, etc.

5.2.1 General

After the analysis at country level, it has been observed major differences in the availability of climatic and hydrological observed data. Since these data are a fundamental part of the studies on long term climate variability (a first step towards the study o climate and hydrological change), it is noted a lack of integrated assessments of studies on climate variability and change in Amazon´s water balance, as well as on climate trends and water resources variability for the whole Amazon

Basin, with the participation of all Amazon countries and with common methodologies and strategies that would allow for a regional integration.

In the past, some international initiatives and programs such as LBA (Brazil-European Union-USA-Some Amazon countries), HYBAM (IRD France and Peru, Ecuador, French Guiana, Bolivia and Brazil), and TROPENBOS (The Netherlands and Colombia, Guyana and Surinam) have been able to solve this problem at least partially during their life span of few years. Something more permanent is needed.

The SIPAM program also would be an important source of data for monitoring climate and hydrological extreme conditions, with the consideration that SIPAM could be extended to all Amazon countries (currently besides Brazil, Venezuela and Peru are implementing SIPAM). It is clear that data collected from SIPAM in every country will be shared among scientists working in Amazonia, may be under the umbrella of OATC.

We believe that an effort lead by the OATC, via the GEF-Amazonas could result on the establishment of a common framework for studies on climate variability and change in climate and water resources at a regional level. This effort can involve the major players listed in Section 5, including major water agencies in the Amazon countries, the NMHS (from civilian and military activities), universities, NGOs and research institutes.

The meteorological and hydrological data collected by the NMHS is subject to the Resolutions 25 and 40 from the WMO, that establishes that all data collected from the NMHS, that are basically supported by the tax payers be made available to anyone working in Amazonia (assuming that are for scientific and non commercial purposes). Unfortunately, these resolutions are not followed by all the NMHS in the Amazon countries and whenever data is available there is a price charge that sometimes is prohibitive for anyone working on scientific issues of Amazonia.

The OATC should assume an integrator role given the current sometimes disarticulated coordination among different countries. It is firmly believed that the OATC has the political potential as a regional articulation mechanism to promote the integration of Amazon countries and its institutions to joint experiences, knowledge and resources within the context of sustainable use of its water resources.

Specifically, we propose a partnership sponsored by the OATC on the scientific-environmental-political framework, towards the integration of studies, monitoring activities, and future planning of the water resources in all countries in the region.

To accomplish this, we suggest these lines of action coordinated by the OATC:

a) An implementation of a Regional Climatic and Hydrological Archive for the Amazon region, with the contributions from the NMHS (that are the main responsible for data collection), and other agencies that collect hydrological and climatic data in Amazon countries, such as the National Water agency in Brazil (ANA), and the Navy in Peru (DHN). A regional data bank could be hosted in a country indicated by the OATC, and the data would be available only for scientific studies relevant to the objectives of GEF-Amazonas, and with the compromise of the NMHS and institutions that the data collected be released for the demands of GEF-Amazonas.

The data bank could be either implemented as (i) a centralized archive with contributions from all NMHS and with indications of acknowledgments, or (ii) a distributive archive, where only a map with the stations and record information could be accessible to anyone one, and when data is requested there interested parties will be transferred to the NMHS web sites. Even though (ii) would be the best option for the NMHS, we believe that option (i) will be the best for the user. In here we need the intervention of OATC to guarantee and regulate the operation of this data bank to satisfy the needs of GEF-Amazonas

b) An implementation of a Regional Archive of future climate and hydrological change global and regional model projections for the Amazon region, where climate and hydrological fields, including statistics of mean and extreme, and uncertainty estimates could be made available for scientists working on climate change and impacts in Amazonia.

Currently, CPTEC is implementing a site with high resolution future climate change projections for South America using regional climate models, and certainly a set of projections for Amazonia could be made available for Amazon country´s scientists using the OATC as intermediary. Since the objectives of CREAS are different, there may be a need for some sort of action fro OATC to coordinate with CREAS the access to future climate and hydrological projections. CREAS is producing climate projections at high spatial resolution that can be used for studies on assessments of impacts of climate change and vulnerability assessments.

c) The SIPAM program also could be extended to all Amazon countries. It is clear that data collected from SIPAM in every country will be shared among scientists working in Amazonia, may be under the umbrella of OATC. This will help a lot on the monitoring of extreme conditions, as it was the case of the drought of Amazonia in 2005.

These three actions certainly will depend from the governments of all the Amazon countries, and certainly the role of the OATC as facilitator will help on the negotiations for access to data or at least limited sets of data for Amazonia, both from observations and from the climate change projections.

5.2.2 Specific

Activities proposed in Section 4.2.1.a and b needs to be dealt between OATC and the NMHS, as well as with other institutions that collect data in Amazonia (See Section 5 for a list of those institutions and Annex 2 for the web sites of them).

In the meanwhile, we propose these activities for Section 4.2.2

a) Data archaeology, including the search of climatic and hydrological data for all Amazon countries, searching the archives of the NMHS, regional civil and military data banks and others sources of data

Duration of this task: 48 months

Cost: US $ 2,000.00 per year, total of US $ 8,000.00 (purchase of meteorological data)

b) Search and compilation of references, studies and other documents (including internal reports and unpublished material) relevant to climate change in Amazonia, and to its impacts on society and natural ecosystems. This is a continuous work, free of cost and may take all the period of the project. At the end, we expect to implement a documentation center that will hold of this information, and can be updated and on permanent basis.

Duration of this task: 48 months

For the activities proposed in 4.1.1.b, we can include the following activities, assuming that CREAS will provide the data free of cost. We include also a proposed time line for each specific activity related to changes in climate and hydrology and possible impacts in human society and natural ecosystems:

c) Identification of variables that can be considered for studies on impacts of climate and hydrological change. These variables can be defined according to the needs of the scientists that will study the impacts.

Duration of this task: 6 months

Data producer: CPTEC/INPE as host of the CREAS project

d) Assessments of strategies for model assessments, as well as definition of the global and regional models to be used. It is advisable to choose the wide variety of models available from the IPCC AR4 at the IPCC Data Distribution Centre ( ), and then analyze the individual global models and an ensemble of them for mean and extremes of climate simulations for the present.

The idea is to see what model reproduces realistically present climate, and assuming that the predictability in the future will be the same as in the present. Then, the best models for Amazonia can be indicated and considered for the analyses of future climate change projections. The analyses will include means and extremes, as well as uncertainty assessments. This work can be done by a consultant during 4 months.

Duration of this task: 4 months

Data producer: IPCC Data Distribution Centre

Cost of the consultant: US $ 2,000.00 per month (Total of US $ 8,000.00)

c) Assessments of future regional climate change scenarios using the climate change scenarios derived from CREAS. This is an ongoing activity and the proposed time line is for refinements for the Amazon region. The analyses will include means and extremes, as well as uncertainty assessments for the entire Amazon region. This work can be done by a consultant during 6 months. The final product will be thematic maps of climate change scenarios in the region, usable in GIS format, and accompanied by comprehensive reports.

The maps will include assessments of model skill and also will include risk maps and identification of vulnerable regions in the region that can be overlapped with hydrographic population and demographical maps. The products will be available in Portuguese, Spanish and English, in printed form as well as on CDs, and online at a public web site (may be OATC´s web site).

Duration of this task: 6 months

Data producer: CPTEC/INPE as host of the CREAS project

Cost of the consultant: US $ 2500.00 per month (Total of US $ 9,000.00)

f) Training courses and workshops (2) for scientists in Amazon countries on the analyses and assessments of future climate change scenarios, including the preparation of maps and the statistical analyses of the scenarios. Two 1-week hands-on courses are being proposed, to take place in 2 Amazon countries hosted by institutions that have computer equipments suitable for the analyses of climate change projections, for about 30 people for course

Duration of this task: 1 week

Possible dates: Second quarter of 2008 and 2009

Proposed venues: INPA (Manaus, Brazil), UNAP (Iquitos, Peru)

Total cost (including local arrangements, transportation, honorarium for the lecturers, perdiems for lecturers and 30 participants): US $ 60,000.00 per course=total US $ 120,000.00

g) A 4-day Workshop on vulnerability to climate change in Amazonia, directed for scientists working on climate change and impacts in Amazonia. This workshop could be planned for the first quarter of 2008, hosted by an Amazonian institution either from Bolivia (Santa Cruz) or Colombia (Leticia). The GEF-Amazonas can fund the participation of about 30 participants and 5 speakers, as well as the logistic aspects in the host city. We expect that the host institution can provide some in kind contribution, and that local and regional governments and NGOs can send participants at their own expenses for about 30 participants. We can ask IAI for additional support (may be for 3 or 4 additional participants and 1-2 speakers). We expect a total of about 70 people.

Duration of this task: 4 week

Possible dates: Second quarter of 2010

Proposed venues: Santa Cruz (Bolivia) or Leticia (Colombia)

Total cost (including local arrangements, transportation and perdiem for about 30 participants and 5 speakers):   US $ 60,000.00

h) Implementation of progress reports indicating how the project is going on, press releases, scientific documents and papers all along the duration of the project.

Duration of this task: every 2-months

Cost per year: US $ 2,000.00 (total of US $ 8,000.00 for the 4 years)

5.3 Implementation

The following is a proposal for time table for these activities and costs. We assume that year 1 of the project is 2007.

Year						2007													2008					
Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
4.2.2.a	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4.2.2.b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
4.2.2.c										x	x	x	x	x	x									
4.2.2.d															x	x	x	x						
4.2.2.e																			x	x	x	x	x	x
4.2.2.f																					x			
4.2.2.g																								
4.2.2.h			x			x			x			x			x			x			x			x

Year						2009													2010					
Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
4.2.2.a	x	x	x	x	x	x	x	x	x	x	x	x												
4.2.2.b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4.2.2.c																								
4.2.2.d																								
4.2.2.e																								
4.2.2.f										x														
4.2.2.g																				x				
4.2.2.h			x			x			x			x			x			x			x			x

5.4 Costs and Timetable

This is a proposed budget for these activities during the 4 years of the project, in US $ Dollars

Activity	Year 2007	Year 2008	Year 2009	Year 2010	Total
4.2.2.a	2,000.00	2,000.00	2,000.00	2,000.00	8,000.00
4.2.2.b		8,000.00			8,000.00
4.2.2.c	6,000.00	2,000.00			8,000.00
4.2.2.d		9,000.00			9,000.00
4.2.2.e					
4.2.2.f		60,000.00	60,000.00		120,000.00
4.2.2.g				60,000.00	60,000.00
4.2.2.h	2,000.00	2,000.00	2,000.00	2,000.00	8,000.00
Total	10,000.00	83,000.00	64,000.00	64,000.00	221,000.00

This budget is for the specific activities listed in Section 4.1.2. The general tasks listed in Section 4.1.1, implies negotiations between the OATC, the NMHS and the various levels of government from the Amazon countries, which are hard translate in activities with time line and budgets.

6 MAIN ACTORS

This is a list of institutions that develop monitoring and climate change activities, as well as impacts in various sectors of society in each country. Some of these institutions are the focal point at the government level, such as Ministries of Environment, National Meteorological Services, as well as other institutions linked to the governments. Other institutions are science oriented, such universities and research centers, and also NOGs, such as Greenpeace, WWF at each country. For a complete list of these institutions (including web sites) and others per country, as well as international institutes and projects/programs, please refer to Appendix I.

Basin-wide, perhaps the most important is the OATC. The OATC has proposed an integrated plan for water resources management to GEF, and this has been funded at the level of concept paper. The major water agencies in the Amazon countries are major players on this project, and we hope that this project also includes the participation of scientists from universities, NGO and research institutes. The OATC also can consider the aspects of measurements for water pollution and take action to reduce or prevent contamination from mining and human activities.

The OATC should assume an integrator role given the current sometimes disarticulated measurements among different countries. It is firmly believed that the OATC has the political potential as a regional articulation mechanism to promote the integration of Amazon countries and its institutions to joint experiences, knowledge and resources within the context of sustainable use of its water resources. Specifically, we propose a partnership sponsored by the OACT on the scientific-environmental-political framework, towards the integration of studies, monitoring activities, and future planning of the water resources in all countries in the region.

Colombia

-Instituto de Hidrología, Meteorología y Estudios Ambientales, IDEAM, Bogotá
-Instituto del Medio Ambiente-Universidad Nacional de Colombia, Bogotá
-Alexander von Humboldt Biological Resources Institute, Bogotá
-Amazon Scientific Research Institute –SINCHI, Bogotá
-Instituto del Agua-Programa de Postgrado en Aprovechamiento de Recursos Hidraúlicos, Universidad Nacional de Colombia, Medellín
-Instituto de Ciencias Naturales- Universidad Nacional de Colombia, Bogotá
-TROPENBOS International, Bogota

Peru

-Servicio Nacional de Meteorología e Hidrología SENAMHI, Lima
-Consejo Nacional del Medio Ambiente, CONAM, Lima
-HIBAM-IRD (Hidrogeodinámica de la Cuenca Amazónica) Project that includes Brazil, Perú, Bolivia, Ecuador and France, Lima
-Instituto de Investigaciones de la Amazonía Peruana IIAP, Iquitos
-Instituto Nacional de Recursos Naturales INRENA, Lima
-SIAMAZONIA -Sistema de Información de la Diversidad Biológica y Ambiental de la Amazonia Peruana, Lima

-Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú, Lima, Iquitos.

Venezuela

-Ministerio del Ambiente, Caracas
-Servicio Meteorologico Nacional-MARN, Caracas
-Instituto Venezolano de Investigación Científicas (IVIC), Caracas,

Bolivia

-Servicio Nacional de Meteorología e Hidrología SENAMHI, La Paz
-HYBAM-IRD, La Paz
-Universidad Mayor de San Andrés UMSA, La Paz
-Programa Nacional de Cambio Climático-Ministerio de Desarrollo Sostenible y Planificación, La Paz, Bolivia

Ecuador

-Instituto Nacional de Meteorología e Hidrología INAMHI, Quito
-Ministerio del Medio Ambiente, Quito
-Comité de Cambio Climático del Ecuador (parte del Ministerio del Medio Ambiente), Quito
-HIBAM-IRD, Quito
- National Water Resources Council, CNRH,
-Committee for Nature Defense and Environment CEDENMA

Guyana

-Hydrometeorological Service-Ministry of Agriculture, Georgetown
-National Climate Committee (NCC), Georgetown
-Environmental Protection Agency EPA, Georgetown
-Iwokrama, Georgetown
-TROPENBOS, Georgetown

Suriname

-National Institute for Environment and Development of Suriname (NIMOS), Paramaribo
-TROPENBOS, Paramaribo
-Department of Natural Resources and Environmental Assessment NARENA, Paramaribo
-CELOS - Centre for Agricultural Research in Suriname, Paramaribo

Brazil

-Centro de Previsão de Tempo e Estudos Climáticos CPTEC/INPE, São Paulo
-Instituto Nacional de Meteorologia INMET, Brasília.
-Programa Nacional de Mudanças Climaticas, Ministério da Ciência e Tecnologia, Brasília
-Nucleo de Assuntos Estratégicos, Brasilia
-Instituto Nacional de Pesquisas da Amazonia INPA, Manaus.

-Agencia Nacional de Águas (ANA), Brasília.
-Fundação Brasileira de Desenvolvimento Sustentável, Rio e Janeiro
-HYBAM-IRD, Brasilia
-Universidade de São Paulo USP-IAG, Departamento de Ciências da Atmosfera, São Paulo.
-Universidade Federal do Para UFPa, Belém.
-Empresa Brasileira de Pesquisas Agropecuárias EMBRAPA-Oriente, Belém
-Universidade de São Paulo-CENA, Piracicaba.
-Instituto de Pesquisa Ambiental da Amazônia – IPAM, Belém, Santarém, Brasília.
-Instituto do Homem e Médio Ambiente da Amazônia-IMAZON, Belém.
-PROBIO, Ministério do Medio Ambiente, Brasília.
-Institutito de Pesquisas Econômicas Aplicadas IPEA, São Paulo.

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Appendix I

Institutions and information resources in the Amazon region dedicated to study and development of knowledge in climate change and impacts assessments at the basin and national levels

Colombia

Institution	*City*	*Web Page*	*Downloadable files (pdf, doc, jpg, xls,)*	*Data bases*
IDEAM	Bogotá	www.ideam.gov.co	Yes	Yes
Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt	Bogotá	http://www.humboldt.org.co	Yes	No
Universidad Nacional de Colombia- Instituto del Agua	Medellín	www.unalmed.edu.co	No	No
Instituto Amazonico de Investigación Científica	Bogota	www.sinchi.org.co	Yes	No
Universidad Nacional de Colombia- Escuela de Geociencias y Medio Ambiente	Medellín	www.unalmed.edu.co	No	No
Universidad Nacional de Colombia- Instituto de Ciencias Naturales	Bogota	www.icn.unal.edu.co	No	No
Universidad Nacional de Colombia- Instituto de Estudios Ambientales	Bogota	www.idea.unal.edu.co	Yes	No

TROPENBOS	Bogota	www.tropenbos.nl	No	No

Peru

Institution	*City*	*Web Page*	*Downloadable files (pdf, doc, jpg, xls,)*	*Da ta bases*
INRENA	Lima	www.inrena.gob.pe	Yes	Yes
Dirección de Hidrografía y Navegación de la Marina del Perú	Lima	www.dhn.mil.pe	Yes	Yes
IIAP	Iquitos	www.iiap.org.pe	Yes	Yes
CONAM	Lima	www.conam.gob.pe	Yes	No
UNALM	Lima	www.unalm.edu.pe	No	No
BioDimaz IIAP + Univ, Turku, Finland	Iquitos	www.iiap.org.pe/biodamaz/index.htm	No	No
SIAMAZONIA	Iquitos	www.siamazonia.org.pe	No	No
SENAMHI	Lima	www.senamhi.gob.pe	Yes	Yes
HYBAM	Lima	http://www.mpl.ird.fr/hybam/equipe/equipe_perou.htm	Yes	Yes

Venezuela

Institution	*City*	**Web Page**	*Downloadable files (pdf, doc, jpg, xls,)*	*Data bases*
IVIC	Caracas	www.ivic.ve/ecologia	No	No
Inst, Ciencias Ambientales y Ecológicas, Univ, De los Andes	Merida	icae.ciens.ula.ve	No	No
Ministerio del Ambiente	Caracas	http://www.minamb.gob.ve/CambioClimatico/	Yes	Yes

Bolivia

Institution	**City**	**Web Page**	**Downloadable files (pdf, doc, jpg, xls,)**	**Data bases**

Museo Noel Kempff Mercado	Santa Cruz	www.museonoelkempff.org, linked to www.andesbiodiversity.org	Yes	No
SENAMHI	LaPaz	www.senamhi.gov.bo	Yes	Yes
SINSAAT	La Paz	www.sinsaat.org.bo	No	No
UMSA-IHH	La Paz	www.ihh.umsa.bo	Yes	Yes
HYBAM-IRD	La Paz	http://www.mpl.ird.fr/hybam/equipe/equipe_bolivie.htm	Yes	Yes
Programa Nacional de Cambio Climatico	La Paz	www.pncc.org.bo	Yes	Yes

Ecuador

Institution	***City***	*Web Page*	***Downloadable files (pdf, doc, jpg, xls,)***	***Data bases***
INAMHI	Quito	www.inamhi.gov.ec	Yes	Yes
Ministério Del Médio Ambiente	Quito	www.ambiente.gov.ec	Yes	No
Cambio Climático Ecuador	Quito	www.ambiente.gov.ec/AMBIENTE/cclimatico/WEB/Presentacion/FrameSet1.html	Yes	No
HYBAM-Ecuador	Quito	http://www.mpl.ird.fr/hybam/equipe/equipe_equateur.htm	Yes	No

Guyana

Institution	***City***	**Web Page**	***Downloadable files (pdf, doc, jpg, xls,)***	***Data bases***
EPA	Georgetown	www.epaguyana.org/index.htm	yes	No
IWOKRAMA	Georgetown	www.iwokrama.org	No	No
Hydrometeorological Service	Georgetown	www.sdnp.org.gy/minagri/hydromet/index.htm	Yes	Yes
Guyana Nacional Communication Plan	Georgetown	www.sdnp.org.gy/minagri/hydromet/initial_communication/index.htm	Yes	No
TROPENBOS	Georgetown	www.bio.uu.nl/tropenbos/	No	No

Suriname

Institution	***City***	**Web Page**	***Downloadable files (pdf, doc, jpg, xls,)***	***Data bases***
TROPENBOS	Paramaribo	www.tropnebos.nl	No	No
NARENA	Paramaribo	www.tropenbos.nl	No	No
CELOS	Paramaribo	www.tropenbos.nl	No	No

Brazil

Institution	***City***	***Web Page***	***Downloadable files (pdf, doc, jpg, xls,)***	***Databases***
Museo Goeldi	Belém	www.museu-goeldi.br	Yes	Yes*
IPAM	Belém	www.ipam.org.br	Yes	No
IMAZON	Belém	www.imazon.org.br	Yes	No
INPA	Manaus	www.inpa.gov.br	Yes	Yes
CPTEC-INPE	São Paulo	www.cptec.inpe.br	Yes	Yes
INMET	Brasília	www.inmet.gov.br	Yes	Yes
ANA	Brasília	www.ana.gov.br	Yes	Yes
HIBAM	Brasília	http://www.mpl.ird.fr/hybam/equipe/equipe_bresil.htm	Yes	Yes
ANA-Rede Hidrometeorologica Nacional	Brasília	www.ana.gov.br/rhn/index.htm	Yes	Yes
USP-IAG	São Paulo	www.iag.usp.br	Yes	Yes
UFPara	Belem		No	No
UFViçosa	Viçosa		Yes	Yes
EMBRAPA-Oriente	Belem	www.embrapa.br	Yes	Yes
USP-CENA	Piracicaba		Yes	Yes
IPAM	Belém, Santarém, Brasilia	www.ipam.org.br/ipam/oipam.php	Yes	Yes
IMAZON	Belem	www.imazon.org.br/index.htm	Yes	No
PRODES-INPE	São Paulo	www.obt.inpe.br/prodes	Yes	Yes
IBGE	Brasilia	www.ibge.gov.br	Yes	Yes
SIVAM	Rio de Janeiro, Brasilia	www.sivam.gov.br/	No	No
SIVAM	Rio de		No	No

	Janeiro, Brasilia	http://www.sipam.gov.br/portal/		
IPAM	Belem	ipam.org.br	Yes	No

Regional & International Projects relevant to Climate Change and impacts (including Amazonia)

Institution	*City*	*Web Page*	*Downloadable files (html, pdf, doc, jpg, xls,)*	*Data bases*
UNFCCC	Bonn, Germany	www.unfccc.int	Yes	No
IPCC	Geneva, Switzerland	www.ipcc.ch	Yes	No
IGBP	Stocholm, Sweden	www.ibge.net	Yes	No
IIED	London, UK	www.iied.org	Yes	No
OATC	Brasilia,	www.andesbiodiversity	Yes	No
WWF	Worldwide	www.wwf.org	Yes	No
GREENPEACE	Worldwide	www.greenpeace.org	Yes	No
Andes Biodiversity	Santa Cruz, La Paz & Lima	www.andesbiodiversity	Yes	No
LBA	Sao Paulo	www.cptec.inpe.br/lba	Yes	Yes
EOS-Amazon	Seattle	boto.ocean.washington.edu/eos	Yes	Yes
UNESCO	Montevideo	www.unesco.org.uy/phi	Yes	No
HIBAM	Brasilia	http://www.mpl.ird.fr/hybam/	Yes	Yes
AARAM-Peru	Lima	www.lamolina.edu.pe/aaram-peru/	Yes	No
CATHALAC	Panama	www.cathalac.org	Yes	Yes
LBA-Hydronet	Durham	www.lba-hydronet.sr.unh.edu	Yes	Yes
GRDC	Koblenz	www.bafg.de/grdc.htm	Yes	Yes
GEWEX	Washington	www.gewex.org	Yes	Yes
GPCP	Washington	cics.umd.edu/~yin/GPCP	Yes	Yes
TROPENBOS	Wageningen	www.tropenbos.nl	Yes	No
WMO	Geneva	www.wmo.int	Yes	No