Climate, Environmental Changes and Infectious Diseases: Scenarios and Uncertainties for the Brazilian Health Surveillance

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Introduction

The occurrence of climate change, principally that due to global warming induced by human actions, was first identified in the 1950s. At the end of the 19th Century, the Swedish researcher Svante Arrherius had raised the possibility of temperature increase due to carbon dioxide emissions. During the 1980s, researchers of environmental question became increasingly concerned with the impact of these changes on ecosystems. In the 1990s, models were developed to both explain climate variability during the century and evaluate the contribution of natural components (volcanoes, alterations in Earth's orbit, solar explosions, etc.) and anthropogenic components (greenhouse gas emission, deforestation and burning of forests, destruction of ecosystems, etc.) to these variations. The first global report on climate changes and health was published by the WHO in 1990 (WHO, 1990). A convention on climate changes was created during ECO-92, together with conventions on biological diversity and desertification. However, the subject of climate changes only caught the eye of the media in the last year, with repercussions on government agendas, research and the popular imagination.

The publication of the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC-AR4) in February 2007; the film "An Inconvenient Truth", winner of an Oscar for best documentary in 2007; and the media treatment given to a series of extreme events from a climate and social point of view, such as hurricane Katrina, which destroyed New Orleans; the heat wave in Europe in 2003, when more than 35,000 deaths were recorded, Catarina, which affected the south of Brazil in 2004, and the drought in Western Amazonia in 2005, even without a consensus on their causes, brought to the forefront and reinforced the debate on the origins of and effects of climate change on a global scale. Both hurricane Katrina and the heat wave in Europe were evidence that the impacts of climate change will not be exclusive to poorer countries, but truly global and at the same time localized. This debate has been marked by the inevitable interconnections between technical, technological, political and social questions. While the visibility given to global changes has supported a renewed, wider environmental agenda , the catastrophic and globalizing view of these changes may create a feeling of impotency or even insensitivity with respect to changes that may seem inexorable. Additionally, this debate has intrinsic problems related to the different languages and interests of researchers, entrepreneurs, managers and society. Far from trying to obtain a consensus from these different social actors, the principle objective of this text is to assess the uncertainties facing Brazil in a scenario of climate and environmental changes on a global scale, as well as contribute to the identification of resources that may be used to develop a network for diagnosis, modelling, analysis and intervention of the repercussions of these changes on the health of the Brazilian population in the 21st century.

Climatic processes: Trends and uncertainties

First, we would like to stress that the Earth's climate has always been subject to changes, produced by long or short cycles which are recorded in the history of humankind. Periods of warming followed by a period of cooling were observed in the Middle Ages, and known as the small Ice Age. Some of the great human migration waves, such as the 'barbaric invasions' of groups from the North and East of Europe to the South, and the arrival of Asian groups on the American continent via the Bering Strait, are partially due to climatic phenomena. These cycles may have originated in natural processes, linked to alterations in the Earth's rotational axis, solar explosions and the dispersion of aerosols emitted by volcanoes. Other climatic phenomena, more localized in space and more concentrated in time, are relatively frequent, such as hurricanes, flooding due to intense rain or melting ice, heat waves, etc. Until the 20th century, these phenomena were considered manifestations of "nature" as an Aristotelian concept, and were thought to be uncontrollable, unpredictable and unavoidable. Recently, many of these phenomena have been attributed to global climate changes, which is certainly an exaggeration, frequently stimulated by the media.

In academic forums, an important discussion has been taking place on climate and which portion of these phenomena can be attributed to global climatic changes, since some atmospheric phenomena are due to the greenhouse effect and others are due to natural cycles. The first systematic temperature records date from the 1850s and a historical analysis of these records allow us to recognize a trend towards an increase in the average temperature of the planet. This increase has been accompanied by industrialization and the emission of gases resulting from burning fossil fuels. Recovery of older data on the Earth's climate has been possible by analysing the composition of ice from the Arctic and Antarctic. This data has shown that concentrations of CO2 and CH4 in the atmosphere have never been so high during the last 600,000 years (IPCC, 2007). The increase in the greenhouse effect1, caused by the accumulation of gases, is supposed to have produced an increase of one degree Celsius in the average temperature during the last century.

Climate changes may be understood as any change in climate over the years, due to natural variability or as a result of human activity (IPCC, 2007a). Recently, the IPCC reported that there is a 90% chance that the global warming observed in the last 50 years was caused by human activity (IPCC, 2007b), through the increase in the emission of greenhouse gases. This increase in greenhouse gas emissions may induce heating of the atmosphere, which may result in a global climate change in the long term (McMichael, 2003). Climate changes reflect the impact of socio-economic and cultural processes,

[1] Note that the greenhouse effect existed even before the appearance of man on Earth, and is responsible for beneficial effects, such as filtering the sun's rays, stabilising the temperature of the atmosphere and cycling of gases essential for life.

such as population growth, uncontrolled urbanisation, industrialization and the increase in consumption of natural resources and in demands on biogeochemical cycles (McMichael, 1999; Confalonieri et al, 2002).

According to the IPCC report (AR-4, 2007), following this trend, some of the effects of global warming may be:

- By the end of this century, the average temperature of the Earth may raise 1.8ºC to 4ºC. According to the worst predictions, this increase may reach 6.4°C;

- The ocean level will rise 18 cm to 59 cm by the year 2100.
- Rain should increase by approximately 20%;
- The ice at the North Pole may fully melt in the summer by 2100;
- Warming of the Earth will not be homogeneous and will be felt more on the continents than in the ocean. The Northern hemisphere will be more affected than the Southern.

These predictions are the result of simulation models that have been perfected by various institutions all over the world. In Brazil, the INPE's role has been prominent, particularly that of the CPTEC in monitoring and developing Global Atmospheric Models (GAMs) and Atmosphere-Ocean Global Coupled Models (AOGCMs) for predicting climate changes (Marengo, 2007). Note that these models are sensitive to boundary conditions such as gas emission scenarios and the quality of meteorological data coverage. Figure 1 shows the distribution of meteorological stations on Earth. The result of one of the predictions is shown in Figure 2.

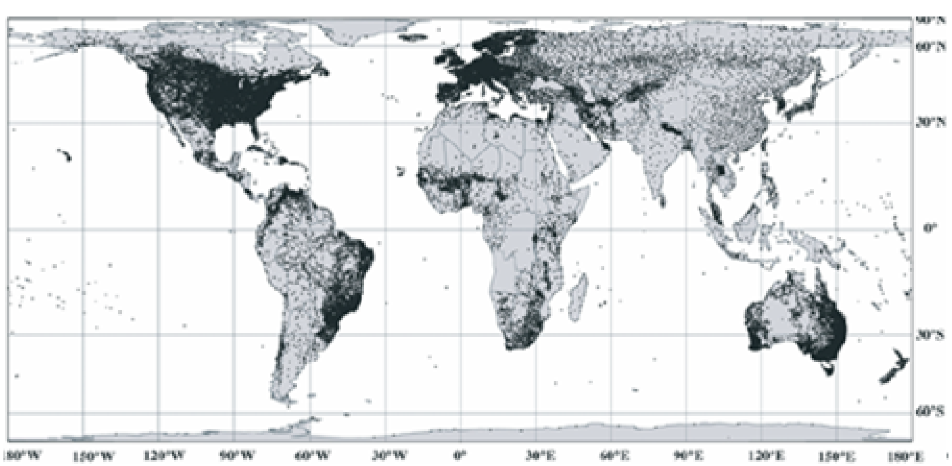

Figure 1: Distribution of the meteorological observation network on Earth. Source: OMM, 2005.

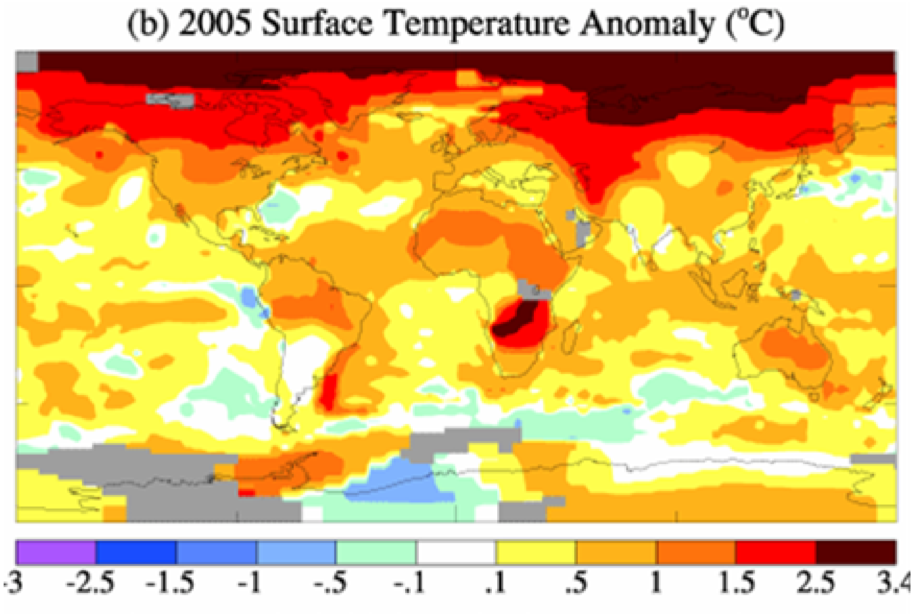

Figure 2: Temperature anomalies in 2005. Source: IPCC, 2007.

Note that the surface resulting from the model shows a temperature increase greater that 2ºC in high latitudes in the Northern hemisphere and 1ºC near the equator. In regions with a low density of meteorological stations, there is a tendency to overestimate anomalies or produce unreliable estimates, such as in equatorial Africa, the Middle East and Antarctica. Brazil has a network of meteorological stations that covers most of the coast, but has few inland, especially in the North and Central-West regions. Additionally, most of the stations are not automatic and record only rainfall, not temperatures.

The global prediction models produce unreliable estimates when applied at the regional level. Most models take fluxes of energy between the soil, air and ocean into account, but underestimate the role of the use and coverage of land in these fluxes. The Amazon, for example, has been playing a buffering role on temperature variations due to the great amount of circulating water and evapotranspiration. The reduction of its native vegetation will produce difficult-to-estimate effects on the entire planet, since there will be an excess of water and heat to be redistributed throughout the entire planet (Gerten et al., 2004). Changes in temperature and precipitation patterns will necessarily result in changes in composition and location of biomes, in addition to causing changes in agricultural practices. On the other hand, these land use changes promote alterations in nutrient, water and heat cycles (Nobre et al., 2007). These global climate change feedback processes are rarely considered in prediction models.

For Brazil, researchers have identified some important climate change scenarios (Marengo, 2007):

- More intense El Niño - Southern Oscillation events: Droughts in the North and Northeast and flooding in the South and Southeast;
- Reduced rainfall in the Northeast;
- Increased flows in rivers in the South;
- Significant change in swamp, Pantanal and Hileia Amazonica ecosystems.

As highlighted above, there is no way to separate the effects of these climatic phenomena from the occupation processes that these regions have suffered. Especially in the Amazon, climate oscillations are superimposed on intensification of burning and deforestation. The 2005 drought in Western Amazonia could have been the result not of global climate processes, but rather of change in land use patterns in Brazil and in nearby countries (Marengo, 2007). Deforestation causes a reduction in the capacity for retention of rainwater and a proportional increase in the surface flow of this water in rivers. In short, it increases the variability of river flow. This change in river flow can be seen in the occurrence of floods in the same region in the Amazon a few months after the dry period.

Also from a thermodynamic point of view, the global warming process can be seen as an accumulation of heat, not just by the atmosphere but also in the water and soil. This energy can be mobilized and dissipated quickly and in concentrated for, generating extreme events (Nordell, 2007). This is one possible explanation for the increase in the frequency and intensity of hurricanes in the Northern hemisphere. In summary, this process, together with land use changes, can not only cause global increases in temperatures, but can also increase the amplitude of temperature and precipitation variations.

Large cities are characterised by heat generation and their coverage by structures reduces the percolation of rainwater and increases the upward flow of winds, which makes them vulnerable to warming and flooding (Campbell-Lendrum and Corvalán, 2007).

Annual climate variability is already well characterised. There is a pendular rhythm with the alternation of hot and cold seasons in moderate zones, and dry and wet seasons in tropical zones. But in certain periods, this rhythm is upset. On an inter-annual, global scale, the El Niño (hot phase) and La Niña (cold phase) can be identified, also known as ENSO (El Niño/Southern Oscillation). It is characterised by irregularities in the temperature of the surface of the Pacific Ocean, which influences atmospheric circulation and alters precipitation and temperature in various locations. The warming and subsequent cooling in a typical ENSO episode can last 12 to 18 months (Trenberth, 1997). This phenomenon generally has large-amplitude consequences and occurs at irregular intervals. The origin of these modifications is still poorly understood and, consequently, their prediction and amplitude in the long term are still difficult to assess.

In Brazil, some studies indicate that the semi-arid Northeast, North and East of Amazonia, the South of Brazil and neighbouring areas are affected strongly by the ENSO phenomenon. There is an increase in precipitation in the South, particularly during the spring of the first year and during the fall and beginning of winter of the second year. The North and East of Amazonia and the Northeast of Brazil are affected by the decrease in precipitation, principally in the second year, between February and May, when the semi-arid region has its rainy season. Temperatures in the Southeast of Brazil increase, making winter milder. In other regions of the country, the effects are less pronounced and vary from one episode to the next (Sampaio, 2000). An overview of what happens in Brazil and in South America during El Niño and La Niña can be seen in Figure 3.

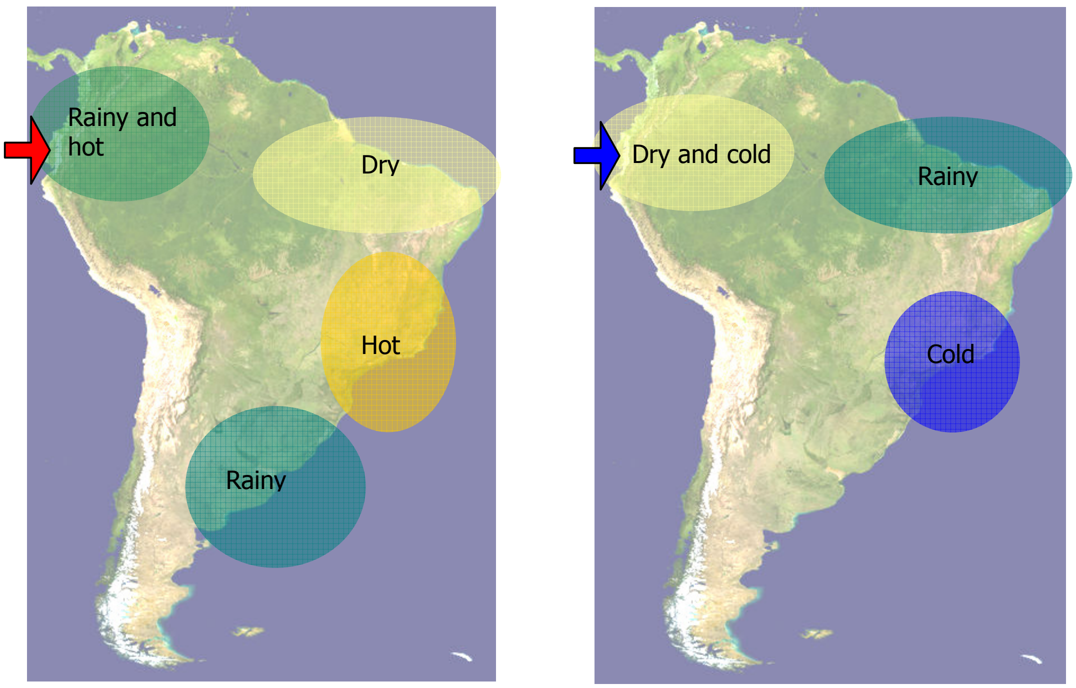

Figure 3: Impact of El Niño (left map) and La Niña (right map) on South America. Adapted from INPE/CPTEC (2006).

However, the 1997-1998 El Niño drew attention due to the serious consequences at a global level, with important physical and economic damage (drought, floods, loss of agricultural productivity, etc.) and losses of human lives. Despite the difficulty in compiling homogeneous, complete data, the Compendium of climate variability indicates that almost 10 million people were affected or displaced by the disastrous effects of this phenomenon (Sari Kavats, 2000). Important malaria epidemics were recorded in various places around the world, such as Pakistan, Sri Lanka, Vietnam and in various countries in Africa and Latin America in which it is endemic.

Since this important El Niño event, epidemiologists and entomologists have begun to pay special attention to the impacts of large climate phenomena on health. The WHO created a specific study group for this topic in 1999, which stresses the permanence of events like El Niño and the challenges of not forgetting and repeating errors of the past (OPS, 2000). However, most studies that relate this event to vector diseases are done at a global or continental level (Githeko et al., 2000; Gagnon et al., 2002; Basher and Cane, 2002; Thomson et al., 2003), while the impacts of El Niño vary greatly depending on the intensity of the event and the regions which it affects (Dessay et al., 2004). More detailed studies at the regional level are still needed to confirm the impact of these events on the dynamics of infectious diseases. However, the difficulty in carrying out this type of study is large due to the difficulty in obtaining climate and health data on this scale, with a historically compatible series that allows assessment of the impact of climate anomalies on health.

In addition to the known ENSO, other climate anomalies affect the dynamics of the climate in Brazil, especially precipitation, such as the inter-season Madden-Julian Oscillation (MJO) lasting 30-60 days, the intertropical systems such as the high level cyclonic vortices in the Northeast and the South Atlantic convergence zones (ZCAS) in the South and Southeast, among others (Kiladis and Mo, 1998; Cunningham and Cavalcanti, 2006).

The role of biomes - the example of the Amazonia Biome

The atmosphere is a vital natural resource for humanity, and which until the middle of the 20th century appeared to not have been affected by human activity. However, in the last 50 years, changes in soil use and coverage patterns associated with economic exploitation of natural resources, generally inadequately managed and producing a strong impact on the structure and functioning of terrestrial biomes, have resulted in environmental changes at a global level with impacts on the environmental services guaranteed by these biomes and vital for mankind. The identification of human influence on climate changes is one of the principal aspects analysed by the IPCC–TAR (IPCC, 2001 A-C). The burning of biomass in tropical forest is one of the examples of human pressure with significant changes for environmental losses, or in other words, lost opportunities for sustainable use. Among the various services that ecosystems provide as regulators of environmental conditions are the maintenance of biodiversity, cycling of water and maintenance of carbon stocks, which mitigate the worsening of the greenhouse effect.

The countries that burn the most biomass on Earth are in the tropical and subtropical regions of South America, Africa, Southeast Asia and part of Oceania (Freitas et al., 2005) contributing directly to the global climate change phenomena. In South America, the estimates for release of aerosol particles into the atmosphere from biomass burning represent one third of all particulate material released into the atmosphere on the entire planet, reaching 35 Tg/year of particles (Andreae, 1991). In Brazil, the principal ecosystems affected by burning are the Amazon rainforest and the savannahs (Artaxo et al., 2001). Given the current global warming outlook, a study presented in 2004 (Nepstad et al., 2004) points to the possibility that the

Amazon rainforest could lose much of its humidity with the intensification of the dry season, making the region more vulnerable to burning.

The "Legal" Amazon region has suffered significant changes in soil use and coverage patterns in the last decades due to intense human occupation accompanied by national and international economic pressures. The Amazon lost approximately 17% of its native forest in the last three decades (PRODES, 2006). The complexity of the Amazon, a unique biome which accommodates almost 13 million Brazilians and which Professor Berth Becker provokingly calls an "urban jungle" (Becker, 2004), is an immense challenge to understanding. Understand the mosaic of processes responsible for changes in land use and coverage in the region in different time and spatial scales, observed through the dynamic of deforested area patterns, is fundamental. The interaction of more realistic land use and coverage models with climate models, taking into account different scales, the heterogeneity of the Amazon region, its different cultural expressions and its peculiar forms of configuration and use of land, is essential for studies of the relations between climate, the environment and health. The Amazon is many Amazons and for this reason a large, but crucial challenge in the time of global changes and their implications for infectious diseases and health vigilance at a regional level in the 21st century (Figure 4).

There are various political, economic and social factors that pressure ecosystems, resulting in deforestation and, consequently, the burning of biomass. The various dimensions involved in the question have provoked constant debate and a search for understanding of the causes of deforestation. The debate is rich with many positions and arguments. In general, the viewpoints complement each other, seen from a transdisciplinary space, but break down when the viewpoint is strictly unidisciplinary. The effects of this for public environmental policies and territorial management are serious. The role of science is to clarify, establishing bases for debate outside the passions and geopolitical agendas for the region, whether scientific or political-institutional agendas. Regardless, we can observe a common set of factors in the literature on the forces that drive the different processes in the region. The construction of highways, the expansion of cattle farming, the increasing extraction of wood, the intensive increase in single-crop agriculture, the weakness of institutions, the mobility of the population, the *aviamento* or indentured servant system, traditional in the Amazon since the 19th century, and based on violence and illegality (Santos-Júnior et al., 1996; Santos-Júnior, 2001), multi-modal networks, new information networks and the new and old social networks form a complex tableau of actors, processes and patterns of deforestation and emissions in the Brazilian Amazon. (Fearnside, 2006; Soares-Filho et al., 2005; Escada et al., 2005; Câmara et al., 2004; Evans and Moran, 2002). The complex interaction of these forces has produced a pattern of economic activities responsible for the emission of gases and aerosol particles into the atmosphere through the burning of biomass in pastures, savannahs and primary forests (Artaxo et al, 2002, Bulbovas et al, 2007).

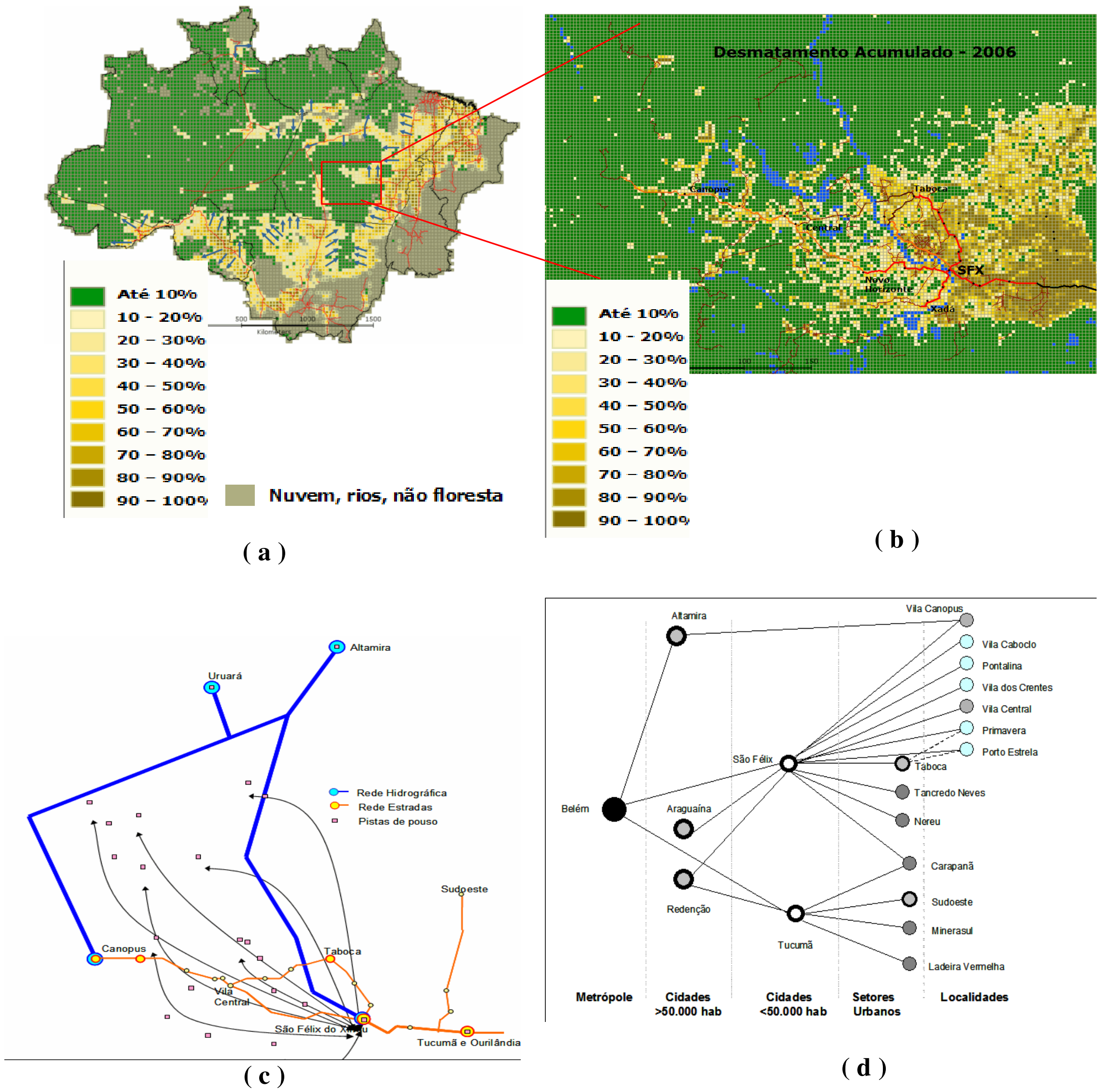

Figure 4: **(a)** Spatial patterns of accumulated deforestation for the Amazon from 1997 to 2006 (97-00; 00-03; 03-06), using a cellular database with *25 X 25 Km* cells. **(b)** Accumulated deforestation in finer resolution for a border area in Terra do Meio, PA, with 2*.5 X 2.5 km* cells, with transport infra-structure superimposed. **(c)** Detail of the complexity of infra-structure networks for access and connectivity in the region—Highways, rivers and landing strips. **(d)** Hierarchical network of cities, villages, locations and settlements in the Xingu-Iriri region in the Terra do Meio, showing a new and complex urban space developing in the Amazon. [SOURCES: Adapted from Amaral et al., 2007 and Escada et al., 2007].

For the global climate, the Amazon rainforest has as one of its principal characteristics an intense metabolism that results in a natural source of trace gases, aerosol particles, volatile organic compounds and water vapour for the global atmosphere (Guenther et al., 1995; Andreae and Crutzen, 1997). The emission of hydrocarbons such as isoprene and terpene are also significant, together with a large variety of oxygenated compounds (Artaxo et al., 2005). The high availability of solar radiation, added to the large quantity of water vapour in the atmosphere, are characteristics that favour high atmospheric chemical reactivity in the tropical region (Andreae and Crutzen, 1997). Emissions of methane and carbon dioxide in flood areas in the Amazon rainforest represent an important portion of the emission of these gases, recently observed in the Amazon on a large scale (Artaxo et al., 2005). Andreae and Crutzen (1997) identified that during the rainy season more than 90% of aerosol mass consists of organic material. The study of the behaviour of the aerosol particles emitted naturally by the Amazon rainforest has been a challenge for the understanding of the chemical component of the atmosphere and its relevance in the complexity of climate change impacts at regional and global levels.

Various studies have already shown that the chemical composition of the Amazon atmosphere in the dry season suffers changes due to the increase in the emission of trace gases and aerosol particles from burning of the Amazon rainforest and the savannah, the central region of Brazil, with local, regional and global environmental effects (Guenther et al., 1995; Andreae et al., 2004; Kaufman et al., 1998; Artaxo et al., 2002; Artaxo et al., 2005). Most studies emphasize the threat that burning represents for the Amazon rainforest, accelerating the episodes of climate changes. The aerosol particles are of special climatic interest because they act like cloud condensation nuclei (CCN), altering their formation mechanism and the albedo, consequently altering the radiative processes, affecting the radiation load (Guyon et al, 2004). Burning alters the hydrological cycles in tropical regions, reducing the volume of rainfall and the chemical and physical composition of the atmosphere (Yamasoe et al., 2000). This can also reduce the radiation incident on the surface due to the large quantity of aerosols, and can have implications on the primary production of the vulnerable ecosystems (Eck et al., 1998). The emission of trace gases and aerosol particles from the Amazon affects the entire South American continent through two principal pathways: The South Atlantic Ocean and the Tropical Pacific Ocean (Freitas et al. 2000, Freitas, 1999). Thus, the environmental impacts of burning have a fundamental role in local, regional and global climate changes.

Even considering that the principal global source of greenhouse gases is fossil fuels, burning in the Amazon and the savannahs represent the principal Brazilian contribution to the global sources of various greenhouse gases such as CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide) (Liousse et al., 2004) It also contributes significant amounts of CO, NO_2 (nitrogen dioxide), HCNM (non-methane hydrocarbons), methyl chloride and methyl bromide, volatile organic compounds (VOCs) and dozens of other gases (Andreae et al., 2002). The emission of ozone-forming gases by burning increases the concentrations of these gases, which may compromise the health of the population in the areas influenced by the burning, as well as the health of the unburned forest, since the ozone is phytotoxic, affecting locations thousands of kilometres away from the burned areas (Bulbovas et al., 2007).

Atmosphere dynamics and health problems

It is believed that human health problems associated with climate changes do not necessarily originate in climate alterations. The human population under the influence of climate changes will show the multi-causal effects in an exacerbated or intensified form. Many studies focusing on public health questions try to relate them to climate changes. Health studies generally indicate factors related to climate changes that affect human health, but are rarely developed with this objective. An evaluation of the effects on health related to climate change impacts is extremely complex and requires an assessment integrated with an interdisciplinary approach from health professionals, climatologists, social scientists, biologists, physicists, chemists, and epidemiologists, among others, to analyse the relations between social, economic, biological, ecological and physical systems and their relations to climate changes (McMichael et al., 2003).

Climate changes can impact human health through different means. The impact can be direct, as with heat waves or deaths caused by other extreme events like hurricanes and flooding. But often the impact is indirect, being mediated by environmental changes, such as the alteration of ecosystems and biogeochemical cycles, which can increase the incidence of infectious diseases, treated in this document in greater details, but also non-transmissible diseases, which include malnutrition and mental diseases. Note, however, that not all health impacts are negative. For example, the increase in mortality seen during winters may be reduced with the increase in temperatures. The increase in dry areas and periods may reduce the propagation of some vectors. However, the negative impacts are generally considered more intense than the positive impacts.

The consequences of this increase in variability and the number of extreme climatic events on public health are difficult to predict. Some models must be sought to concatenate climatic processes with health events. The following schema was proposed by McMichael et al. (2006) (Figure 5).

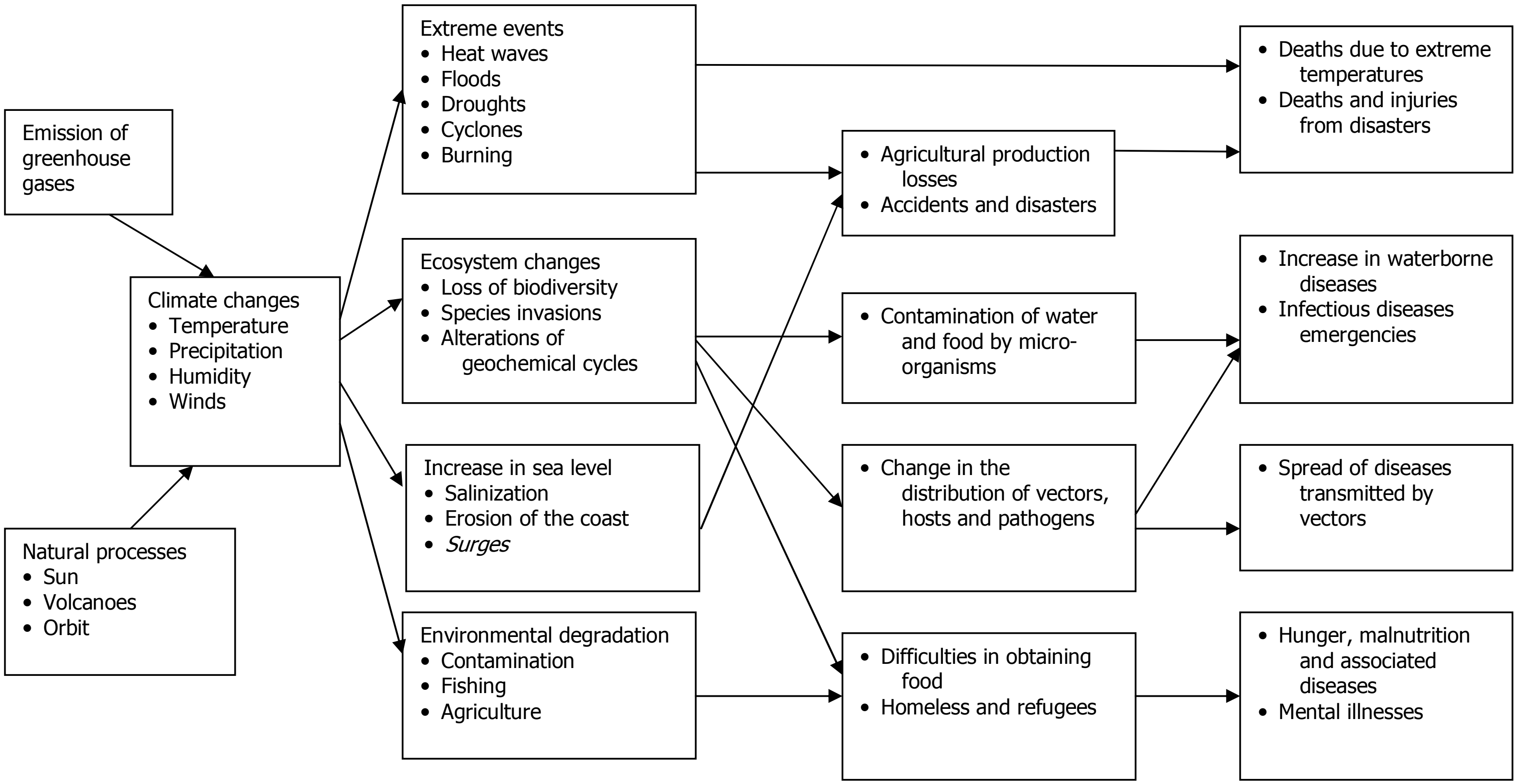

Figure 5: Possible effects on health conditions from climate change. Adapted from McMichael, Woodruff and Hales. Lancet, 2006.

You can see by the schema that global warming can have direct consequences with respect to morbidity and mortality through the production of disasters like flooding, heat waves, droughts and burning of forests. A heat wave in France in 2003 caused about 15,000 deaths, principally women, the elderly, residents of large cities, widowers and unmarried people. Some of these deaths can be attributed to global climate changes (McMichael et al., 2006). But the fact that a considerable percentage of these deaths could have been avoided put the entire health and social protection system of the country in check. The increase in mortality must be seen as a sum of extrinsic factors (climate and social) and factors intrinsic to the health system. Ageing, poverty, isolation and difficulty in accessing health services, together with an increase in temperature, condemned urban social groups abandoned by their families and by public services, especially during the summer holidays (Fleuret and Séchet, 2004). In this and various other cases, the assessment of health risks due to global climate changes cannot be disassociated from social analyses, which consider social inequality a structural factor of today's society.

Seasonal climate fluctuations have an effect on the dynamics of vector diseases, such as a greater rate of dengue in the summer and malaria in the Amazon during the dry period. Extreme events introduce considerable fluctuations, which can affect the dynamics of waterborne diseases, such as leptospirosis, viral hepatitis diseases, diarrhoeic diseases, etc. These diseases can become more prevalent with flooding or droughts that affect the quality of and access to water. Respiratory diseases are also influenced by burning and the effects of thermal inversions that concentration pollution, directly impacting the quality of the air, principally in urban areas. Additionally, malnutrition can occur due to agricultural losses, especially in the case of subsistence farming, due to frosts, strong winds, droughts or abrupt flooding.

The variation of human responses to climate changes appears to be directly associated to questions of individual and collective vulnerability. Variables such as age, health profile, physiological resilience and social conditions directly contribute to the human responses to climate variables (Martins et al, 2004). Some studies also mention that some factors which increase vulnerability to climate problem are a combination of populational growth, poverty and environmental degradation (IPCC, 2001), especially in children, with an increase in respiratory and diarrhoeic diseases resulting from settlement of people in frequently inadequate locations (McMichael et al., 2003).

Atmospheric conditions may influence the transport of micro-organisms, as well as pollutants originating in fixed and mobile sources, and the production of pollen (Moreno, 2006). The effects of climate changes may be potentialized, depending on the physical and chemical characteristics of the pollutants and climatic conditions such as temperature, humidity and precipitation. These characteristics define the time period during which pollutants remain in the atmosphere, and they can be transported long distances in favourable conditions such as high temperatures and low humidity. These pollutants associated with climatic conditions can affect the health of populations far from the pollution generating sources.

The alterations in temperature, humidity and rainfall can increase the effects of respiratory diseases, as well as alter exposition to atmospheric pollutants. Given the evidence of the relation between some effects on health due to climatic variations and the levels of atmospheric pollution, such as episodes of thermal inversion, increases in pollution levels and an increase in respiratory problems, it seems inevitable that long-term climate changes will affect human health at a global level.

In urban areas, some effects of exposure to atmospheric pollutants are potencialized when climate changes occur, principally thermal inversions. This can be seen in relation to asthma, allergies, bronchopulmonary infections and infections of the upper-respiratory tract (sinusitis), principally in the more susceptible groups, which includes children under 5 and individuals over 65. The effects of atmospheric pollution on human health have been widely studied all over the world. Epidemiological studies show an increase in the risk associated with respiratory and cardiovascular diseases, as well as general and specific mortality associated with exposure to the pollutants present in the atmosphere (Pope et al., 1995; OPAS, 2005; Anderson et al., 1996; Rumel et al., 1993; Cifuentes et al., 2001). According to the WHO, 50% of chronic respiratory diseases and 60% of acute respiratory diseases are associated with exposure to atmospheric pollutants. Most studies relating air pollution levels with health effects were developed in metropolitan areas, including the large capitals in the Southeast of Brazil, and show a link between morbidity/mortality due to respiratory diseases and increases in atmospheric pollutants, especially particulate material (Saldiva et al 1994; Gouveia et al, 2006). Most particulate material is fine (PM 2.5). The size of the particle, its surface and chemical composition determine the risk to human health. The increase in heart attacks, the multiplication of asthma cases and the increase in acute respiratory syndrome cases are some of the effects already reported in various studies (Gouveia et al., 2006).

Some studies show that high temperatures and high concentrations of atmospheric pollutants can generate increased hospitalizations, emergency room visits, consumption of medication and mortality rates (http://www.epa.gov/globalwarming/impacts/health/index.html). The interface between pollution and climate must also be considered a risk factor for heart diseases, as a consequence of oxidative stress, respiratory infections or haemodynamic changes. Temperature increases are also associated with increases in allergenic particles produced by plants, increasing the number of cases of individuals with allergic or asthmatic responses (Zamorano et al., 2003; U.S. Climate Action Report, 2002).

The elderly are more vulnerable in areas where air pollution is more intense. This, together with high ambient temperatures, causes stress and loss of physiological resilience. Social conditions, such as housing, food and access to health services are factors that increase the vulnerability of those exposed to episodes of climate changes which, when added to exposure to atmospheric pollutants, may cause synergetic effects and worsen health conditions. In areas with or without limited urban infra-structure, principally in developing countries, all these factors fall on the most vulnerable individuals and, consequently, the poorest, pressuring the public health infra-structure, overwhelming services and increasing health spending (Martins et al., 2004; IPCC, 2001).

Emissions of gases and particulate material into the atmosphere are principally due to vehicles, industry and the burning of biomass. In Brazil, stationary sources and large fleets of vehicles are concentrated in the large metropolitan areas located principally in the South, while burning of biomass occurs principally in Legal Amazonia, situated in the North of the country. According to the Brazilian inventory of carbon emissions, 74% of emissions occur due to burning in the Amazon, while 23% of emissions are from the power sector (MCT, 2005).

In Amazonia, the intense burning of biomass covers an area of about 4 to 5 million km^2, observed using remote sensing (Freitas et al., 2005). Studies in the region performed during the rainy season, when natural emissions predominate, show that the concentration of aerosol particles in on the order of 10 to 15 $\mu g.m^{-3}$, with a concentration on the order of 100 to 300 particles cm^{-3}. In the dry season, due to emissions from forest burning, the mass concentration rises to about 300 to 600 $\mu g\ m^{-3}$, while the number of particles rises to 15,000 to 30,000 particles cm^{-3} (Yamasoe, 1999). Most biogenic particles are large, with diameters greater than 2 μm, and are made principally of fungi, spores, fragments of leaves and bacteria in an enormous variety of particles.

The closer the location of the burning, the greater its effect on health. But the direction and intensity of air currents has great influence on the dispersion of atmospheric pollutants and on the areas affected by the plume from the fire. If the predominant winds lead to densely populated areas, a larger number of people will be subjected to the effects of the contaminants. This is the case of Southeast Asia, where burning provokes clouds of pollutants on a regional level, impacting the health of hundreds of millions of people (Ribeiro and Assunção, 2002).

In 2005, 73% of the burning sites in the country were detected in the region of the arc of deforestation, which includes the states of Acre, Amapá, Amazonas, part of Maranhão, Mato Grosso, Pará, Rondônia, Roraima and Tocantins. Of these, the state of Mato Grosso contained the greatest concentration of deforested area and burning sites, with 38% and 30%, respectively (IBAMA, 2007). In the state of Mato Grosso, respiratory tract diseases were the principal cause of hospitalisation in children under five, responsible for 70% of cases in the High Forest region. Among the principal categories of hospitalisations in Mato Grosso for respiratory tract infection in this age group were pneumonias, responsible for 73% of hospitalisations in the state, followed by asthma, responsible for 14% (Mourão et al, 2007). In Rio Branco, Acre, one of the principal negative impacts caused by air pollution due to burning is the mortality rate between 1998 and 2004, which increased 21% during the burning period in relation no non-burning periods. During the burning period, the mortality rate was 3.3 per thousand inhabitants, while in the non-burning period this rate was 2.7 (Silva, 2005).

Effects on infectious diseases

In the case of infectious diseases, the mechanisms producing illness and deaths are more indirect and mediated by innumerable environmental and social factors. Two examples are highlighted in this text: the possible expansion of transmission areas for vector-related diseases and the possible increase in the risk of waterborne diseases.

Various diseases transmitted principally by vectors are limited by environmental variables such as temperature, humidity, soil use patterns and vegetation (Hay et al, 1996). Today, vector-transmitted diseases are still an important cause of morbidity and mortality in Brazil and the world. The life cycle of vectors, as well as the reservoirs of hosts that participate in the disease transmission chain, is strongly related to the environmental dynamic of the ecosystems where they live. Dengue is considered the principal re-emergent disease in tropical and subtropical countries. Malaria continues to be one of the largest public health problems in sub-Saharan Africa, Southeast Asia, and the Amazon countries in South America. Cutaneous and visceral leishmaniasises have increased incidence and geographical distribution. Other diseases, such as yellow fever, filariasis, West Nile fever, Lyme disease and others transmitted by ticks and innumerable arboviruses have variable sanitary importance in different countries on all continents. Global warming of the planet has also generated scientific concern about the possible expansion of the current area of incidence of some diseases transmitted by insects (Tauil, 2002). The factors that influence vector disease dynamics are multiple, and include environmental factors (vegetation, climate, hydrology), socio-demographic factors (migration and population density), biological factors (life cycle of vector insects and infectious agents), medical-social factors (immunological state of the population, effectiveness of local health systems and specific disease-control programs, etc.) and the history of the disease in the locale. These last two factors are often forgotten in the hurried causal analyses of the impact of climate changes on vector diseases (Bruce-Chwatt and Zulueta, 1980).

Vector-transmitted diseases in tropical countries appear to be one of the principal public health problems that could arise from warming. Various mathematical models have been constructed to predict the consequences of an increase in temperature on malaria, for example (Tanser et al., 2003; Hales and Woodward, 2003).

However, the relation between climate and malaria transmission continues to be very complex and is different depending on the locations studied (Reiter et al., 2004). At least for malaria, dengue and yellow fever, climate is rarely the principal determinant if its prevalence or geographical reach. Rather, local ecosystem impacts caused by human activities have been much more significant (Reiter, 2001; Rogers and Randolph, 2000). Most models are based on data restricted to specific locations and environmental variables linked principally to vectors or plasmids, without considering social factors and development and control policies that are equally important in the dynamics of malaria, as well as for other vector diseases.

The history of malaria, one of the oldest vector diseases, clearly shows the importance of these factors. Due to its endemic character, it was responsible at various times for as many deaths as wars (Mouchet et al, 2004). During almost five centuries, it devastated a large part of Europe and the rest of the world (Figure 6). The worst period for transmission of this disease in Europe was much colder than the current period, during the Small Ice Age in the Middle Ages (Reiter, 2003). This era was characterized by poor sanitary conditions. As of the 18th century, numerous changes in the way the population lived, such as sanitation, housing, but also drainage work, soil use and agricultural practices, translated into progress against malaria in various regions of the globe (Hay et al., 2004). In Brazil, where until very recently, in the 1970s, malaria was encountered in various regions, there have been changes in this distribution which have now focused on the Amazon region (Barata, 1998).

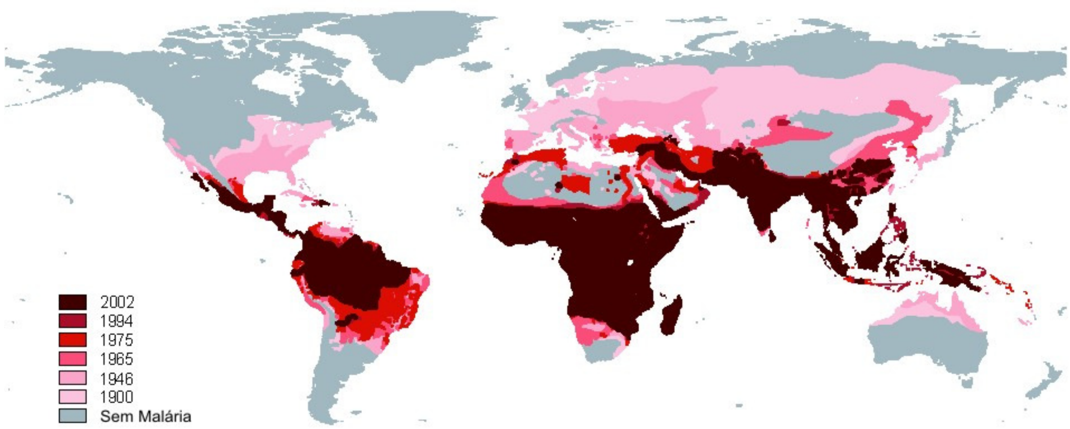

Figure 6: Retraction of malaria transmission areas in the 20th century. Adapted from Hay et al., 2004.

These facts show that the complexity of environment-disease processes must be considered by investigators before affirming that the expansion of malaria and other vector diseases is caused directly by global warming.

Health protection and comfort are the principal objectives of sanitation systems. Since the first sanitation interventions in large cities in the end of the 19th century, there have been significant reductions in indicators like infant mortality and the occurrence of epidemics. In Brazil, there has been a gradual increase in water supply services, which today reach 91.3% of the urban population (according to 2002 PNAD data). At the same time, the high incidence of various waterborne diseases such as schistosomiasis, hepatitis A, leptospirosis, gastroenteritis, and others continues. Even with the expansion of the water network, collection and treatment of sewage and trash does not reach all areas, leaving sanitation systems extremely vulnerable. According to preliminary evaluations by the WHO, problems related to basic sanitation cause about 15,000 deaths per year in Brazil (www.who.int/quantifying_ehimpacts/en).

Increasingly, urbanization and population density increases create risks that are characteristic of large urban centres, with vulnerable water sources and networks. There are various reports of outbreaks of waterborne diseases transmitted by the water distribution system (e.g., Godoy et al., 2003; Winston et al., 2003). The expansion of these systems, in this case, can also increase risks. The decay of public sanitation services in Russia () has increased risks associated with water distribution due to the precariousness of these systems. The supply system, in this case, functions more as a vehicle for diffusion of infectious agents than a protection factor for the population (Winston et al., 2003). The existence of a generation (cohort) of people living in large cities that have never had contact with some waterborne infectious agents may accentuate these outbreaks from the epidemiological viewpoint and serious from a clinical viewpoint.

According to Lee and Schwab (2005), the principal problems faced today by water supply systems in the Third Word are related to the intermittent vulnerability of these systems, and not their coverage. The intermittency of supply, in turn, allows the intrusion of pathogenic agents through contaminated water in distribution networks (LeChevallier et al., 2003). Most inhabitants of the city of Rio de Janeiro (about 95% of domiciles according to the 1991 demographic census) are supplied by the general water network. On the other hand, the contamination of the general water supply network by coliforms encompasses most of the population at risk, representing about 35% of the population in the entire city (Barcellos et al., 1998). Due to the known heterogeneity of urban soil occupation and the uneven city topography, problems with water supply are concentrated in socially and spatially vulnerable groups and areas.

This precarious universalization of sanitation services may increase the risks of the populations served by these systems. The increase in variability, both in quality and quantity of water in sources, may seriously affect the operation of water supply systems. These systems are subject to infiltration by micro-organisms and can produce outbreaks of waterborne diseases. Additionally, accidents, such as breaking of dams in water reservoirs, damage to the network or water reservoirs, and consumption pressure due to temperature increases, may lead to a collapse of supply systems. Even in countries where sanitation is universal and functions well, measures to increase the flexibility of these systems, through the increase in water reserves in homes and cities, are being proposed, along with alternative supply sources (Meuleman et al., 2007).

Methodological alternatives for monitoring and preparation

The evaluation of possible impacts from global changes on health is made difficult by the inadequacy of traditional methods used to analyse the relations between health and the environment. The greatest challenges are the absence or insufficiency of historical disease data in Brazil. Most national databases were created in the 1980s and 1990s, which do not allow analysis of long-term trends. Most predictions of health conditions due to global changes are produced by extrapolating the results of local, short-term studies to global, long-term scenarios, which creates uncertainty and imprecision. The design of epidemiological studies based on the individual do not appear to be adequate for these problems, since they presume a distinction between exposed and unexposed groups, which is not the case with studies related to global changes (McMichael, 2002). Additionally, the dynamics of external events will also change with global warming, and the study of the effect of these climate conditions on health is even more complex. On the other hand, classical statistical modelling does not incorporation of non-linear relationships and structures representing dependency between observations, expected in this context.

New methodologies must be sought, which include analysis of extensive temporal series, the adoption of sentinel events and areas and the use of geoprocessing to analyse aggravating situations. Alert systems based on environmental parameters must be implemented for early detection of changes in infectious diseases.

Environmental monitoring for health applications comprehends various aggravators and factors such as burning, deforestation, flooding, urbanisation and others. All of these aspects contribute to and will be affected by climate changes. The interaction between these factors is complex and uncertain. Under favourable climate conditions, some diseases are limited to a portion of susceptible individuals in the population and to other factors such as mobility of individuals, intervention measures, housing and nutrition conditions, which are not directly related to climate but which affect the patterns of the diseases.

One useful tool for monitoring the environmental dynamic is remote sensing specifically in Brazil, with an extensive territory, with great diversity of fauna and flora and difficult-to-reach regions. Some medium and high spatial resolution satellites with a low temporal resolution are employed in the study of changes in soil coverage and use, such as LANDSAT, CBERS, SPOT, and IKONOS. However, high temporal resolution satellites are ideal for climate change monitoring.

Climate data can be obtained through local measurements from meteorological stations or measurements derived from satellite images. Remote sensing data can generate indices that substitute meteorological variables, such as the average land surface temperature (LST) and the vegetation index (NDVI). These indices can be obtained with a resolution from 1 to 8 km using data from the AVHRR sensor on the NOAA satellite, or with a resolution of 250 to 1000 meters using the MODIS sensor. Another index, the cold cloud duration (CCD), obtained by meteorological satellites such as GOES and Meteosat, is used to indicate precipitation. These sensors have a high temporal resolution, of 15 minutes (GOES and Meteosat), 12 hours (NOAA) and 24 hours (MODIS) and cover portions of continents. The real-time information obtained from meteorological satellites, GOES and Meteosat, are used in weather prediction models (www.cptec.inpe.br). Additionally, data is available from these satellites/sensors for relatively long periods of time. The AVHRR sensor data from NOAA satellites, for example, provides daily estimates of LST and NDVI since 1981 and this data is stored and available for analysis. One can, for example, construct a temporal series of malaria occurrences and of environmental variables for various space-time sets, analysing seasonalities and anomalies. These graphs can show cyclic patterns inherent to the disease, as well as indicate factors like under-notification, interventions and correlations with environmental factors (WHO, 2005). Data obtained from satellites must be provided on a spatial and temporal scale adequate for this type of analysis. This does not yet exist. The ideal would be to manipulate this data, making available indices in useful scales, as well as other environmental and health data.

The consequences of global warming on health can be minimized through preventive measures such as improving surveillance systems that provide alerts regarding the emergence or re-emergence of infectious diseases or vectors. This measure could control the proliferation of vectors without damage to the environment, inform the public about how to protect itself, vaccinate and rapidly treat the population at risk. Another measure would be to minimize risks by predicting when environmental conditions, specifically climate conditions, are favourable for diseases. In this case, satellite images and climate models can be particularly useful (Epstein, 2000).

To increase the capacity of the health sector for controlling transmissible diseases, new instruments for epidemiological practice and surveillance must be developed, incorporating environmental aspects, risk identifiers and automatic and semi-automatic methods which allow detection of outbreaks and their follow-up in space and time. For this reason, the questions raised about global climate changes are relevant to public health and we need to understand how they affect ecosystems on a local scale. This will provide better information on the dynamics of the climate and environmental variables involved in the integrated risk characterisation models. We need to produce the instruments necessary in advance and, consequently, increase the preventive capacity of the health sector so that it can optimise its activities and resources to prevent diseases, promote health and minimise the damage to the population exposed to these risks.

The structuring of the health sector in recent years increased the capacity for registration of health events and aggravators. The hierarchical and territorial structure defined with the constitutional establishment of the SUS (Single Health System) in 1988 also defined spatial units for information collection and the DATASUS has achieved its mission of organizing the health databases. Add to this the increasing access to a much more comprehensive set of demographic and environmental data, such as the 2000 Census published by the IBGE with the network of census sectors made available for each city. On the other hand, the systems producing systematic climate and environmental data have evolved greatly in recent years. The INPE, in particular, has made advances on making available information and data on climate and biomass on a national level in Brazil. Even more important, there is an alignment of policies related to the data produced, labelling them a public asset and therefore granting free, unrestricted access to them. Data from Brazilian CBERS series satellites (Satélite Sino-Brasileiro de Sensoriamento Remoto da Terra - http://www.cbers.inpe.br/) is distributed on the Internet free of charge. The data from models and climate information are produced and distributed by CPTEC-INPE under the same policy.

In times of global changes, one of the most important and necessary changes is in the alteration of institutional policies at a local and global scale for access to environmental data, satellite images, temperature and climate data and socio-demographic information with location records in geographic coordinates that can be incorporated into analyses and in the production of health maps. The Brazilian capacity for data generation with spatial and temporal references has grown a great deal. Access policies are not as wished. Special data with a social function, geodata, must be released (Habeas Data), establishing the possibility of full access to the health information systems and climate and environmental information systems. More than this, we need a new, broader understanding of health information systems (SISs). Access to climate and environmental data more directly is essential for the new challenges of regional health surveillance. Obtain this integration is fundamental for the health sector. It is not just a technological integration. It requires a multi-institutional effort and the formation of human resources in health able to produce, collect, store, access, treat and analyse this data.

However, the Brazilian capacity to analyse this set of data, at various spatial scales and units, is still much less than our capacity to produce it. We must establish new methods for space-time analysis which allow detection of patterns and changes in the occurrence of multiple events to support regional epidemiological surveillance (Knorr-Held and Richardson, 2002; Kulldorff, 2001; Rogerson, 2001; Assunção et al., 2002, 2001; Câmara and Monteiro, 2001; Christensen and Ribeiro-Jr, 2002; Ribeiro and Diggle, 2001; Shimakura et al., 2001; Carvalho and Santos, 2005). In the field of Information Technology (IT), geotechnologies permit analysis and recognition of spatial and temporal patterns from various sources, made available in databases that should support geometrical representations, as well as traditional tabular descriptions. These patterns may reveal processes whose structures we seek to detect, monitor and visualise.

To overcome this challenge, we must share work, data, methodologies, software and results. This sharing can take place based on three common languages: the first, that of space, information that allows us to localize the elements of analysis is space; the second, the methodological, which positions the problem as having multiple dimensions and allows us to overcome the trap of reduction to a solely environmental, or solely social, or solely biological viewpoint for the health/disease process under investigation; the third is the technical-scientific, which requires new methods and instruments to treat an intrinsically complex problem.

We must mobilise to find answers and produce the Spatial IT instruments, methods, algorithms and software products to create epidemiological surveillance and endemic disease control systems able to predict based on the use of large spatial-temporal databases with SIS data, with data characterising the population and location. Socio-environmental information systems for local and national health are needed. One way to begin this mobilisation is to intensify efforts to georeference and homogenize the locations of databases in the epidemiological surveillance system for diseases and compulsory notification, which will allow multi-scale analysis, thus facilitating a greater understanding of the dynamics of morbidity and mortality for the various health management levels (local, city, state, regional and national).

These systems must include not only data and indicators, but also support technologies such as geographic databases, geographic information systems and spatial-temporal analysis, and the capacity to incorporate these new techniques and methodologies in the dynamics of the services, in the context of endemic disease control.

The Geocapacita program (www.capacita.geosaude.cict.fiocruz.br), 'Spatial approaches to health", is an example of how collective, multi-institutional work can generate material for the training of human resources with characteristics and profiles appropriate for the new challenges, in addition to production of technology and instruments for use in service.

In a context of global environmental and climate changes, the uncertainties about nature and its impact on the scale of local ecosystems are added to the complexities of the new realities of an urban Brazil, suggest new questions when facing the old problem of transmissible diseases in the context of public health. The synergy between social processes and the ecosystems in which they exist, associated with the persistence of inadequate living conditions, has allowed the proliferation and dissemination of diseases endemic to these territories where previously they were rare. Leptospirosis is a good example, with two distinct profiles. In the endemic situation, the groups affected are poor, due to the transmission method based on contact with rat urine, which requires extremely precarious sanitary conditions. However, with flooding caused by intense rain, which also affects poor individuals, the disease has a much larger radius of risk (Barcellos and Sabroza, 2001).

The same thing occurs with the transmission of dengue, filariasis, and visceral leishmaniasis, all occurring in large Brazilian cities, some striking the same population groups, all transmitted by vectors, others with important animal reservoirs, each one with different characteristics, but for which we cannot isolate the effects of control o each from the others. There are two fundamental aspects of addressing these problems: the capacity of detection, recording and early follow-up of number of cases and location of occurrence, and the identification and modelling of risk factors and protection in endemic and epidemic situations in these territories.

Conclusions - Beyond climate changes

The health sector faces a great challenge. Climate changes threaten achievements and efforts in relation to reduction of transmissible and non-transmissible diseases. Actions to create a healthier environment could reduce by a fourth the global disease rate, and eliminate 13 million premature deaths (Pruss-Ustun, Corvalan, OMS, 2006). From an epidemiological point of view, if climate changes represent a series of exposure to various risk factors, the furthest cause of this exposure is changes in the environment due to the accumulation of greenhouse gases. This means that this exposure cannot be avoided in the short term. The modifications that could be promoted to alter this situation on a global level may take decades to have a stabilizing effect on the climate. Therefore, the health sector must take measures and adapt to reduce as much as possible environmental impacts, which are inevitable. This adaptation must begin with: inter-sector discussions, since the actions (including the fight against gas emission and reduced consumption) of other sectors affect the health sector; strategic investment in health protection programs for populations threatened by environmental and climate changes, such as vector-transmitted disease surveillance systems, water supply and sanitation, as well as a reduction in the impact of disasters. On the other hand, the determinants of global climate changes can only be overcome in the long term, with mitigation measures. In this case, the health sector can also play an important role. Note that the development model and production of power cause climate changes, and also health problems through air pollution, which results in more than 800,000 deaths per year; traffic accidents, which cause 1.2 million deaths per year, and a reduction in physical activity, which results in 1.9 million deaths per year. This means that a change in the infra-structure for production, consumption and circulation could represent a reduction in the emission of greenhouse gases on the one hand, and a reduction in the various important causes of mortality on the other hand.

The world is suffering changes that are not limited just to climatic aspects. Parallel to climate change processes, globalisation (increasing the connectivity of people, markets and information), climate changes (altering ecosystems, reducing biodiversity and accumulating toxic substances in the environment) and the increased precariousness of government systems (reducing investments in health, increasing the dependence of markets and increasing social inequality) are accelerating. The risks associated with global climate changes cannot be assessed separate from this context. On the contrary, the risks are the product of dangers and vulnerabilities, as they are commonly measured in engineering. The dangers of global changes are due to environmental conditions and the magnitude of events. Vulnerabilities are shaped by social conditions, marked by inequality, the different capacities for adaptation, resistance and resilience. An estimate of the vulnerability of the Brazilian population indicated that the Northeast is the region most sensitive to climate changes due to low social and economic development indices (Confalonieri, 2005). These assessments are based on the supposition that populations with lower income, poorer education and poorer housing suffer the greatest effects of environmental and climate changes. However, as Guimarães (2005) stresses, the poorest individuals in the cities and in the countryside have shown an immense capacity for adaptation, since they are excluded from technical systems. Even though vulnerability is greatest among poor populations, one cannot say that the included, more affluent members of society are free of risk; on the contrary, their (immunological and social) response capacity is lower.

The possible expansion of disease transmission areas cannot be understood as a return of diseases like malaria, yellow fever, dengue, leptospirosis, schistosomiasis and others. Or better, the possibility of the return of these diseases is within the context of historical bases completely different from those existing in the 19th century. The social and technological transformations occurring in the world in the last decades allow us to predict that these diseases acquire, over time, factors other than the biological ones. The possibility of predicting, diagnosing and treating some people and excluding others from these systems increased the regional and social vulnerability differences and transformed social inequalities into an important environmental risk differential. The health sector must not just predict these risks and provide responses for the impacts caused by environmental and climate changes, but also act to reduce social vulnerabilities through changes in individual, social and political behaviour for a more just and healthier world.

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