



## CLIMATE AND CLIMATE CHANGE

### Introduction

Climate variability is deeply rooted within West African society. The 1930-1960 wet period, the 1970-1980 droughts and the return of rainfall in the 1990s and 2000s illustrate this clearly and have demonstrated the population's vulnerability, in particular in the Sahel zone. The climate changes analysed by the Intergovernmental Panel on Climate Change (IPCC) indicate the future trends likely to develop at the global and African levels: rising temperatures, rising sea levels, changes in the level and variability of rainfall, etc. They create new challenges and risks, but also provide new opportunities for the African continent.

However, climate projections for West Africa are not sufficiently reliable. The complicated and uncertain measurement of the climate's future impacts on the region calls for a measure of prudence in their analysis. However, this does not prevent examining the past and developing certain world-wide and regional projections, while bearing their intrinsic limitations in mind, or from raising certain questions about West Africa's future.

### I. Climate Fluctuations in History

#### 1.1 At the Heart of a New Interglacial Period

The climate goes through different cycles of variable duration, alternating between cold and hot periods. The Wilson cycle is the longest of these cycles. It occurs every 300 million years, when the gap between continents narrows due to the interplay of their tectonic plates and the consequent changes in ocean circulation and in erosion (uplift of mountain ranges), triggering an overall cooling of the planet<sup>1</sup>.

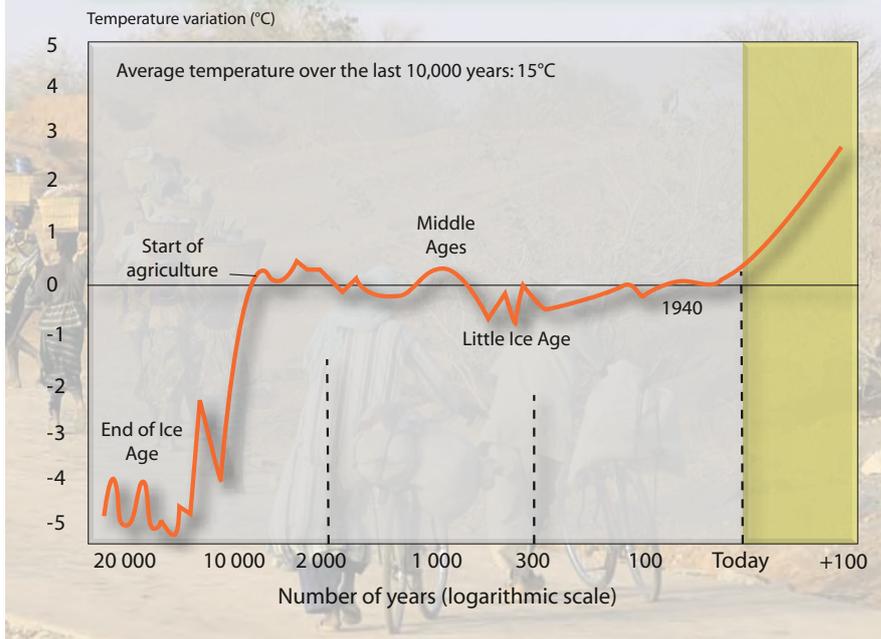
The Atlas on Regional Integration is an ECOWAS — SWAC/OECD initiative, financed by the development co-operation agencies of France, Switzerland and Luxembourg. Divided into four series (population, land, economy, environment), the Atlas chapters are being produced and will be available on-line on the site

[www.atlas-westafrica.org](http://www.atlas-westafrica.org)

1. Denhez Frédéric (2007) *Atlas du réchauffement climatique*. 'Autrement' magazine.

Other, shorter cycles linked to star movements punctuate climate alternations. The Earth has gone through several phases of warming and cooling over the last 700,000 years, at an average frequency of 100,000 years. A cycle consists of a sudden rise in temperature, followed by a warm period of around 10,000-20,000 years, called the interglacial period. This is then followed by a gradual cooling of the planet and the initiation of a glacial era. The end of the glacial stage is followed by a sudden reheating, leading to a new cycle. The last glacial period reached its climax 18,000 years ago. The planet has been going through an interglacial period for over 10,000 years. Indeed, the warm period undoubtedly had some bearing on the development of agriculture and sedentary cattle breeding (Neolithic period).

**Figure 1. Temperature Trends over the Last 20,000 Years**



## 1.2 From “Greenland” to Famine

Within these long cycles, more intense and less frequent variations can be measured. The 10<sup>th</sup> and 11<sup>th</sup> centuries were marked by a warm and less humid period. It was the era when Viking sailors discovered and baptised “Greenland” (the “Green Land”) and established colonies at the southern tip of the island. The reigning temperatures allowed for cereal cultivation. This phase, called the medieval optimum, was no warmer than the early 21<sup>st</sup> century (see Figure 1).

At the end of the Middle Ages, the Northern Hemisphere cooled down considerably, a process that continued until the beginning of the 19<sup>th</sup> century. A thermal low was reached in the 17<sup>th</sup> century. This small glaciation or Little Ice Age seemed to correspond to low solar activity. It was marked by a succession of particularly harsh winters, accompanied by food shortages and famines.

## 1.3 Global Warming in the 20<sup>th</sup> Century

Ground temperature measurements taken between 1906 and 2005 show a general rise of 0.74°C<sup>2</sup>. This warming cycle seems to have intensified over the last fifty years, with a 0.13°C increase in temperature per decade. 1998 and 2005 recorded the highest surface temperatures since 1850. The trend seems to be correlated with an increase in greenhouse gas concentrations in the atmosphere (see Box 1), such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). These gases are considered to be primary causes of global warming.

2. IPCC (2007) *Climate Change 2007. Fourth Assessment Report (AR4)*.

### Box 1. Greenhouse Gases

When solar radiation reaches the Earth’s atmosphere, a part of it (28%) is directly reflected back (back to space) by the Earth’s air, white clouds and uncovered surface areas (particularly white, ice-covered areas like the Arctic and Antarctic). This is called the **albedo**. Incidental sun rays that are not reflected back into space are absorbed by the atmosphere (21%) and the Earth’s surface (51%). This part of the radiation absorbed by the Earth creates heat (energy), which is then returned towards the atmosphere, especially at night and in winter, in the form of infrared rays. This is known as **black body radiation**. This radiation is partly absorbed by greenhouse gases and then re-emitted towards the Earth in the form of heat, hence its name, **greenhouse effect**. Without this phenomenon, the Earth’s average temperature would fall to -18°C, after which ice would spread its blanket across the planet, the Earth’s albedo would rise and its temperature would likely stabilise at -100°C.

## II. Climate Change and International Awareness

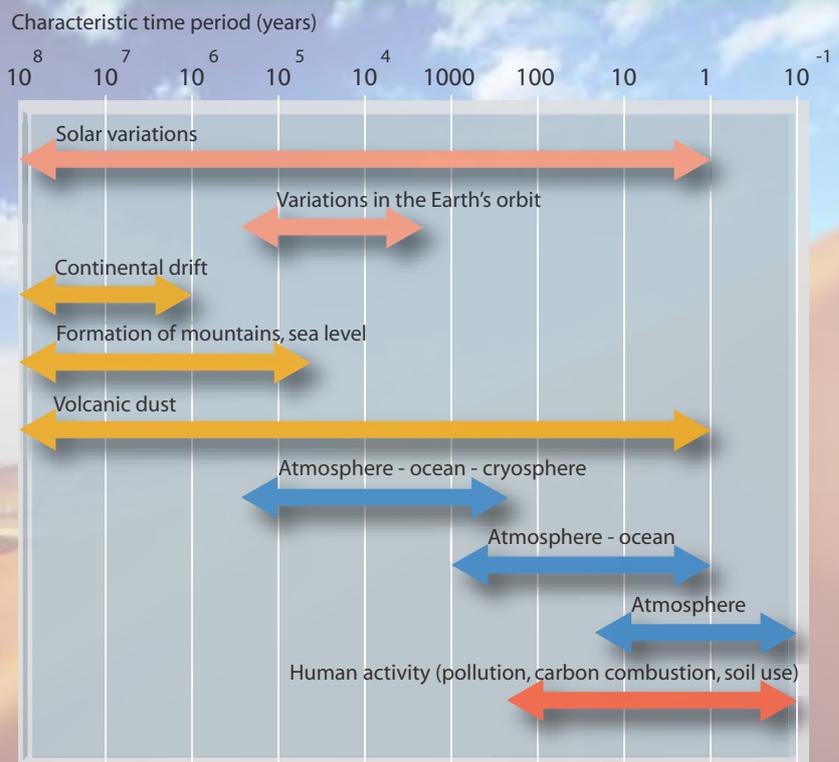
### 2.1 Certainties and Uncertainties

In understanding a system as complex as climate, uncertainty will probably always reign. The quantity of greenhouse gases and atmospheric dust, solar energy and its distribution across the Earth's surface, ocean movement and the position of the continents are just some of the factors influencing the climate at different stages in time (see Figure 2).

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change in Article 1 as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The scientific community does not make this distinction, defining climate change as resulting from the combined effect of human activity and natural climate variability.

In this regard, the latest IPCC<sup>3</sup> report confirmed with a "very high degree of confidence" the primacy of human responsibility over natural factors in global warming, through the combined effect of greenhouse gases, aerosols and the albedo (scientists do not unanimously agree with the IPCC conclusions - see Box 2). The first, which lead to warming, are mainly the result of the combustion of fossil energies (carbon dioxide)

Figure 2. Main Causes of Climate Change and their Time Scale



Sources: Atlas du réchauffement climatique; IPCC (2007)

3. The Intergovernmental Panel on Climate Change (IPCC in English, GIEC in French) was set up jointly by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) in 1988. The latest report (Climate Change 2007) is the fourth in a series that began in 1990; it draws up an assessment of six years of work undertaken by a network of 2,500 scientists, based on actual observations and increasingly effective climate models.

and the development of agriculture (methane and nitrous oxide). The second and third, however, lead to global cooling. As for natural factors, the effect of solar radiation is to a limited extent an added factor to other global warming dynamics.

The future rise in greenhouse gases will intensify global warming and impact the world's climate system in several ways. According to the scenarios developed<sup>4</sup>, the Earth's average temperature will rise by 1.8°C to 4°C (1.1 to 2.9°C according to the minimum scenario; 2.4 to 6.4°C according to the highest scenario) and sea levels will rise by 18-38 cm to 26-59 cm by the end of the century, with widespread heat waves and heavy periods of rainfall<sup>5</sup>.

## 2.2 International Commitments

The energy sector, largely dominated by the use of fossil fuels, contributes to over 80% of greenhouse gas emissions, including 95% in the form of CO<sub>2</sub> (see Map 1). The reduction in these emissions largely depends on a change in energy models, which could accelerate due to the possible ending of the oil era by the end of this century. Alternatives do exist (hydraulic, nuclear, solar, wind, bio-fuel energy, etc.), but they come with their own economic, technical and environmental constraints and, therefore, time constraints as well. For the coming generation, fuels will remain at the heart of energy consumption.

Faced with this perspective, the UNFCC is seeking to stabilise atmospheric greenhouse gas concentrations at a level that would prevent any "dangerous anthropogenic perturbation to the climate system". Meeting in 1997 in Kyoto, the 3<sup>rd</sup> session of the Conference of the Parties to the UNFCC finally adopted a Protocol fixing the greenhouse gas emission reduction target for the 2008-2012 period at 5% as compared to 1990, defining specific targets for each of the countries in Annex I of the Convention<sup>6</sup>: for instance, -8% for the European Union, -7% for the USA but, on the contrary, +8% for Norway and +10% for Iceland. Many of the protocol signatory countries would have difficulty in complying with these ratios. Three so-called "flexibility" mechanisms were developed to facilitate actions to be undertaken with regard to the reduction of emissions:

- The trading of emission quotas (Emissions Trading), enabling Annex I countries to sell or purchase emission rights between them;

### Box 2. Global Warming "Sceptics"

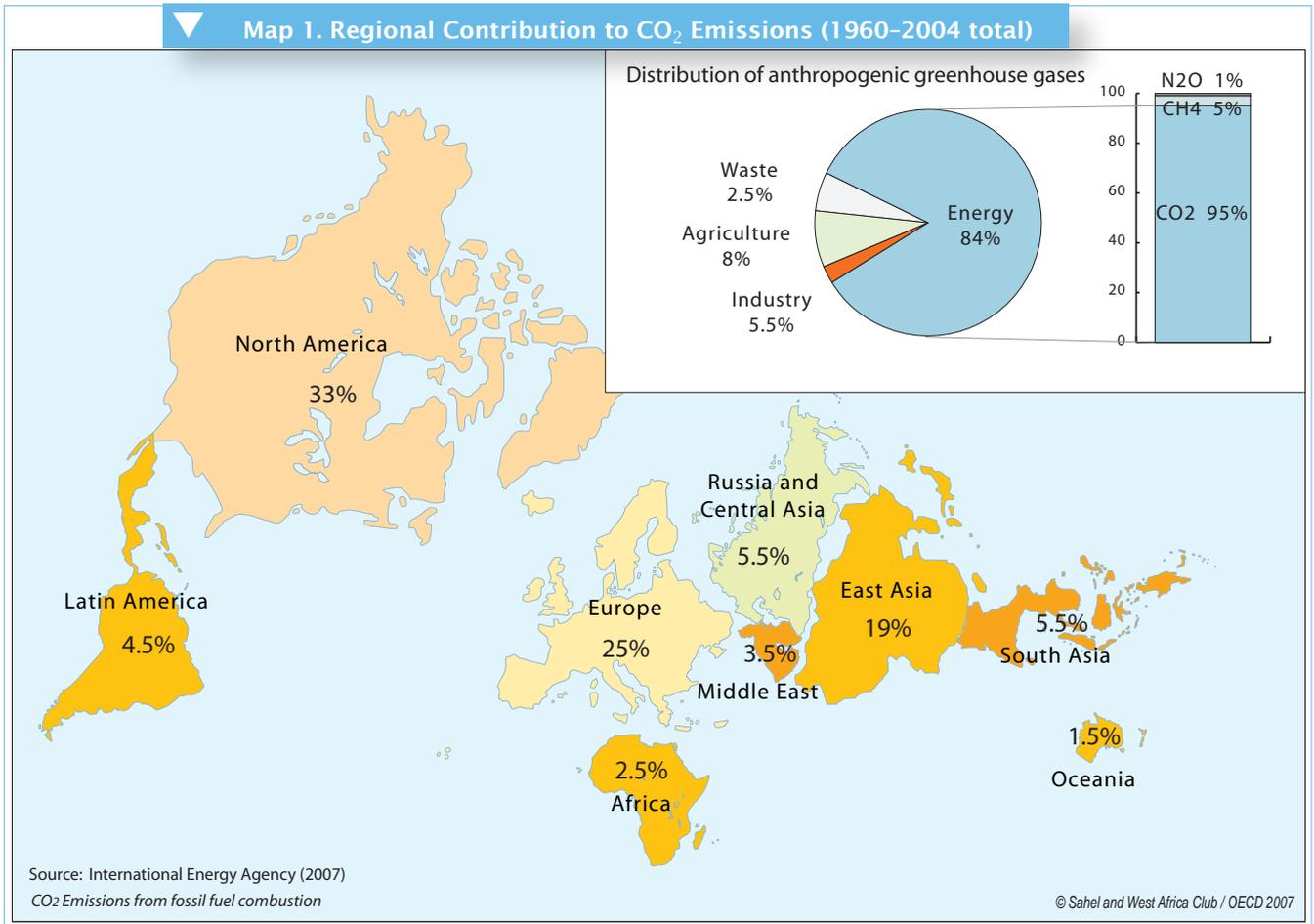
There are a number of important high-level scientists who are not proponents of the work carried out by the IPCC. They are critical of this work, the results and the way in which it functions. While many of them do not refute the reality of recent global warming, they sometimes dispute the anthropogenic origin as set out in the letter signed by 61 scientists sent to the Canadian Prime Minister in October 2006: "The evidence drawn from observations does not support computer-generated current climate models (...). The expression "climate change is a reality" is meaningless and is used by militants to convince the general public that climatic catastrophe is imminent (...). This fear is unjustified. The planet's climate changes continually due to natural causes. Human impact is impossible to distinguish from natural occurrences."

A petition signed by 19,000 American scientists already set out: "There is no convincing scientific evidence that human release of carbon monoxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate. Moreover, there is substantial scientific evidence that increases in atmospheric carbon dioxide produce many beneficial effects upon the natural plant and animal environments of the Earth" (<http://www.oism.org/project/>).

In his book, "Global Warming: Myth or Reality?" The Erring ways of Climatology", Marcel Leroux, Professor Emeritus of Climatology at the University Jean-Moulin (Lyon, France) writes: "The Greenhouse effect is not the cause of climate change. The probable causes are thus: well-established palaeoclimatic orbital parameters (...); solar activity (...); volcanic activity and associated aerosols (more particularly sulphates), of which the (short-term effects) are undeniable; and further on, the greenhouse effect and in particular that caused by water vapour, of which the impact is not known. These factors are constantly combined and it seems difficult to establish the relative importance of these various factors on the climate's evolution. At the same time, there is a tendency to highlight the anthropogenic factor which is, clearly the least credible among all of the factors cited above."

Source: Diplomatie magazine special series No. 4 (2007), <http://www.pensee-unique.fr/paroles.html>

4. Some scenarios are based on the assumption that no policy on limiting human factors in global warming is implemented. Others include such policies (mitigated projections).
5. A downward correction has been made in temperature or sea level increases as compared to the Third assessment report (TAR, 2001). Within the framework of the TAR, forecasts highlighted a 1.4 to 5.8°C rise in mean temperature and a 0.09 to 0.88 m rise in average sea levels the world over between 1990 and 2100.
6. Annex I countries are the industrialised States that were OECD members in 1992, in addition to transition economies, including the Russian Federation, the Baltic countries and some Eastern and Central European countries (a total of 41 countries).



7. Although the USA did not ratify the Kyoto Protocol, several American cities and states actually apply it.

Joint Implementation (JI), which would enable the stakeholders to make investments aimed at reducing greenhouse gas emissions outside their national territory and thereby benefit from the emission credits generated by the reductions achieved;

The Clean Development Mechanism (CDM), similar to the previous mechanism, but favouring investments by Annex I countries in Annex II countries.

The USA, which did not ratify the protocol, are not committed to complying with these ratios<sup>7</sup>. Moreover, neither India nor China is committed to complying. However, these countries contribute substantially to greenhouse gas emissions: the USA is the prime contributor, with China and India in 3<sup>rd</sup> and 6<sup>th</sup> position respectively (see Map 1 and Table 1). The impact of East Asia's industrialisation and rapid growth on greenhouse gas emissions is of great concern to the international community. The governments of these States are not

### Box 3. Reliability of Climate Models

Climate projections are based on models that are able to achieve good large-scale simulations with increasingly better performances. Some of these climate models are, for instance: Hadcm3, ECHAM4, NCAR, CCSR, CSIRO, CGCM2, etc. However, their ability to reproduce the climate varies according to different world regions. They therefore have several limitations with regard to taking certain climate factors, such as clouds, into account.

At best, models can only forecast with an accuracy of up to three degrees the increase in balance point caused by the doubling of the concentration of carbon dioxide in the atmosphere.

The lack of comprehensive knowledge about former climate cycles does not help in forecasting the future with any accuracy. Current greenhouse gas concentrations already surpass the maxima reached in the "recent" past (740,000 years), and it is impossible to "read" any climate corresponding to possible future carbon dioxide or methane rates in ice cores or sediments.

On the basis of the changes in population growth, greenhouse gases and energy consumption, various climatological models enable us to envisage about forty scenarios of future climate changes. None of these take any global conflicts or disasters into consideration, nor any (unforeseeable) changes in natural factors (volcanoes, natural cycles).

Sources: *Atlas du réchauffement climatique*; IPCC (2007)

less concerned, as illustrated by the development of renewable energies in India (the country is now the fourth biggest producer of wind energy in the world) or the construction of the world's first ecocity (Dongtan) by the Shanghai Municipal Corporation in China. However, the magnitude of the responses required goes well beyond these measures. The quest for more sensible energy consumption is a path that needs to be explored by the entire international community.

The revision of the Kyoto Protocol adopted in Nairobi (Kenya) in November 2006 placed greater emphasis on the so-called “emerging” and “developing” countries: the expansion of the agreement to countries such as China or India, the implementation of the Clean Development Mechanism (CDM), the functioning modalities of the Adaptation Fund to be used to guard against the impacts of global warming in poor countries and the establishment of a fund to develop “clean energies” for Africa, were at the centre of the debate.

Following the Bali Conference in December 2007, all of the countries present decided to launch a series of negotiations leading to a new agreement that would replace the Kyoto Protocol as from 2013. Africa, which contributes the least to greenhouse gas emissions and is considered to be the most vulnerable to the effects of climate change, will have to find its own place in these negotiations.

### III. The African Continent and Climate

#### 3.1 Climate Variability and Characteristics

Africa has gone through different climate periods in the past. Before the end of the ice age (-18,000) the continent was almost a desert. Then a rainy period began between -12,000 and -5,000. It led to the eradication of most arid areas and enabled the development of agriculture and cattle breeding in what is known today as Western Sahara. The existence of a gigantic Lake Chad during the Middle Holocene period (over 6,000 years ago) attests to these historical fluctuations<sup>8</sup>.

The climate in Africa today is almost the same as 2,000 years ago, with more arid or more humid phases. The era of the first great Sahelian empires (10<sup>th</sup> to 15<sup>th</sup> centuries) was a rainy period during which living conditions were far more favourable than they are today. However, in the early 19th century, the continent was struck by an arid period that lasted a few decades. The stream flow of the Nile fell considerably and Lake Chad dried up. These fluctuations continued during the next century. After a short dry period, a humid phase began, lasting until the 1960s. The 1970-1980 decade was once again marked by an aridification of the climate, which was a heavy burden on the population.

**Table 1. The World's Ten Biggest CO<sub>2</sub> Contributors**

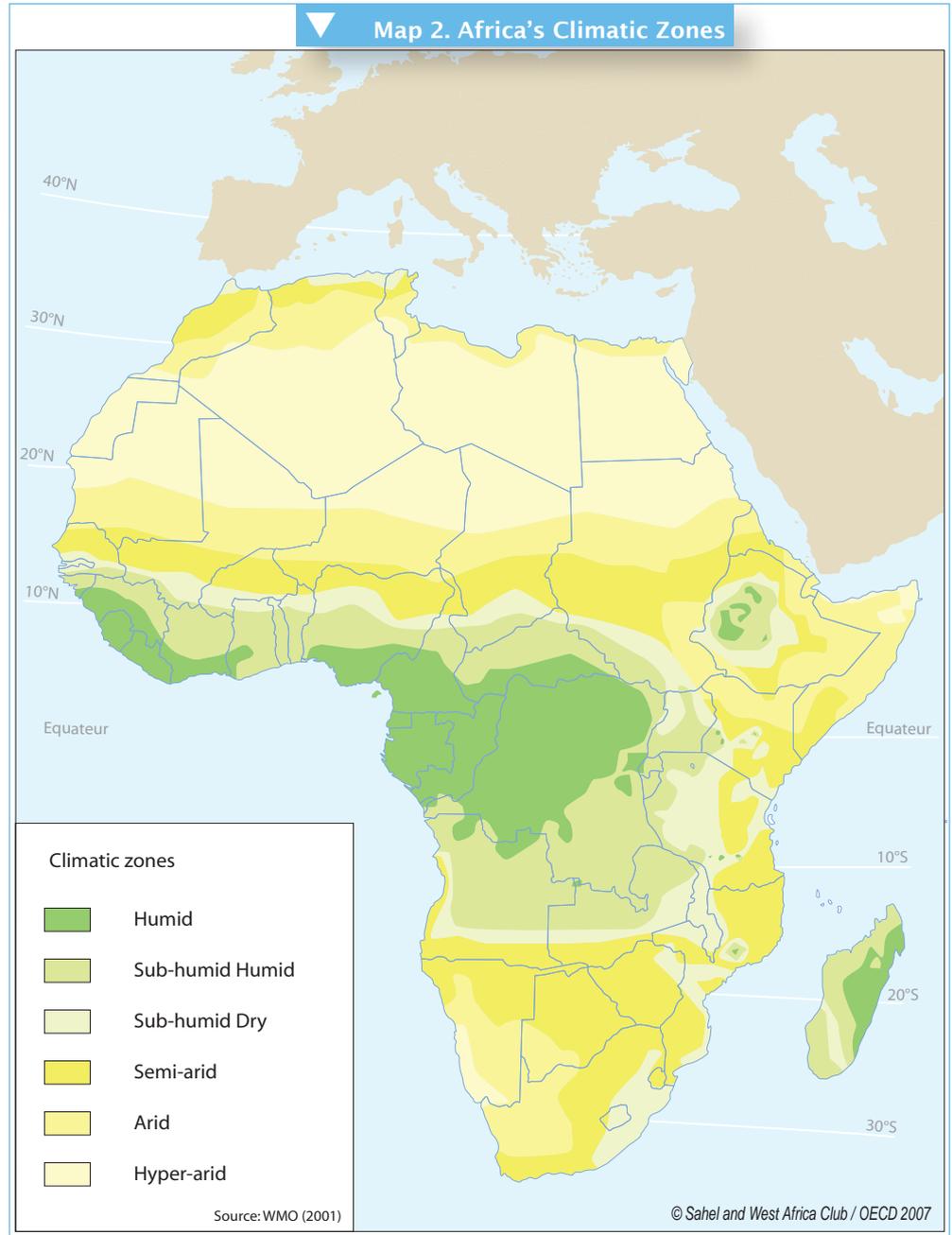
	Country (or region)	CO <sub>2</sub> emissions (2000-04 average)	
		Total (Mt)	Per capita
1	USA	5,700	19
2	European Union	3,870	8
3	China	3,670	3
4	Russian Federation	1,520	11
5	Japon	1 200	9
6	India	1,020	1
7	Canada	540	16
8	South Korea	445	9
9	Mexico	360	3
10	Australia	350	16

Source: International Energy Agency (2007)



8. Lying in what is now the world's biggest inland basin (i.e., one in which running water does not reach the sea and is lost in the soil), the Lake covered a 340,000 km<sup>2</sup> surface area (the size of Côte d'Ivoire today) and reached a maximum depth of 160 metres (currently less than 10 m), forming the fourth largest lacustral reservoir in the world after the Caspian Sea and the Baikal and Tanganyika Lakes.





9. Nicholson, Sharon E. (2001) *Climatic and environmental change in Africa during the last two centuries.*



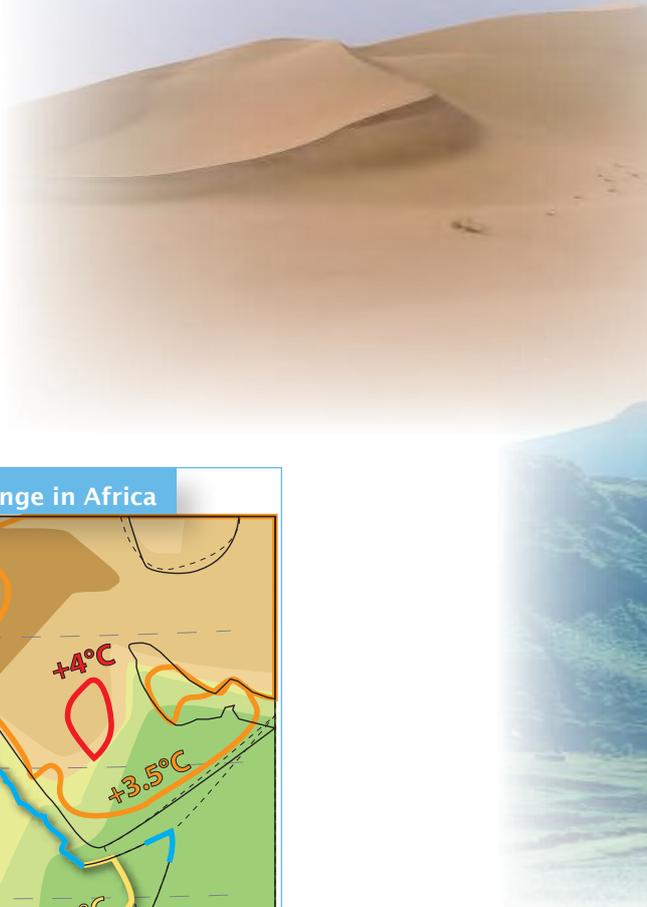
Today, most of the African continent is tropical, except for the Mediterranean region and South Africa. Rainfall varies according to an enormous gradient of +1 mm/year in some Saharan regions to +5,000 mm/year at the equator. There is very little variation in temperatures, generally high, throughout the year. However, day-night temperature variations are greater - as much as 10-15°C (even more in the deserts), whereas inter-annual variations South of the Sahara remain between 6 and 10°C<sup>9</sup>.

### 3.2 Contrasting Picture of Climate Change

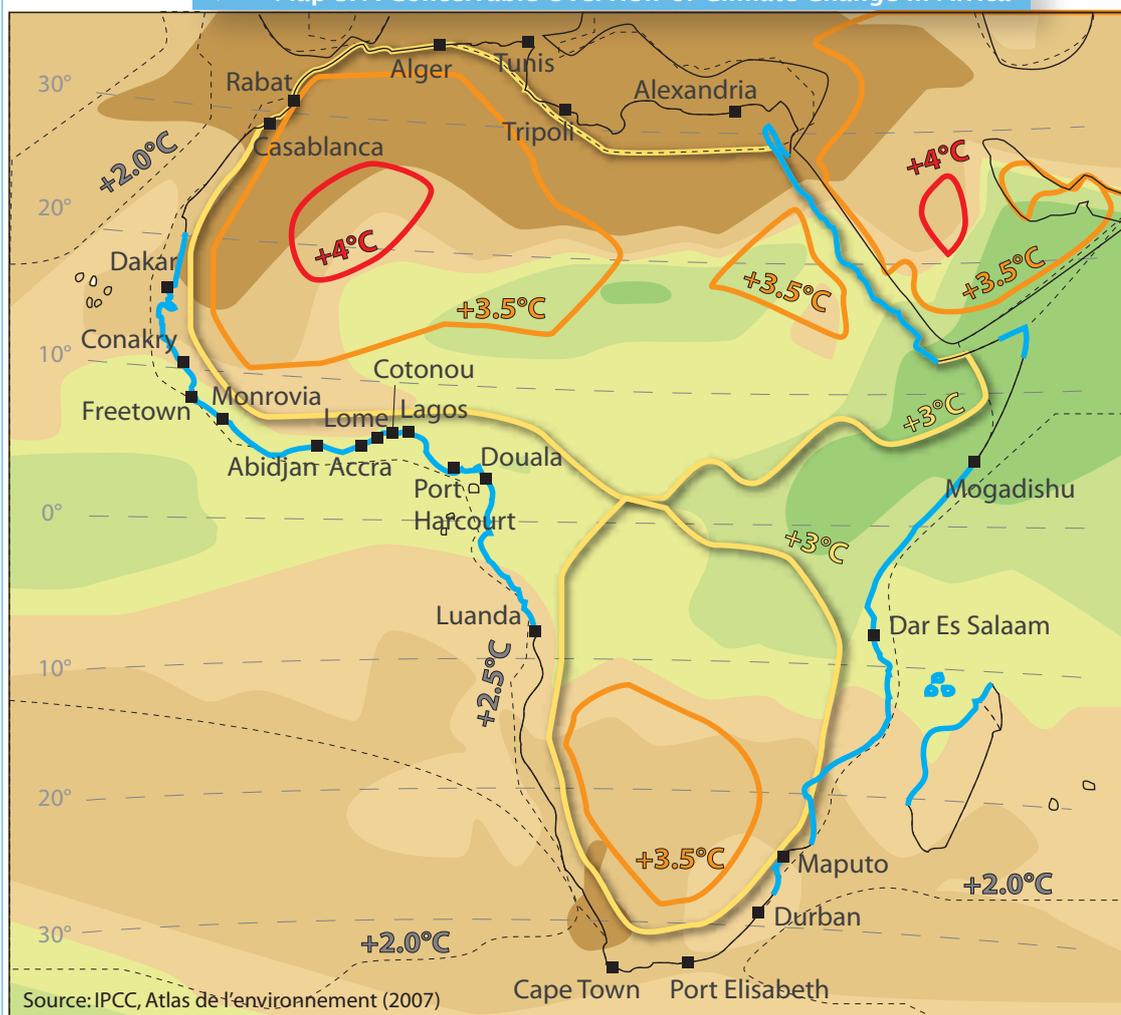
Climate models are relatively useful when it comes to forecasting temperature changes in Africa. In its latest report, the IPCC confirmed that in the 21<sup>st</sup> century, global warming would be more intense in Africa than in the rest of the world. The average rise in temperature between

1980/99 and 2080/99 would be between 3 and 4°C for the continent as a whole, 1.5 times greater than at the global level. The increase would be less marked in coastal and equatorial areas (+3°C) and the highest increase would take place in the Western Sahara region (+4°C).

However, the results of rainfall projections remain uncertain. North Africa, Southern Africa and East Africa are some of the regions where there is less uncertainty. Africa's Mediterranean coast, like the Mediterranean coastline in general, is likely to experience a decrease in precipitation (-15 to -20%) over this century. The drying-out process will affect the Northern bank of the Sahara and the West African coast up to its 15° latitude North (Dakar's latitude). At the other end of the continent,



Map 3. A Conceivable Overview of Climate Change in Africa



Projections (2080/99 compared to 1980/99)

Rainfall variations (%)

	> 15		- 5 to 0
	5 to 15		-20 to -5
	0 to 5		< -20

Temperature variations  
 + 3.5°C

 Threatened mangroves, fragile ecosystems and deltas

 Coastal urban center of over 1 million inhabitants

© Sahel and West Africa Club / OECD 2007

10. Today, this mechanism essentially benefits the major emerging countries (China and India).
11. Africa Partnership Forum (2007) *Climate change and Africa*. 8<sup>th</sup> Africa Partnership Forum meeting, Berlin - Germany, 22-23 May 2007.

less rainfall is expected during the winter and especially in spring in Southern Africa. Along the tropical belt, the results achieved by the models show an increase in rainfall in the Horn of Africa. However, no conclusions can be drawn regarding rainfall in West Africa (see Map 3).

### 3.3 New Opportunities for the Continent

Apart from climatic uncertainties and its vulnerability, Sub-Saharan Africa could benefit from this situation in terms of energy diversification/transition and agricultural trade.

Due to its low energy consumption, it is the lowest greenhouse gas producing region today. But biomass use (80% of energy demand) is the primary cause of deforestation in Sub-Saharan Africa. Electricity production consumes an increasing amount of thermal energy (oil and gas): 80% today, as compared to 2/3 some 25 years ago. In the future, its energy supply choices will be increasingly dictated by environmental issues and the climate challenge in particular.

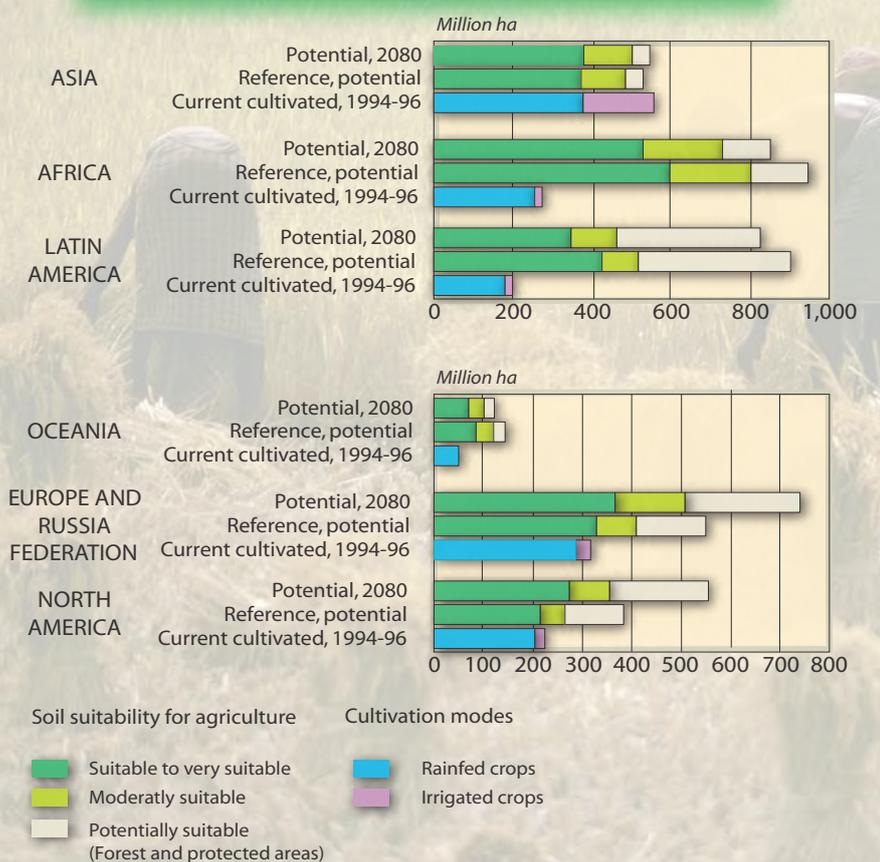
Africa has considerable hydroelectric, solar and wind energy potential that could be developed within the framework of the CDM<sup>10</sup> or with investment in clean energy and development. A regional approach may be better suited for attracting this kind of investment, all the more so since several countries share these resources (e.g. cross-border river basins).

Vegetation, in particular Central Africa's forest resources, makes this region an important "climate protector" for the world due to the role of carbon sinks. If the forest were recognised as a world public good<sup>11</sup>, an energy transition mechanism could be envisaged in order to limit the consumption of this environmental resource.

Climate change will certainly have an impact on agricultural surface areas at world level and on the food security of its population. It seems that along with Latin America, the African continent will suffer the largest agricultural land losses. But these losses would be marginal as compared to potentially cultivable land. In 2080, the African continent will still have the largest potential agricultural land area (see Figure 3).

North America, Europe and, to a lesser extent, Asia will see a rise in their agricultural potential. New land will be cultivated and crop intensity will increase. However, the realisation of a greater part of Africa's agricultural potential can also be envisaged,

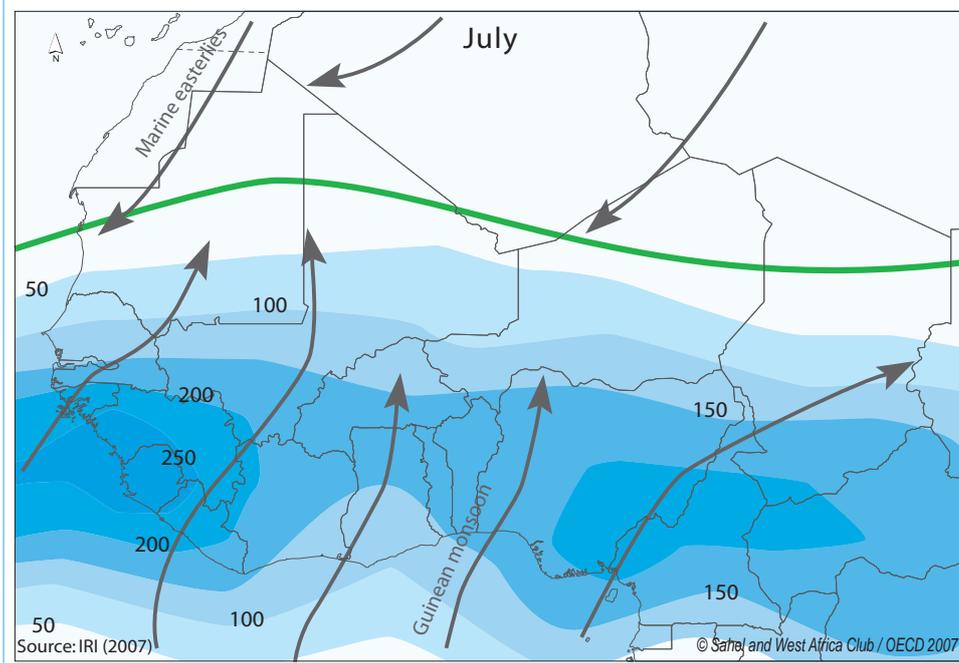
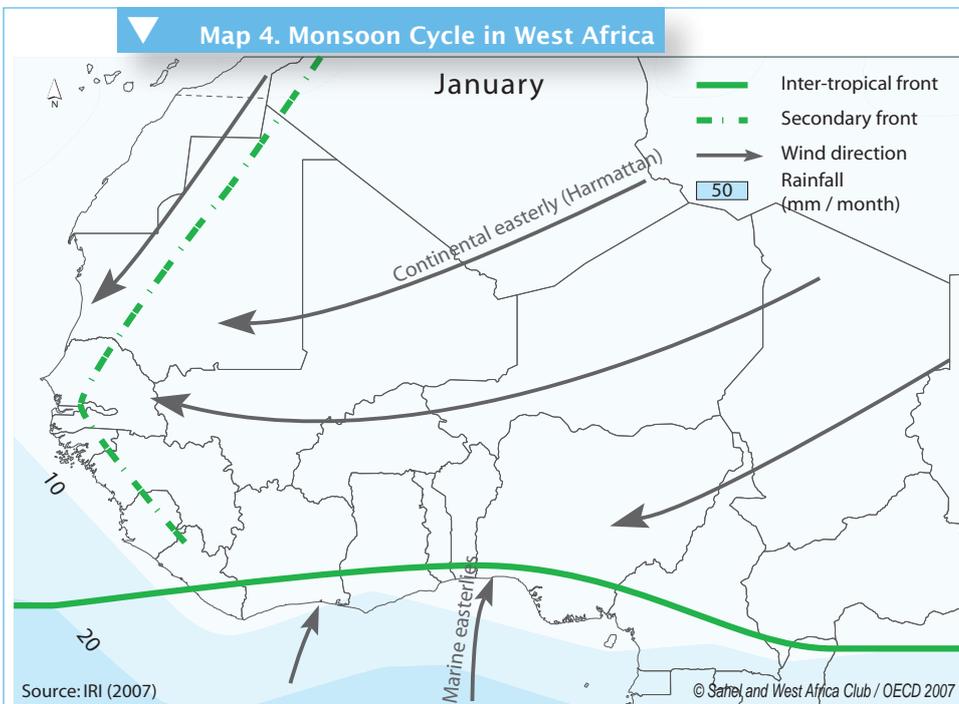
Figure 3. Agricultural Potential Prospects in the World



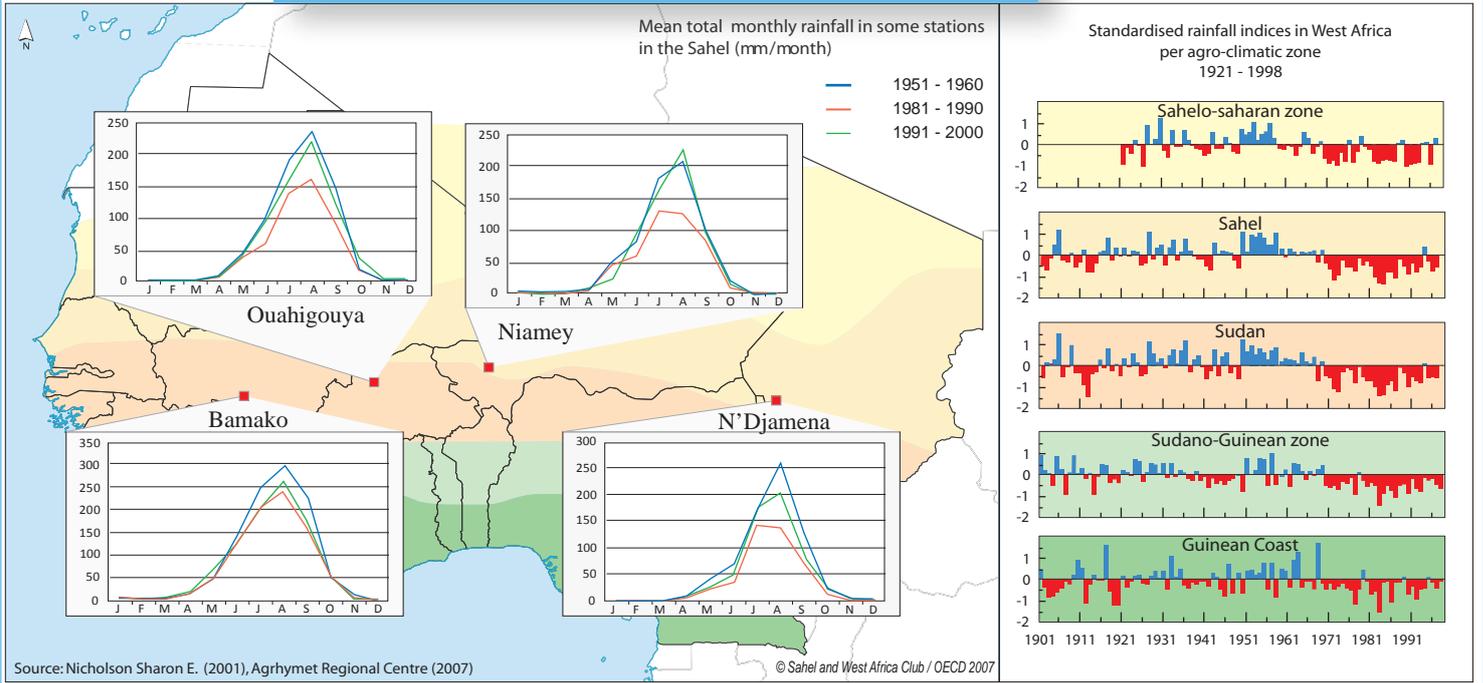
Source: Fischer et al (2002) Climate change and agricultural variability

in order to meet the rising need for food products in Asian countries and the development of bio-fuels (bio-diesel from palm oil) in Europe and America (ethanol from cereals), although greater caution is called for in the case of this hypothesis. Africa will have to find the right balance between land resources, food security and the development of new partnerships and external markets.

Indeed, inflationist effects on cereal markets, partly supported by the demand for bio-fuels and rise in transportation costs, can already be felt. The increase in imported cereal prices is also being witnessed in West African markets. This points to a risk of short-term food insecurity but is also seen as an opportunity to make better use of local production and processing in the longer term.



Map 5. Changes in Pluviometric Indices in West Africa



- The origin of the term monsoon comes from the Arabic word mawsim. For Arab sailors, it meant the season of favourable winds for sailing to India.
- Sahel and West Africa Club (2006) *The ecologically vulnerable zone of Sahelian countries*. Atlas on Regional Integration in West Africa, SWAC/OECD.
- For instance, when ocean surface temperatures are warmer in the southern Atlantic Ocean than the North, a monsoon cycle emerges in the South, which can deprive the region of its customary rainfall.
- El Niño (which means the Child Jesus in Spanish) takes its name from the fact that it takes shape around Christmas. It characterises a sudden change in the Equatorial Pacific's oceanic and atmospheric circulation, which translates into a rise in ocean surface temperatures.

## IV. Vulnerabilities and Impacts in West Africa

### 4.1 West Africa's Climate between Global Phenomena and Regional Dynamics

Rainfall patterns in West Africa are linked to the seasonal movement of the inter-tropical convergence zone, where the hot and dry tropical easterly winds blowing in from the northeast meet with the humid air masses coming in from the Southern Atlantic Ocean, linked to the onset of the monsoon<sup>12</sup> (see Map 4). The semi-arid zone, essentially including the Sahel and Sahel-Saharan belt, is marked by a single rainy season. The Sahel receives most of its rainfall between July and September. Further south, the climate in the Gulf of Guinea countries is marked by the alternation of two rainy seasons and two dry seasons.

There has been a substantial reduction in rainfall in West Africa over the last fifty years, with a clear break between 1968 and 1972. The reduction is extremely clear in the Sahel, with highly deficit periods in 1972-73, 1982-84 and 1997. This trend has taken the form of a 200-kilometer downward slide in isohyets towards the South and a historic aridification process in the area's climate<sup>13</sup>. The decrease in rainfall has not spared the Sudanese and Guinean areas either. The change in rainfall pattern that has taken place in the previous decades may not necessarily settle. Since the mid-1990s, a return to better rainfall conditions has been noted, in particular in continental Sahel (see Map 5).

Temperature changes in northern and southern Atlantic Ocean and Indian Ocean water surfaces<sup>14</sup> as well as surface temperature anomalies in the Pacific, linked to the El Niño<sup>15</sup> phenomenon, are an important

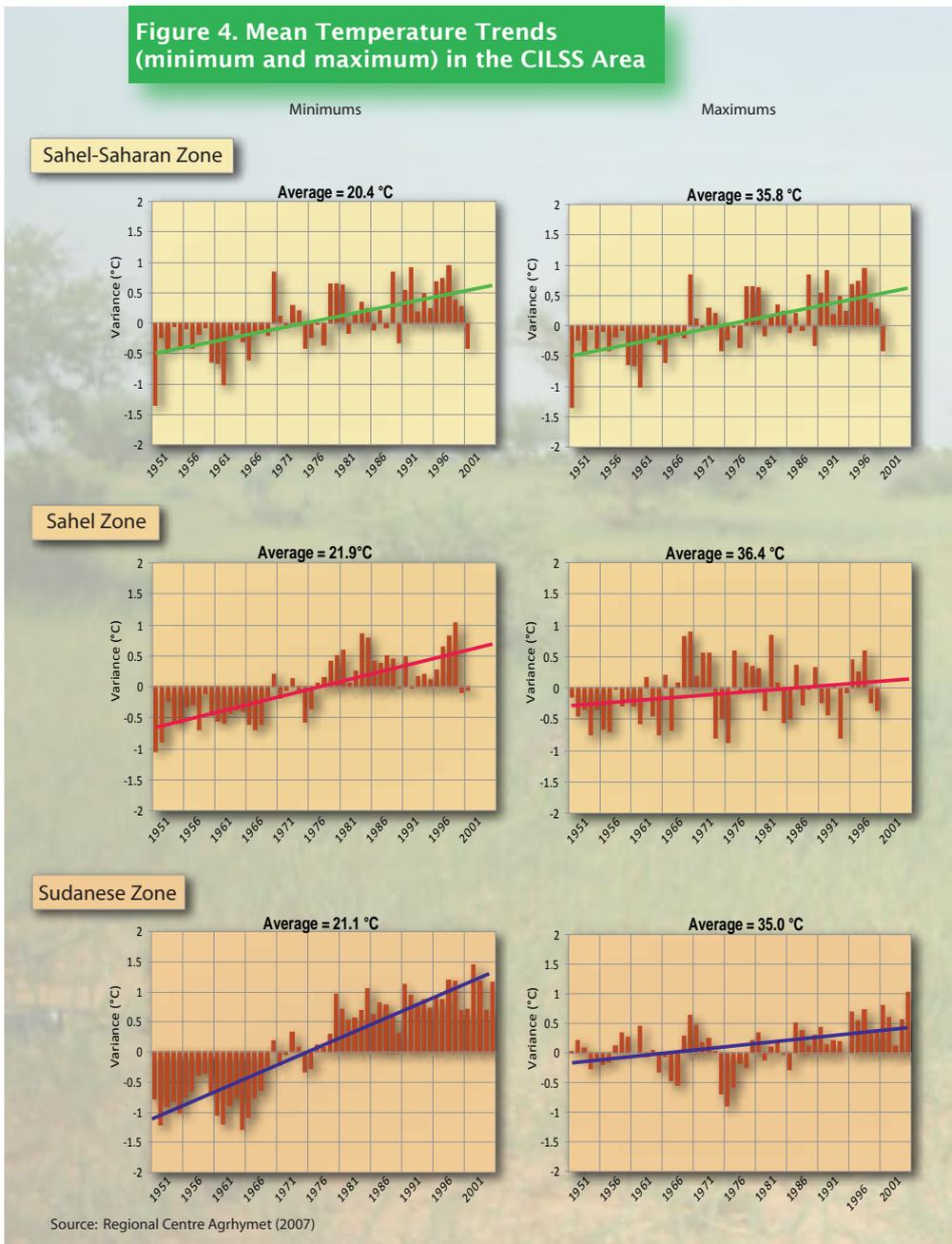


driving force for West Africa's monsoon activity. Temperature variations in the oceans, which are sensitive to global climate changes, will undoubtedly have repercussions on the West African monsoon. In addition to these global phenomena is the effect of continental surface processes (vegetation, soil moisture, water cycle or albedo) on monsoon dynamics. However, the interactions/retroactions between continental dynamics and the climate are as yet insufficiently understood.

Between global factors and regional and continental dynamics, West Africa's climate is subject to considerable variations. This is particularly true in the Sahel, where rainfall, lower than in the coastal area, varies by more than 1,000 mm over a distance (North-South) of 750 km. Hence, this region is extremely sensitive to vagaries of the inter-tropical convergence zone: from one year to the next, there may be more than a 30% variation in the length of the rainy season.



**Figure 4. Mean Temperature Trends (minimum and maximum) in the CILSS Area**





Another climate variable is the fact that changes in West Africa and particularly the Sahel's temperatures have been faster than global warming. The increase has varied between 0.2 and 0.8°C since the end of the 1970s. And this trend is stronger in terms of minimum rather than maximum temperatures (see Figure 4).

## 4.2 West Africa's Climate Change Scenarios: still highly uncertain

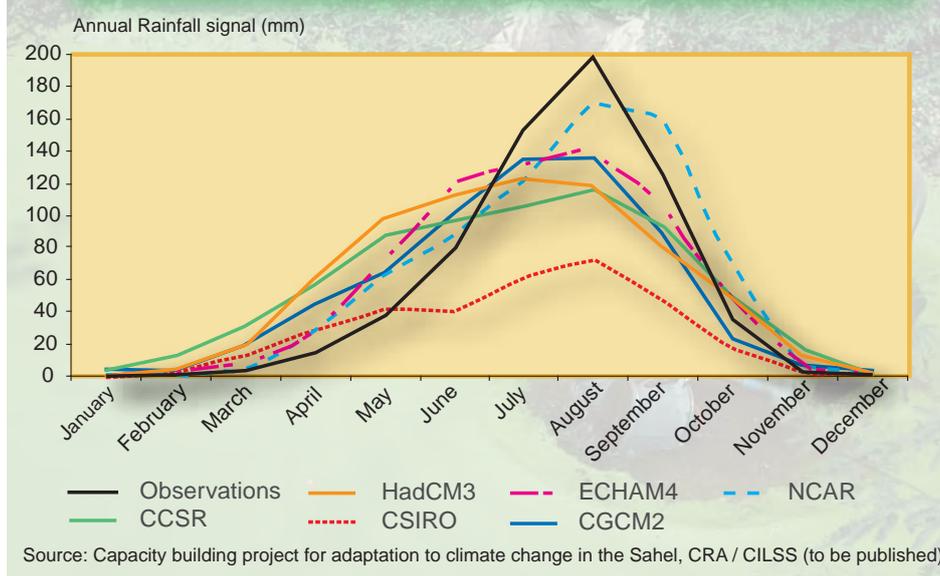
There is still a fair amount of uncertainty in rainfall-related climate projections for West Africa. If a simple average of all the scenarios is taken, slight humidification in the Sahelian region, with no real changes along the Guinean coast can be inferred.

Recent tests have shown the limited capacity of models to forecast West Africa's climate. For instance, in the models, the start of the rainy season appears 1-2 months prior to the dates actually observed<sup>16</sup>. A comparison of the Sahelian climate observed (1961-1990) with climates simulated by six general circulation models recommended by the IPCC (see Figure 5) illustrates these shortcomings. Contrary to the real situation, the models show a marked rainy season almost throughout the year, along with a considerable bias (140-215 mm/year) in annual aggregate rainfall estimates as compared to the data observed.

These results favour a better understanding of West Africa's climate, to be used as a basis to develop regional climate models, provided that statistical series are sufficiently long and reliable<sup>17</sup>. However, the current rainfall network is far from being able to guarantee an error margin lower than 10% in agro-meteorological analyses. In the CILSS countries, only 1.5% of the region has an adequate number of rainfall stations to enable a better picture of rainfall patterns. The desert and agro-pastoral areas are the worst off in this regard.

The IPCC also acknowledges the limitations of research on extreme climate events. Climate changes are likely to enhance the frequency and seriousness of floods and droughts in regions with high rainfall variability. Among the activities currently undertaken on climate forecasting, the ACMAD, the AGRHYMET Regional Centre and their partners have established seasonal forecasting facilities for the rainy season at the regional level<sup>18</sup>. Short-time forecasts of this kind help anticipate and manage climate risks better during the

Figure 5. Poor Performance of Climate Models in the Sahel Region



16. Kamga, André F. and Buscarlet, Etienne (2006) *Simulation du climat de l'Afrique de l'Ouest à l'aide d'un modèle climatique régional*. "La météorologie", the French Meteorological Society's newsletter.
17. Some of the historical information is still available only on paper.
18. The PRESAO, which drafts forecast charts on the probability of lower, equal or higher than normal rainfall, is an example of the tools developed.

cropping season, floods or stream flows. A local-level analysis would undoubtedly make it possible to draw up forecast charts that are better adapted to local actors.

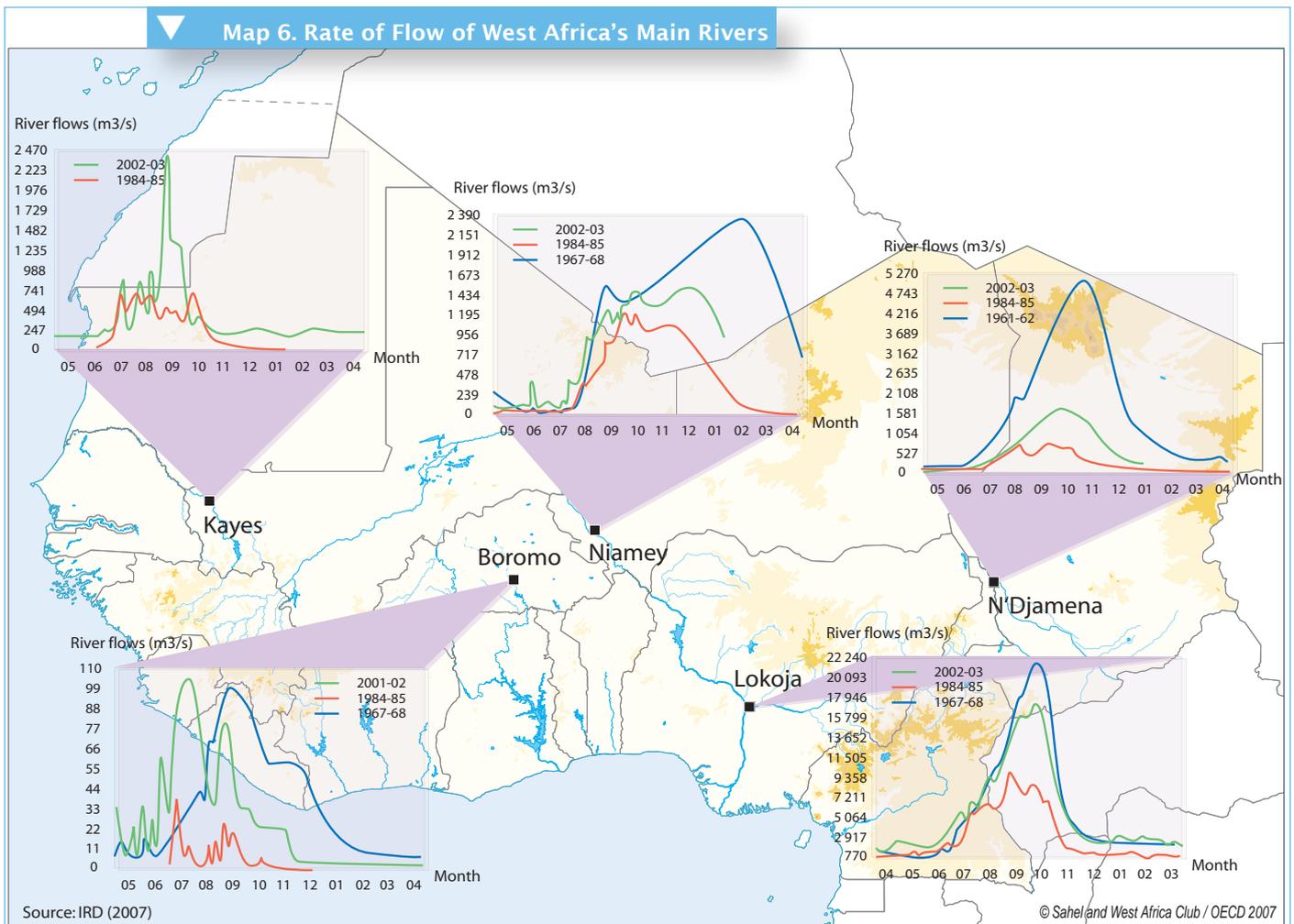
### 4.3 Impact on Water Resources

The region's countries share their surface water resources, which are concentrated in a few watershed areas, the main ones being found in Niger, Lake Chad, Senegal, the Gambia and the Volta. Following the decrease in rainfall since the 1970s, the main rivers have witnessed a drop in their stream flows (See Map 6). The Niger River's (Onitsha) stream flow fell by 30% between 1971 and 1989; those of the Senegal and Gambia Rivers fell by almost 60%<sup>19</sup>. The reduction was relatively greater than the drop in rainfall levels. Along with climatic factors, the increase in water demand is a major factor of this resource's depletion.

Rapid fluctuations in Lake Chad's surface levels are a good illustration of this fact. Before the 1980's, the drop in rainfall levels (rainfall over the Lake represents 13-14% of the annual water input) and the consecutive decrease in the Chari River's flow rate (83% of the lake's yield) and that of its tributary, the Logone, explain largely the reduction in the lake's surface area, apart from evaporation and seepage. After the 1980s, irrigation for farming and arboriculture in the Chari and Logone basins is one of the



19. IUCN (2004) *Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification.*



- 20. Andigué, Job (2007) *Impacts du changement climatique sur le lac Tchad*. Agrhymet Regional Centre, CILSS.
- 21. Sahel and West Africa Club (2006) *Transboundary river basins*. Atlas on Regional Integration in West Africa, SWAC/OECD.



main causes of the reduction of water in Lake Chad<sup>20</sup>. “Partially covered waters” are subject to these fluctuations (see Map 7), and assessing the impact on perennial bulk water is still difficult. Between 2003 and 2007, there was a notable increase in “partially covered water” surface areas, definitely associated with increasing rainfall.

Climate variability and the construction of dams in response to increasing population consumption or the growing number of irrigation and hydroelectric projects have led to rising tension and potential conflicts between countries over shared river basins. About 15 dams have been built in the Niger River basin (see Map 8). There are numerous

projects (Fomi and Kamarato in Guinea; Kénié, Tossaye and Labezanga in Mali; Dyodyonga and Gambou between Benin and Niger; Kandadji in Niger; Lokoja, Makurdi and Onitsha in Nigeria<sup>21</sup>) and the balance between different water uses and the climate risks involved will have to be considered.

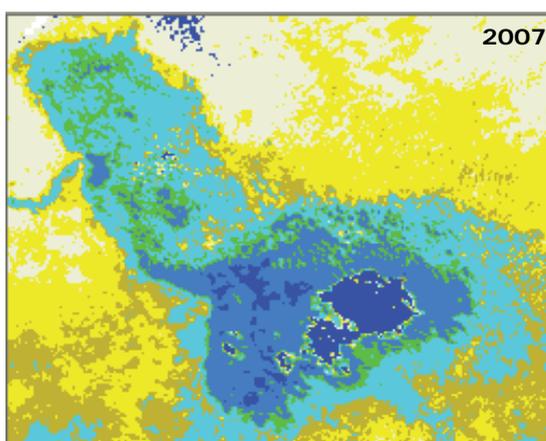
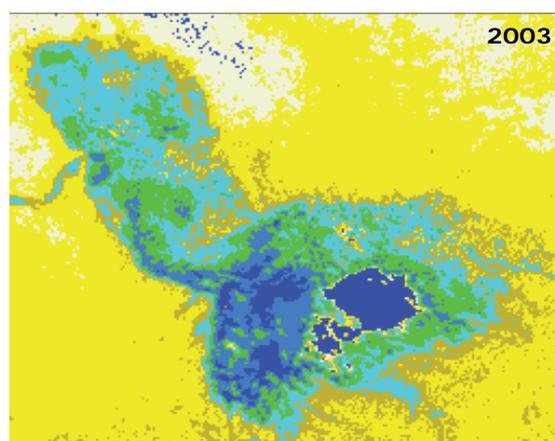
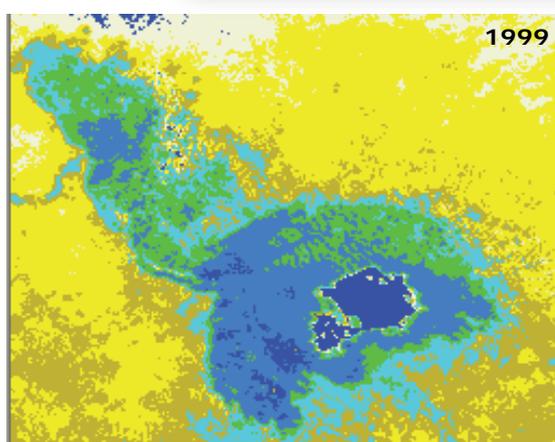
In the future, climate change could have a lasting effect on the quantity of water in circulation in basins or even in ground

**Table 2. Lake Chad's surface areas (1998-2007 average)**

	Average surface areas (sq. km)
Bulk water	1,940
Partially covered water	4,633
Aquatic vegetation in archipelagos	4,585
Swamps	5,588

Source: Regional Centre Agrhymet (2007)

▼ **Map 7. Changes in Lake Chad's Surface Area (January 1999, 2003 and 2007)**



Source: Regional Centre Agrhymet (2007)

water levels that are recharged during the rainy season<sup>22</sup>. But on the whole, West Africa does not face a mid-term renewable water shortage threat, although some challenges may emerge locally. Better use and integrated regional management of available renewable water supplies are essential.

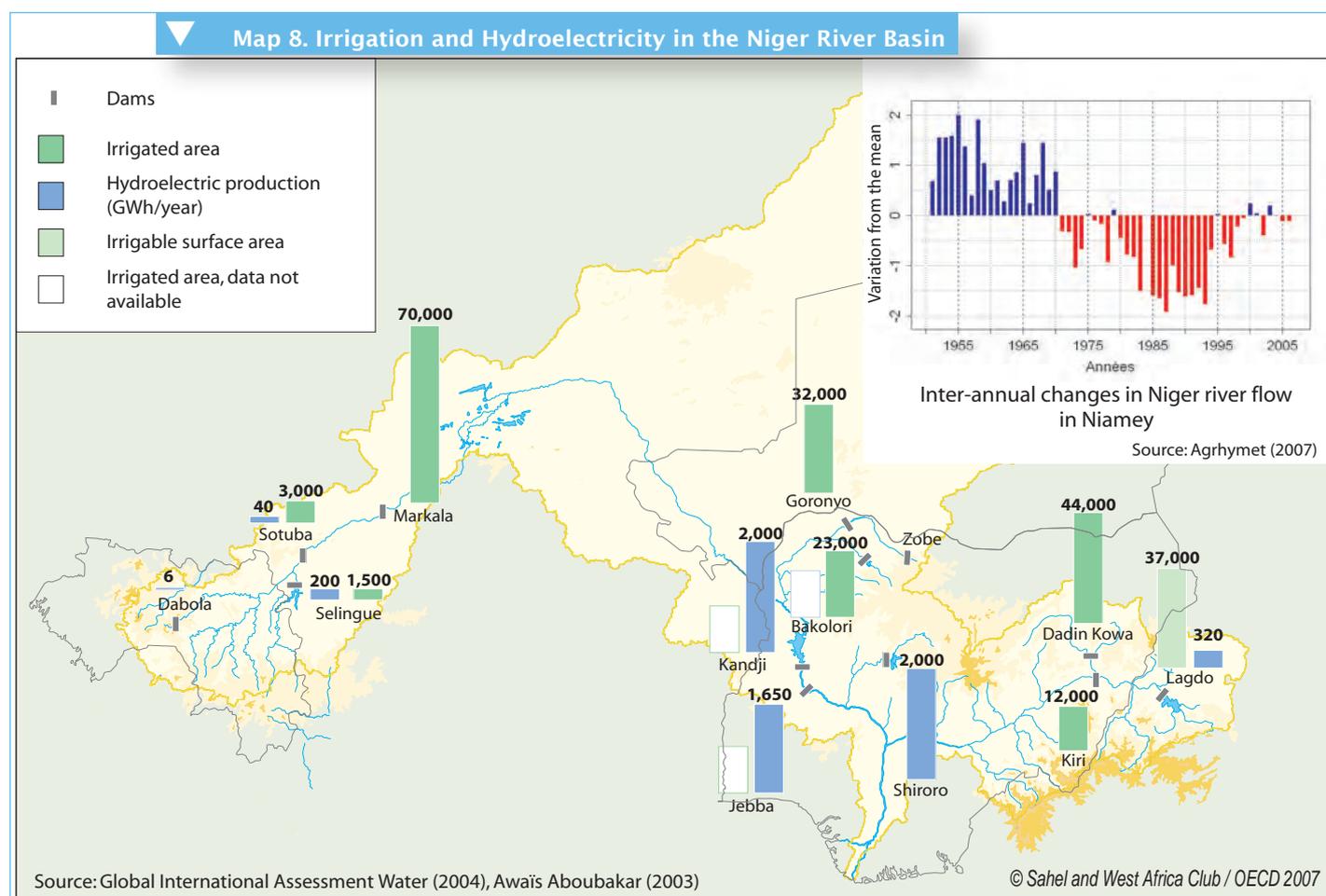
#### 4.4 Possible Impacts on Cereal Farming

West African farming is directly correlated to weather hazards. By 2100, estimated farm sector losses will vary between 2-4% of the regional GDP<sup>23</sup>. Pastoral and agro-pastoral areas will undoubtedly be the most affected by climatic variations. Food crops, mainly focused on cereal production in Sahelian countries, essentially depend on the rainy season's characteristics, along with other climatic and environmental factors.

Case studies undertaken in Senegal, Mali, Burkina Faso and Niger have come up with divergent results<sup>24</sup>. The average yield of millet and sorghum – the staple diet of the Sahelian population – is likely to fall by 15 to 25% in Burkina Faso and Niger by 2080 (see Graph 6a). These crops should be less vulnerable to temperature variations lower than 2°C and to slight rainfall variations ( $\pm 10\%$ ).

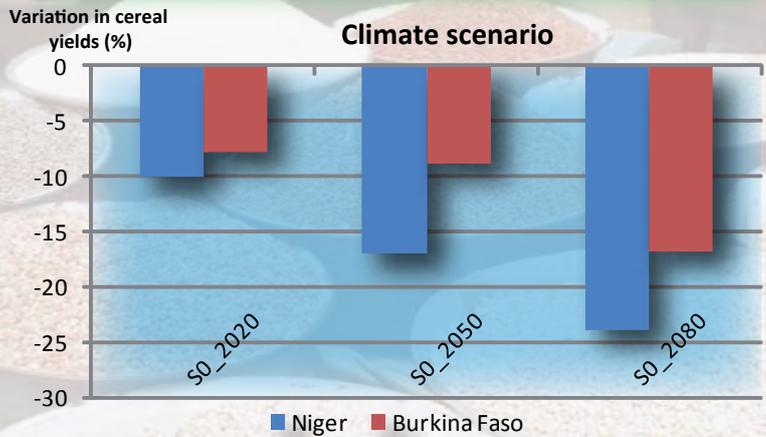
Conversely, average rice yields should increase, whether it is produced under rainfed or irrigation conditions (see Figures 6b and 6c). A rise in the

22. With a return to better rainfall conditions, ground water levels have sometimes recharged since the 1990s in the Sahel. [Koulim et al (2005) *La sécheresse au Sahel, un exemple de changement climatique*. ENPC Climate Change Workshop - VET Department].
23. IPCC (2007) *Climate Change 2007. Fourth Assessment Report (AR4)*.
24. For more details about the hypotheses used, see: Sarr Benoit, Traore Seydou, Salack Seyni (2007) *Évaluation de l'incidence des changements climatiques sur les rendements des cultures céréalières en Afrique soudano sahélienne*. Agrhymet Regional Centre, CILSS, Niamey.



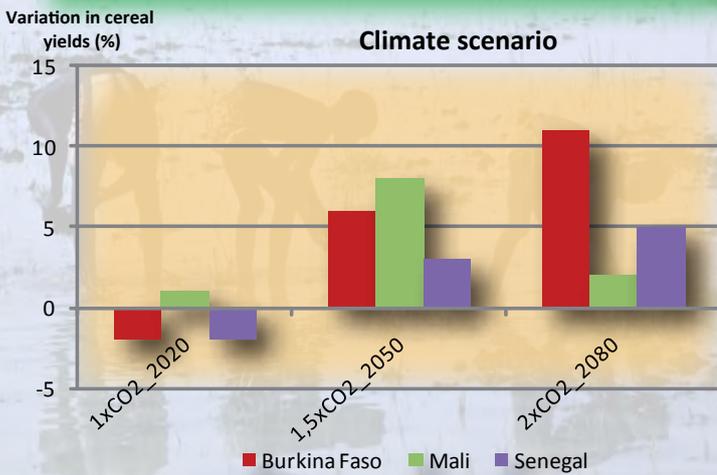


**Figure 6a. Impact of Climate Change on Millet/Sorghum Cereal Yields in Niger and Burkina Faso**



Source: Regional Centre Agrhymet (2007)

**Figure 6b. Percentage Change in Rainfed Rice Yields**



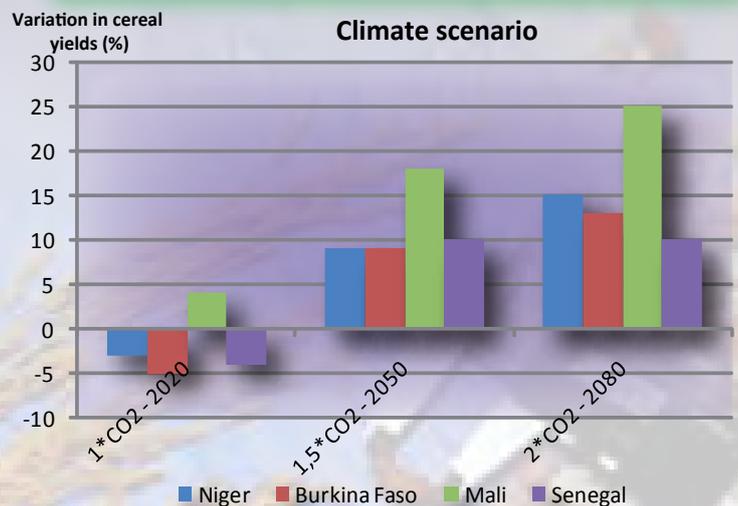
Source: Regional Centre Agrhymet (2007)

atmospheric concentration of CO<sub>2</sub> (fertilizer effect), a moderate increase in temperature and adequate water resources would lead to a 10-25% increase in cereal yields in the CILSS countries' irrigated areas and a 2-10% increase in rainfed rice.

However, these impacts do not take changes in the cropping season into account (changes in the sowing date or extreme rainfall conditions), nor changes in the breeding and migration areas of destructive crop pests (see Box 4). Moreover, climate change could lead to a change in the location of optimal cropping areas (the lowering of isohyets since the 1970s was followed by a change in West Africa's cotton growing areas<sup>25</sup>).

25. See Sahel and West Africa Club (2006) *Cotton. Atlas on Regional Integration in West Africa*.

**Figure 6c. Percentage Change in Irrigated Rice Yields**



Source: Regional Centre Agrhymet (2007)

## 4.5 Uncertain Future of Migrant Livestock Farming

Along with cereal production, livestock farming plays an important role in all Sahelian countries. It contributes up to 10-15% of the GDP in Burkina Faso, Mali, Niger, Senegal and Chad (even more in Mauritania). Migratory pastoralism<sup>26</sup> (70-90% of cattle breeding is migratory) remains a production mode adapted to some Sahel-Saharan ecosystems. It has undergone significant transformations due to population growth, the political options selected or environmental changes such as climatic variations.

One of the significant innovations occurring in the Sahel over the last decades has been the birth and popularisation of agropastoralism, i.e. the combination of farming and livestock breeding within the same farm. This new resource development system stems from a strategy adopted by farmers and shepherds to limit the risks associated with the uncertain climate. Farming helps shepherds limit the purchase of cereals during the lean period; farmers, on their part, seek to diversify their activities and capitalise on their income sources by investing in cattle.

The changes in these practices are coupled with the spatial transformation of activities, following the changes in the Sahel's climate conditions. In search of better pastures, nomadic shepherds go farther and farther away during the wet season, generally towards the North. Once the season ends, they gradually return to their villages where pastures and water supplies remain to be found. The 1973/74 and 1984/85 droughts especially changed the spatial dynamics of migratory herding and pasture lands in the Sahel. The case of Fula breeders in the Dallol Bosso area (Niger) is particularly striking in this regard. Many of these breeders found refuge farther south in Benin and Nigeria where they sometimes settled. These changes proved to be long-lasting and today, the 1973 and 1984 "pastoral runs" have turned into migratory pastures during the dry season (see Map 9)<sup>27</sup>.

26. Migratory pastoralism can be defined as a livestock production system marked by seasonal movements of cyclical nature and of variable scope. These movements take place between complementary ecological zones, under the supervision of a few individuals, with a large section of the group remaining sedentary. Sahel and West Africa Club (2007) *Livestock in the Sahel and West Africa*. Note to decision-makers, Issue 3.
27. Boutrais, Jean (2007) *Crises écologiques et mobilités pastorales au Sahel : les Peuls du Dallol Bosso*. *Sécheresse* 2007; 18(1): 5-12.

### Box 4. Climate Change and Destructive Crop Pests

The climate, the distribution areas of certain insect groups and the emergence of new insect pest distribution areas are closely correlated.

#### *Case of desert locusts*

Desert locusts (*Schistocerca gregaria*) are spectacularly responsive and are able to take advantage of favourable conditions for their multiplication and expansion, such as unexpected rains. During its life cycle, a female can lay around a hundred eggs two or three times. Migratory by nature, desert locusts can also move quickly into areas that favour their growth. In addition, this species is not subject to any diapause or period of suspended growth during its lifetime.

The dessication that would take place after a rise in temperature and/or decrease in rainfall will affect the desert locust's survival and growth conditions, without however eradicating them altogether. On the other hand, any improvement in ecological conditions (soil moisture and vegetation) can promote their growth. An increase in the number of unexpected rainfall episodes apart the usual rainy season would favour reproduction, followed by gregarisation, and would increase the already strong hazard they represent for crops.

Behavioural changes in this species' reproduction areas have already emerged. Thus, while activity has decreased in some areas, new areas seem to be emerging, as indicated by the frequency with which this species has been reported during the exploration carried out in the frontline Sahelian countries.

#### *Case of Senegalese locusts*

The Senegalese locusts' habitat extends between the 10th and 18th north parallels in the Sahelian belt. The outbreaks observed between 1974 and 1980 as well as those reported between 1985 and 1989 seem to have been due to the extraordinary resistance of their eggs to drought conditions and to the disappearance of a number of their enemies. Irregular rainfall led to hatching where adequate rainfall was received and the entry or continued diapause of the eggs where not enough was received. The number of eggs in diapause rose from one year to the next, thereby increasing the overall locust population, which grew further with the return of rains. The insect population's movement was also closely linked to the Inter-tropical Front. If the slide in isohyets observed in the Sahel after 1968 was to recur, it could affect the northern and southern boundaries of the insect's reproductive areas.

#### *Case of cotton stainer*

The cotton stainer (*Dysdercus voelkeri*) moves between the coastal belt and the Sahel during the course of the year. These movements take place in a South-North direction when humidity increases in the South, and in the North-South direction with the advent of dry and hot winds in the North. They follow the Inter-tropical Front's movement and the northern boundary of their movement is limited to the 500 mm isohyet. The change in isohyets could affect the boundaries of this pest's activity zone.

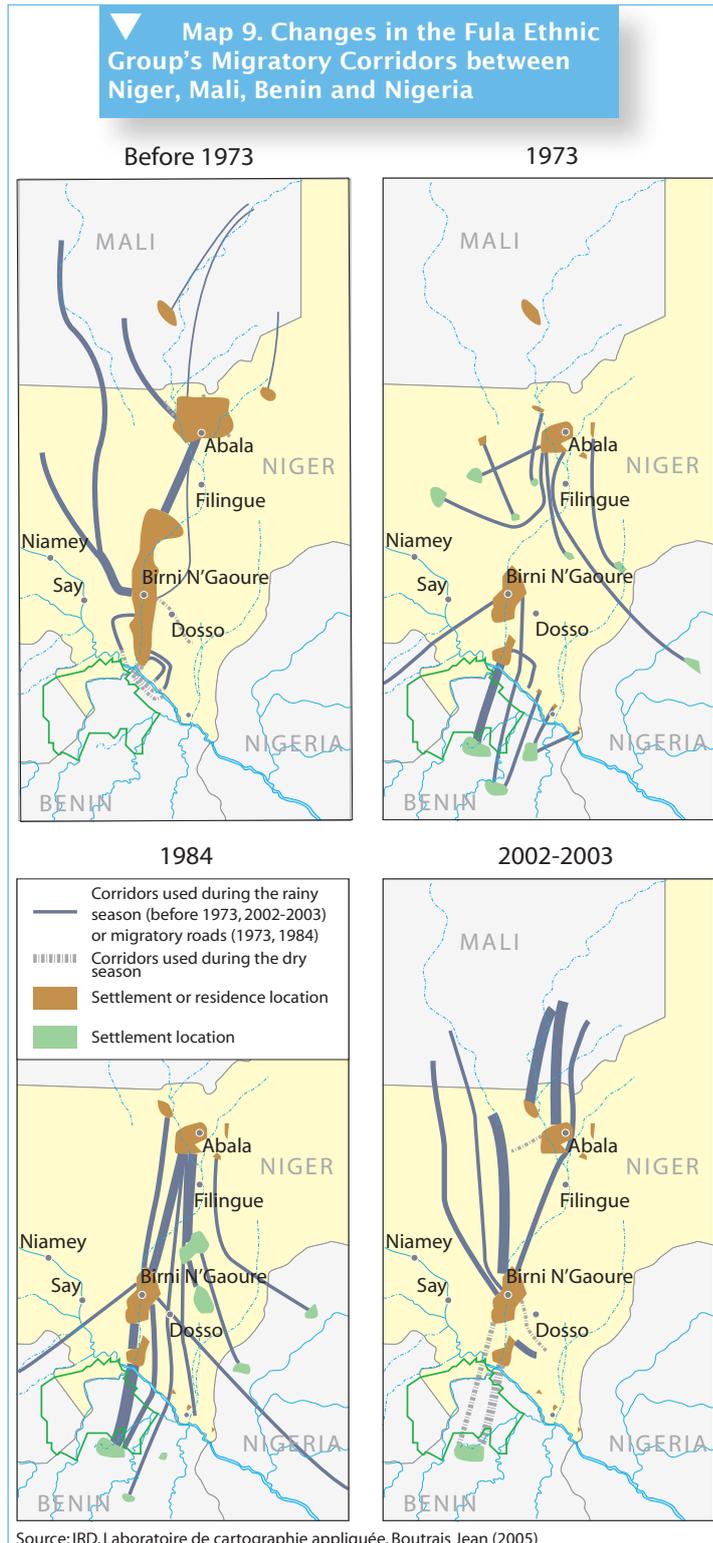
Source: Brahim Sidibe, Amadou Bocar Bal – CRA/CILSS, Annie Monard – FAO (2007)

- 28. Tensions between northern Niger and Mali limit the availability of pastures for livestock farmers in these regions.
- 29. Nicholls, Robert J. (2007) *Adaptation options for coastal areas and infrastructure: An analysis for 2030.*



The environment is an integral part of the life of nomadic cattle breeders in the Sahel. Migratory herding characterises their need to adapt to the changes in the natural environment. Climate changes – favourable or not – will alter the quantity and quality of natural pastures and will undoubtedly lead to new forms of transhumance corridors in the region. But the breeders will have to deal with growing agricultural pressures, greater environmental constraints in the years to come and occasional political risks<sup>28</sup>. Some of them may even turn increasingly

towards agro-pastoralism or a sedentary or semi-migratory livestock breeding system. For others, mobility will remain at the heart of their strategy, provided that it finds support both at national and regional levels.



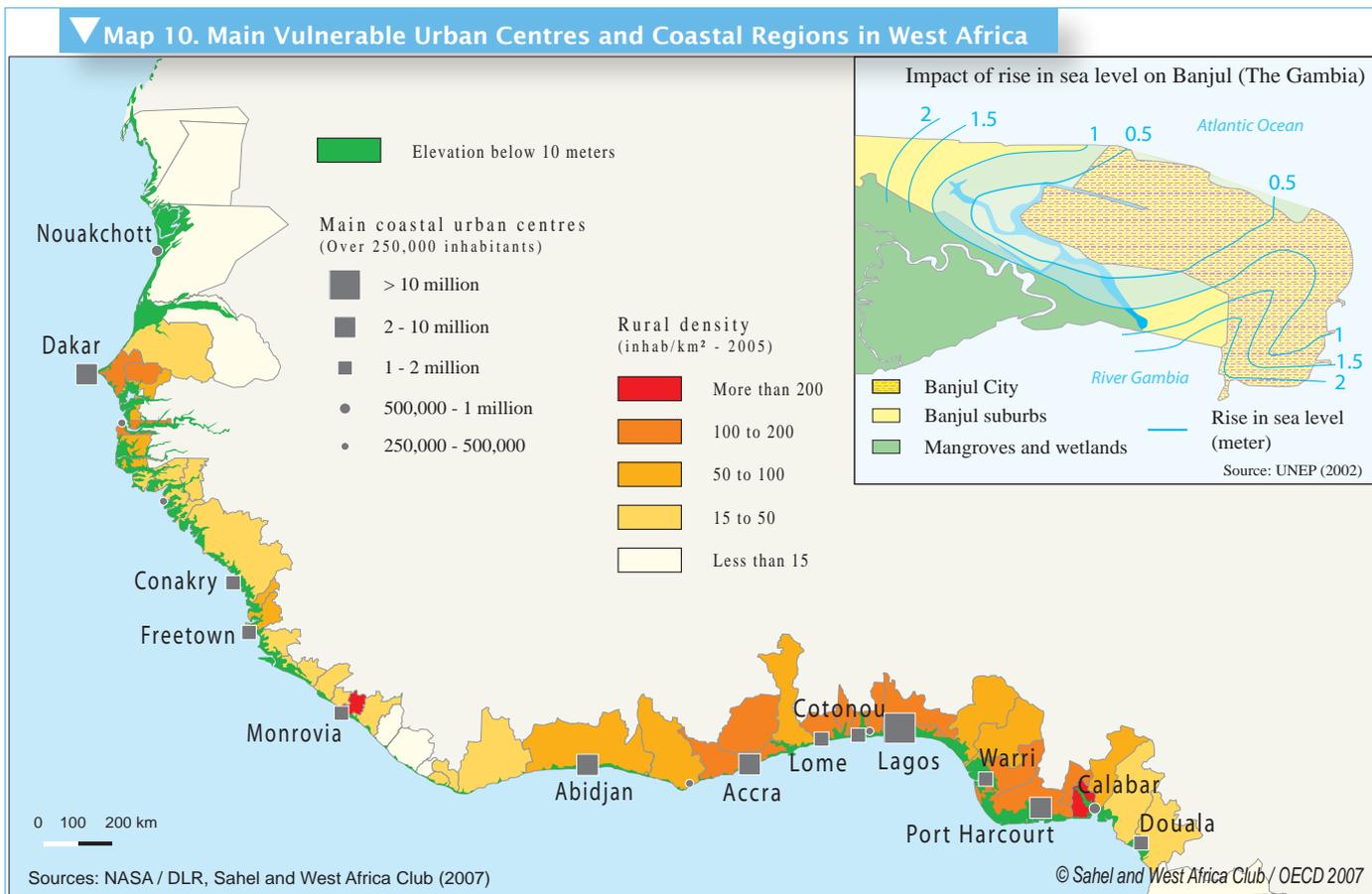
#### 4.6 Coastal Areas and Vulnerable Ecosystems

During the 20<sup>th</sup> century, sea levels rose by an average 1.7 mm per year, i.e. 17 cm in 100 years. This trend is likely to accelerate in the future. Current worldwide projections forecast a 30-50 cm rise in sea levels in the 1990-2100 period<sup>29</sup>.

Over one-fourth of Africa's population lives along a 100 km-long coastal strip. Three regions are especially vulnerable, both from the population settlement areas and ecosystem perspectives – the East African coastline between Kenya and South Mozambique, the Red Sea coastal area and the West African coast.

In West Africa, the areas most vulnerable to a rise in sea levels or extreme incidents arising from the ocean (extremely high tides) have the highest population concentrations and are sometimes the most urbanised (except for the Mauritanian coast). From Douala to Dakar, there are 12 townships of over a million inhabitants along the coastline (see Map 10). Furthermore, productive ecosystems (mangrove swamps, deltas and estuaries) are used for significant economic activities in the fishing, farming and tourism sectors.

The rise in sea levels has had a direct impact on these areas: submergence and coastal erosion, an increase in flood-prone areas and in salinity in estuaries and coastal water tables (see Map 10, example of Banjul). Without policies on adapting to these changes, a 0.5 metre rise in sea levels by 2100 will lead to direct loss of land through submergence



and erosion (see Table 3). Translated into economic terms, infrastructural damage is currently estimated at several hundreds of millions of dollars in Senegal, almost 4.7 billion in Côte d'Ivoire (one-fourth of its current GDP) or even 9 billion in Nigeria (10% of its current GDP).

**H**uman behaviour is the main cause of the ecosystems' degradation or disappearance. However, rising sea levels threaten the coastal regions' biotopes (beaches, lagoons, swamps, etc.), whose disappearance, degradation or salinisation constitute high risks for resident species. Mangrove swamps, which occupy large surface areas in Nigeria, Guinea, Guinea Bissau, Cameroon and Senegal, are particularly sensitive (see Table 4). The submergence of these mangrove swamps or coastal

**Table 3. Vulnerable Coastal Areas and Current Property Value Threatened Areas\***

	Submerged surface area (sq. km)	Surface area lost through erosion (sq. km)	Value of property affected (millions of USD)
Senegal	1,650	28 - 44	345 - 464
The Gambia	46	-	-
Côte d'Ivoire	471	-	4,710
Benin	17.5	22.5	
Nigeria	8,864	78 - 145	9,003

Source: IUCN (2004) *Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification*  
\* Resulting from an increase in sea levels (0.5 m by 2100)





30. Species classified under “critical”, “threatened” and “vulnerable” categories.

**Table 4. Changes in Mangrove Swamps in West Africa**

Ha	1980	1990	2000
Benin	4,400	1,400	1,080
Cameroon	267,000	248,000	229,000
Côte d’Ivoire	89,000	40,000	12,700
The Gambia	64,300	61,700	59,100
Ghana	12,000	11,000	9,000
Guinea	285,000	292,500	290,000
Guinea Bissau	245,000	245,000	245,000
Libéria	19,000	19,000	19,000
Mauritania	140	112	84
Nigeria	999,000	998,000	997,000
Senegal	175,000	175,800	176,700
Sierra Leone	165,600	150,500	135,300
Togo	1,500	1,300	960

Source: FAO (2003) *Situation des forêts du monde*



lagoons could lead to a loss in biodiversity. The IUCN’s Red List currently estimates 723 endangered species<sup>30</sup> in Africa.

### 4.7 Spatial Shifts in Diseases

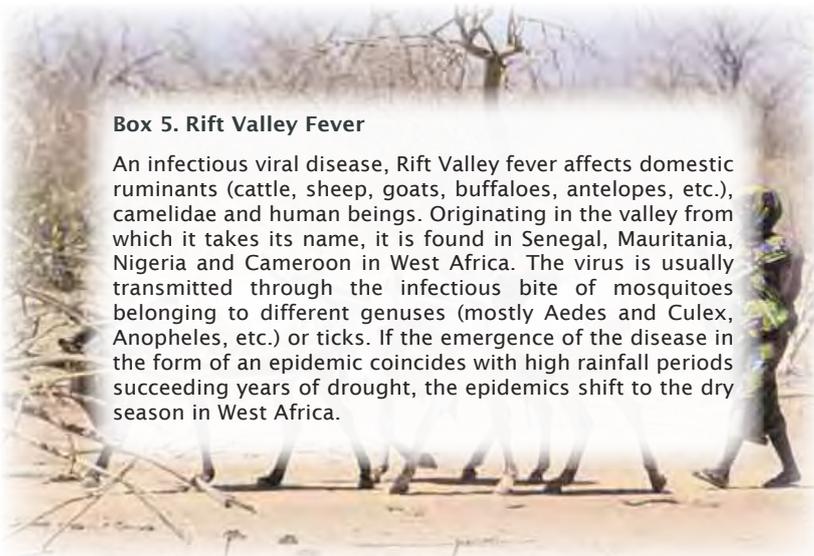
Several vector-borne diseases prevail in West Africa, including malaria, Rift Valley fever (see Box 5), African trypanosomiasis (sleeping sickness), the almost eradicated onchocerciasis or even yellow fever. Rainfall, temperature and hygrometry play an important role in the occurrence of these vectors (see Map 11 on climate zones favourable to malaria transmission in West Africa).

Mosquitoes, the tsetse fly and the large majority of insects (including locusts) need wet and “green” areas to spread. Thus, decreasing rainfall and desertification can limit the development of these species. In Senegal, for instance, such phenomena have resulted in the near-disappearance of *A. funestus* mosquitoes, which has led to a more than 60% drop in the prevalence of malaria over the last thirty years.

But a drier climate does not automatically lead to a decrease in these insects’ growth areas. For instance, mosquitoes can compensate for the areas lost through the drying up of marshland by moving to other ‘habitats’, such as the swamps that form in river beds that are drying up or temporary rainwater ponds. Moreover, the increase in the number of extreme climatic events (irregular rains in particular) could increase these insects’ growth opportunities.

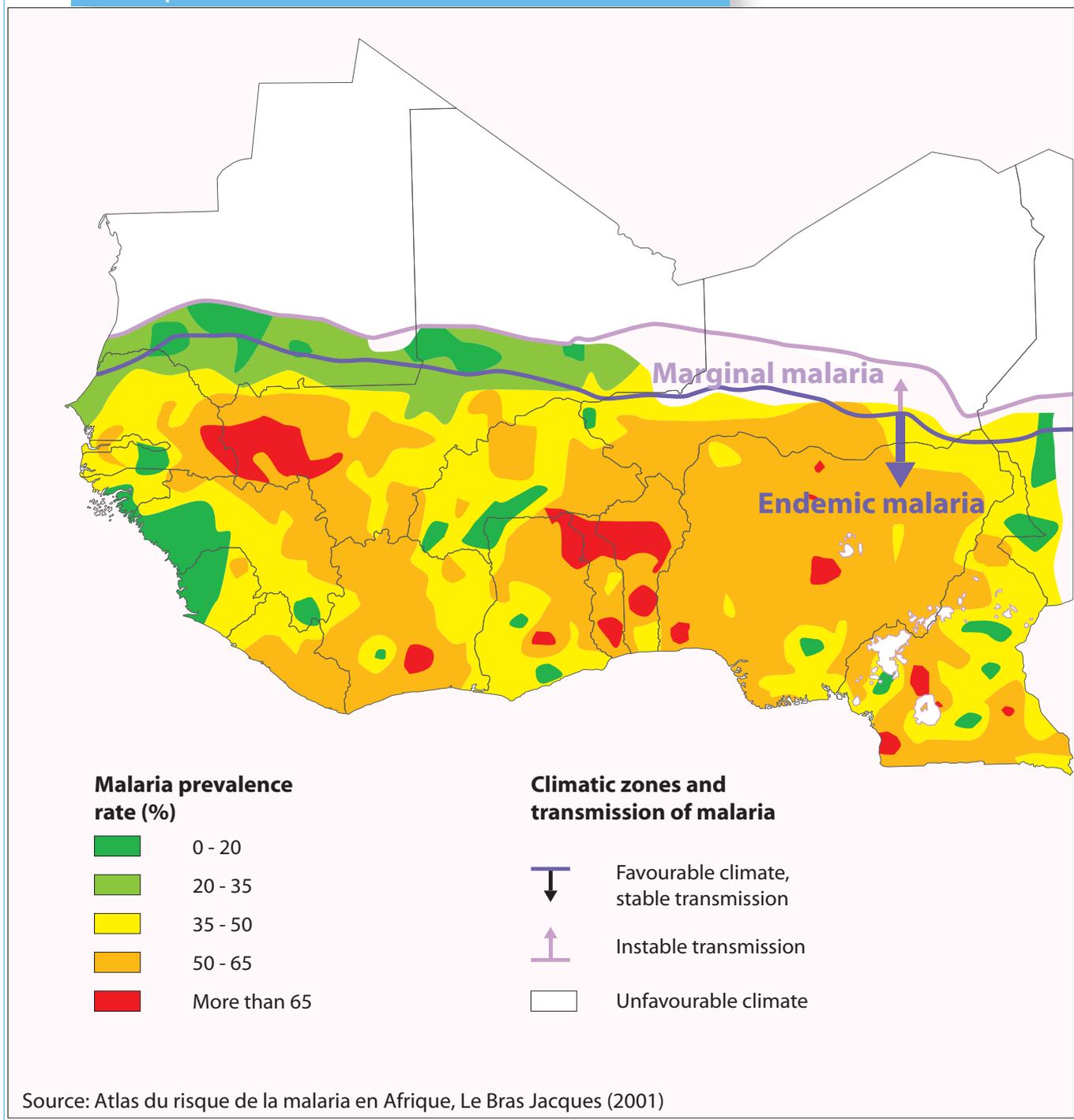
#### Box 5. Rift Valley Fever

An infectious viral disease, Rift Valley fever affects domestic ruminants (cattle, sheep, goats, buffaloes, antelopes, etc.), camelidae and human beings. Originating in the valley from which it takes its name, it is found in Senegal, Mauritania, Nigeria and Cameroon in West Africa. The virus is usually transmitted through the infectious bite of mosquitoes belonging to different genres (mostly *Aedes* and *Culex*, *Anopheles*, etc.) or ticks. If the emergence of the disease in the form of an epidemic coincides with high rainfall periods succeeding years of drought, the epidemics shift to the dry season in West Africa.



Apart from altering the insects’ distribution area, climate changes can lead to human and cattle migration towards areas where fodder is available. The risk of contact with other disease-carrying insects rises and new diseases may develop. Shepherds and farmer-shepherds who fled to the South following the 1970s drought lost a majority of their livestock through African trypanosomiasis – a disease which had not yet been encountered.

Map 11. Climatic Zones Favourable to Malaria in West Africa



The most striking effect of climate change on the transmission of vector-borne diseases will probably be witnessed at the extremes of the temperature range favourable to transmission<sup>31</sup>. Impacts will not be uniform: some regions will experience a rise in transmission risks, while certain diseases will disappear in others. Thus, it is probable that in a large part of Western Sahel and South-Central Africa, the climate would become unfavourable to the transmission of malaria by 2050 to 2080 – the primary cause of mortality in tropical Africa<sup>32</sup>.

31. WHO (2001) World Health Organisation Bulletin, "Changements climatiques et maladies à transmission vectorielles, une analyse régionale". Collection of articles no. 4, 2001. [http://whqlibdoc.who.int/recueil\\_articles/2001/RA\\_2001\\_4\\_62-72\\_fre.pdf](http://whqlibdoc.who.int/recueil_articles/2001/RA_2001_4_62-72_fre.pdf)

32. IPCC (2007) *Climate Change 2007. Fourth Assessment Report (AR4)*.

## Conclusion

The IPCC's work shows global warming trends with near certainty and the significant role played by human activities, although it may be based on imperfect assumptions and models. Their main advantage lies in the collective awareness of what is in the general interest. It is not in the general interest to accurately forecast or know the exact "share of human beings" in climate change. What is in the general interest is knowing that Man can do a great deal to mitigate its causes and impacts.

Like all other world regions, Africa and West Africa must take up this challenge - essentially that of vulnerability and uncertainty. Were the widespread 1973 and 1984 droughts a manifestation of climate change? What about the 2007 floods? As in the past, adaptation to climate variability remains a priority.

Perhaps more than elsewhere, analyses of this region have remained inadequate and the conclusions arrived at by climate projections and their consequences are too uncertain for an effective anticipation of the risks and opportunities linked to climate change. At a time when the National Adaptation Programme of Action (NAPA) and the "regional plan of action for reducing vulnerability in the face of climate change in West Africa" are being formulated, the development of more reliable information systems adapted to local and regional contexts should be at the heart of the strategies adopted. Greater awareness and participation by local actors will also be necessary to formulate and implement these adaptation strategies.

At the international level, the post-Bali meetings as from 2008 and the Conference on food security, climate change and bio-energy in Rome in June 2008 are important events. A common stand on the issue of climate change and the ratification of the Kyoto or Post-Kyoto Protocol ("Bali Protocol") in the African Union (AU) or Regional Economic Communities such as ECOWAS would give greater weight to African countries in negotiations. Funding opportunities associated for the most part with these negotiations would allow them to prepare better for the future.



## Sources and bibliography

- AFSSA (2005) *Fièvre de la vallée du Rift* [http://www.afssa.fr/ftp/afssa/basedoc/1-fievre\\_du\\_Rift.pdf](http://www.afssa.fr/ftp/afssa/basedoc/1-fievre_du_Rift.pdf)
- Africa Partnership Forum (2007) *Climate Change and Africa*. 8<sup>th</sup> Forum meeting on Partnership with Africa/OECD, Berlin - Germany, 22-23 May 2007.
- AMMA (2002) *La mousson ouest-africaine et ses composantes*. February 2002.
- Andigué, J. (2007) *Impacts des changements climatiques sur le lac Tchad*. Agrhymet Regional Centre, CILSS.
- Awaïss, A. (2004) *L'Initiative Bassin du Niger (IBN): développement durable et gestion intégrée d'un grand fleuve*. Afrique contemporaine, Summer 2003.
- Badolo, M.; Ouedraogo, E.Y. (2007) *Contribution à la définition d'une politique climatique sous-régionale en Afrique de l'Ouest*. International climate change review in Africa.
- Boutrais, J. (2007) *Crises écologiques et mobilités pastorales au Sahel : les Peuls du Dallol Bosso*. Climate Research 17, 123-144.
- CRA/CILSS (to be published) *Projet d'appui aux capacités d'adaptation aux changements climatiques au Sahel*. Agrhymet Regional Centre, CRA/CILSS, Niamey.
- Denhez, F. (2007) *Atlas du réchauffement climatique*. Autrement magazine.
- Diplomatie (2008) *Menaces contre la planète*. Diplomatie, hors série n°4, décembre 2007-janvier 2008, Areion.
- ECA (2007) *Climate change and development: Risk and Opportunities for Africa*. ECA/SRO-WA Niamey June 14, 2007.
- IPCC (2001) *Bilan des Changements Climatiques : les Eléments Scientifiques*. Groupe de travail I.

- FAO (2007) *Adaptation to Climate Change in Agriculture, Forestry and Fisheries*. Perspective framework and priorities. <http://ftp.fao.org/docrep/fao/009/j9271e/j9271e.pdf>
- FAO (2007) *Climate Change and Food Security: a Framework for Action*, Rome, 2007. (Document to be published at the Bali Conference).
- FAO (2004) *La biodiversité agricole en Afrique de l'Ouest, situation actuelle, expériences et perspectives*. Agricultural biodiversity in West Africa, experiences and perspectives: <http://www.fao.org/docrep/008/y5667f/y5667f00.htm>
- FAO (2003) *Situation des forêts du monde*. <http://www.fao.org/DOCREP/005/Y7581F/Y7581F00.HTM>
- Fischer, G.; Shah, M.; Velthuizen, H.V. (2002) *Climate Change and Agricultural Vulnerability*. International Institute for Applied Systems Analysis under United Nations Institutional Contract Agreement No. 1113 on "Climate Change and Agricultural Vulnerability" as a contribution to the World Summit on Sustainable Development, Johannesburg 2002.
- Gigli, S.; Agrawal, S. (2007) *Stocktaking of Progress on Integrating Adaptation to Climate Change into Development Co-operation Activities*. Organisation for Economic Cooperation and Development/OECD.
- GIWA (2004) *Guinea Current*. Regional Assessment 42, Global International Waters Assessment.
- International Energy Agency (2006) *CO<sub>2</sub> Emission from Fuel Combustion, 1971-2004, Emissions de CO<sub>2</sub> dues à la combustion d'énergie*. International Energy Agency, IEA/OECD.
- IPCC (2007) *Climate Change 2007*. Fourth Assessment Report (AR4).
- IUCN (2004) *Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification*.
- Kamga, F. A.; Buscarlet, E. (2006) *Simulation du climat de l'Afrique de l'Ouest à l'aide d'un modèle climatique régional*. Journal La météorologie no.52 February 2006, Société Météorologique de France.
- Koulm et al (2005) *La sécheresse au Sahel, un exemple de changement climatique*. Academic year 2004-2005, ENPC Climate Change Workshop - EVT Department.
- N'Djafa, O. H. (2007) *L'adaptation aux changements climatiques au Sahel. Quelles réponses régionales ?* Agrhymet Regional Centre, CILSS, Niamey.
- Nicholls, R.J. (2007) *Adaptation options for coastal areas and infrastructure: An analysis for 2030*.
- Nicholson, S.E. (2001) *Climatic and environmental change in Africa during the last two centuries*.
- Sahel and West Africa Club (2007) *Livestock in the Sahel and West Africa*. Policy Note Number 3.
- Sarr, B.; Traore, S.; Salack, S. (2007) *Évaluation de l'incidence des changements climatiques sur les rendements des cultures céréalières en Afrique soudano sahélienne*. Agrhymet Regional Centre, CILSS, Niamey.
- Sarr, B. (2007) *Le climat ouest-africain et son évolution depuis les années 1950*. Agrhymet Regional Centre, CRA/CILSS, Niamey.
- Sidibe, B.; Bal, A.B. (2007) *Changements climatiques et insectes ravageurs des cultures*. Agrhymet Regional Centre, CRA/CILSS, Niamey.
- WHO (2001) *World Health Organisation Bulletin*, "Changements climatiques et maladies à transmission vectorielles, une analyse régionale". Collection of articles no. 4, 2001, [http://whqlibdoc.who.int/recueil\\_articles/2001/RA\\_2001\\_4\\_62-72\\_fre.pdf](http://whqlibdoc.who.int/recueil_articles/2001/RA_2001_4_62-72_fre.pdf)

## Websites

- African Centre of Meteorological Application for Development (ACMAD)**  
<http://www.acmad.ne/>
- African Monsoon Multidisciplinary Analyses (AMMA)**  
<http://www.amma-international.org>
- Agrhymet Regional Centre (CRA)**  
<http://www.agrhymet.ne/>
- Development Cooperation Directorate (DCD-DAC/OECD)**  
[http://www.oecd.org/document/34/0,3343,fr\\_2649\\_34421\\_39313186\\_1\\_1\\_1\\_1,00.html](http://www.oecd.org/document/34/0,3343,fr_2649_34421_39313186_1_1_1_1,00.html)
- Economic Commission for Africa (ECA)**  
<http://www.uneca.org/>
- Environment Directorate (ENV/OECD)**  
[http://www.oecd.org/departement/0,3355,en\\_2649\\_33713\\_1\\_1\\_1\\_1,00.html](http://www.oecd.org/departement/0,3355,en_2649_33713_1_1_1_1,00.html)
- FAO (website on climate change)**  
<http://www.fao.org/clim/>
- FAO (Climpag site on the climate's impact on agriculture)**  
[http://www.fao.org/nr/climpag/index\\_en.asp](http://www.fao.org/nr/climpag/index_en.asp)
- Intergovernmental Panel on Climate Change (IPCC)**  
<http://www.ipcc.ch/>
- International Energy Agency (IEA/OECD)**  
<http://www.iea.org>
- International Research Institute for Climate and Society (IRI)**  
<http://portal.iri.columbia.edu/portal/server.pt>
- Les sceptiques du réchauffement climatique**  
<http://www.pensee-unique.fr/paroles.html>
- Mapping Malaria Risk in Africa (MARA)**  
<http://www.mara.org.za>
- Système d'Observation du Cycle Hydrologique de l'Afrique de l'Ouest et Centrale (HYCOS-AOC)**  
<http://aochycos.ird.ne/HTMLF/ETUDES/HYDRO/INDEX.HTM>
- United Nations Framework Convention on Climate Change (UNFCCC)**  
<http://unfccc.int>

This document received support and technical contributions from: Stéphane Jost, Paul Brunel and Anna Ricoy (FAO); Ali Abdou, Job Andigué, Mathieu Badolo, Amadou Bocar Bal, Issa Garba, Issaka Lona, Ouaga Hubert N'Djafa, Benoît Sarr, Brahim Sidibe, Bonaventure Somé, Seydou Traore and Hervé Trébossen (CILSS Agrhymet Regional Centre); and André Kamga (ACMAD). We also thank the ACMAD and ECA (Niamey) teams for their participation in this work.

Chapter produced by Christophe Perret, under the supervision of Laurent Bossard  
Maps: Christophe Perret  
Assistant: Sylvie Letassez; Layout: Marie Moncet  
Photos: World Bank: Curt Carnemark, Scott Wallace, Arne Hoel, Thomas Sennett ; ©UNESCO: Roger, Dominique; USAID: A. Fleuret, Richard Nyberg, Laura Lartigue; Abdelkrim Belkilani and Loïc Marchat; Marie Moncet.

