Reviewing climate of West and Central Africa to inform farming systems research and development in the sub-humid and semi-arid agroecologies of the region
Acknowledgement

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About CORAF/WECARD

The West and Central African Council for Agricultural Research and Development (CORAF/WECARD) is one of the four sub-regional organizations that constitute the Forum for Agricultural Research in Africa (FARA). The mission of CORAF/WECARD is Sustainable improvements to the competitiveness, productivity and markets of the agricultural system in West and Central Africa by meeting the key demands of the sub-regional research system as expressed by target groups. CORAF/WECARD is currently composed of 22 National Agricultural Research Systems (NARS) of the following countries in West and Central Africa (WCA): Benin, Burkina Faso, Cameroon, Cape-Verde, Central African Republic, Chad, Congo, Côte d’Ivoire, the Democratic Republic of Congo, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo. These countries cover a total area of over 11.5 million square kilometres, with a population of over 318 million, 70% of whom depend directly on agriculture for their livelihoods.

The CORAF/WECARD secretariat is based in Dakar, Senegal. CORAF/WECARD has revitalised its approach to tackling the region’s agricultural challenges by using a commissioned report prepared by the International Food Policy Research Institute (IFPRI). This report lists priorities for the region based on commodities and thematic areas. Through an intensive participatory process involving a cross section of relevant stakeholders it has developed new Strategic Plan (2007-2016) and, subsequently, an Operational Plan (2008 – 2013) defining its research direction and partnerships. CORAF/WECARD also targets the building of partnerships with relevant regional institutions and the private sector of economies across the sub-region. CORAF/WECARD’s vision is A sustainable reduction in poverty and
food insecurity in West and Central Africa through an increase in agricultural led economic growth and sustainable improvement of key aspects of the agricultural research system with a strong alignment and commitment to the overall goal of the Comprehensive African Agricultural Development Programme (CAADP) of the New Partnership for Africa’s Development (NEPAD).
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<tbody>
<tr>
<td>AEJ</td>
<td>African Easterly Jet</td>
</tr>
<tr>
<td>ACMAD</td>
<td>African Centre of Meteorological Applications for Development</td>
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<td>AEZ</td>
<td>Agroecological Zones</td>
</tr>
<tr>
<td>AGRHYMET</td>
<td>Centre Régional Agro-Hydro-Météorologie</td>
</tr>
<tr>
<td>AMMA</td>
<td>Analyse Multidisciplinaire de la Mousson Africaine</td>
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<tr>
<td>AWHC</td>
<td>Available Water Holding Capacity</td>
</tr>
<tr>
<td>CILSS</td>
<td>Comité permanent Inter-Etats de lutte contre la sécheresse dans le Sahel</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
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<tr>
<td>EAMAC</td>
<td>Ecole Africaine de la Météorologie et de l’Aviation Civile</td>
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<tr>
<td>ECOWAS</td>
<td>Economic Community of West Africa States</td>
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<tr>
<td>GCM</td>
<td>Global Circulation Model</td>
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<tr>
<td>ENSO</td>
<td>El Nino-Southern Oscillation</td>
</tr>
<tr>
<td>IPCC</td>
<td>Inter governmental Panel on Climate Change</td>
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<tr>
<td>ITCZ</td>
<td>Inter tropical Convergence Zone</td>
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<tr>
<td>LGP</td>
<td>Length of Growing Period</td>
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<tr>
<td>ITD</td>
<td>Inter-Tropical Discontinuity</td>
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<tr>
<td>NAO</td>
<td>North Atlantic Oscillation</td>
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<tr>
<td>NARS</td>
<td>National Agricultural Research System</td>
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<td>NMS</td>
<td>National Meteorological Service</td>
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<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
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<tr>
<td>PASR-RV/AO</td>
<td>Programme d’action sous régional de réduction de la vulnérabilité en Afrique de l’Ouest et au Tchad face aux changements climatiques</td>
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<tr>
<td>PET</td>
<td>Potential Evapotranspiration</td>
</tr>
<tr>
<td>RIPIECSA</td>
<td>Recherche interdisciplinaire et participative sur les interactions entre les écosystèmes, le climat et les sociétés d’Afrique de l’Ouest</td>
</tr>
<tr>
<td>RTC</td>
<td>Regional Training Centre</td>
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<tr>
<td>SST</td>
<td>Sea Surface Temperature</td>
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<td>TEJ</td>
<td>Tropical Easterly Jet</td>
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<tr>
<td>UEMOA</td>
<td>Union Economique et Monétaire Ouest-Africaine</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<tr>
<td>WASCAL</td>
<td>West African Science Service Center on Climate and Adapted Land Use</td>
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<tr>
<td>WCA</td>
<td>West and Central Africa</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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<tr>
<td>WRSI</td>
<td>Water Requirement Satisfaction Index</td>
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Introduction

The meteorological record for Africa is relatively short. In 1885, records were kept at nearly 150 stations, but most were in coastal locations and/or confined to countries within Southern Africa and Tunisia or Algeria in the north. Few instrumental observations existed prior to the 20th century. The largest body of observations available is for rainfall, while temperature records are available only for a much smaller number of stations. These records are also shorter than those for rainfall and have not been extensively used.

In West and Central Africa (WCA), the most extensive records available are for the 1950s and 1960s (Figure 2). After that period, a large number of stations opened up in some countries, but in many of those countries (e.g., Chad, Guinea Bissau, Liberia, Sierra Leone, Democratic Republic of Congo) the station networks were adversely affected as a result of political instability, civil wars and economic crisis. Due to civil and/or military conflict, some countries such as Guinea Bissau, Sierra Leone, Liberia and Congo Republic, lost significant meteorological infrastructure as well as data. Despite this relative dearth of quantitative records prior to 1900, there is adequate historical information to put together a reasonable picture of rainfall and temperature variability in WCA throughout the 20th century.

The economies of WCA countries are largely dependent on agriculture which accounts for over 35% of the Gross Domestic Product (GDP) and over 40% of the region’s exports. Agriculture in the WCA region is heavily dependent on rainfall and therefore highly vulnerable to the spatial and temporal anomalies of rainfall. Climate variability impacts vegetation and water resources in the region, thus influencing the nature of the agroecosystems and their potential as productive agricultural domains. This poses major challenges for farmers, pastoralists as well as fisher folk. The occurrence of drought and floods has continued to affect the sub region, especially the Sahel, resulting in famine, malnutrition, diseases, loss of life and property.

The Intergovernmental Panel on Climate Change (IPCC) predicts that in the short-term, the number of extremely dry and wet years will increase during the present century (IPCC, 2007). However, it is still uncertain how rainfall will change over this century in the Sahel, along the Guinean Coast, and in the southern Sahara (IPCC, 2007). It is likely that past climatic trends will continue with semi-arid areas becoming more arid (Druyan et al., 2008). Against this background, the heavy dependence of WCA agriculture on climatic conditions indicates that the sub region is vulnerable to climate change and highlights the need to adopt response strategies. Scenarios of climate change for West Africa indicate that the current climate variability confronting the region is likely to heighten and intensify. Possible impacts on society and economies across the region could be tremendous since they could have an adverse effect on all sectors and sections of the population. Invariably the poor and marginalised populations including small holding farmers, pastoralists and fisher folk (particularly women and children), will be the worst hit.

The current and future threats posed by climate change, unsustainable practices in inshore resource use and management, and water resource management, require the adoption of an ecosystem-based management approach to achieve sustainable livelihoods and biodiversity conservation in WCA. It is imperative that an innovative approach to environmental and resource management, based on robust scientific, economic, social, and traditional knowledge be adopted. This will inform actors and decision makers in adopting evidence-based action
that will ensure the achievement of desired national development outcomes in the face of changing climate in the region.

The purpose of this review is, therefore, to undertake an appropriate assessment of the prevailing climate trend in the CORAF/WECARD semi-arid to sub-humid region, as a crucial input into the design of research interventions aimed at improving livelihoods and to inform decision making in the region. This report reviews the characteristics of the climate of the major agroecological zones in WCA and documents the possible causes of climate variability in the region. The report also analyses the current and future variability and trend of climate and agroclimatic indicators (rainfall, temperature, potential evapotranspiration, onset, cessation dates, and length of growing period), and extreme event occurrences, and evaluates the capacity of CORAF/WECARD National Agricultural Research System (NARS) member countries in terms of weather monitoring and analysis. It is hoped that the results of this review will contribute towards providing the much needed and valuable information on the climatic situation in the WCA region as well as the critical gaps. It is also anticipated that this review will provide key information to help design appropriate research interventions that can contribute towards adaptation to climate change and climate variability in the region.

Figure 2. Rainfall stations in the years 1915, 1925, 1955 and 1985. Only meteorological stations with continuous data are presented. (The stations in the maps are those available in the archive of Nicholson (1993) and only represent a subset of total station availability, but illustrate the temporal trends in the station network)
1. Agroecological zones (AEZ) and climate of West and Central Africa (WCA)

1.1 Agroecological zones
Rainfall varies widely across the African continent, ranging from less than 200 mm to 4,500 mm (Figure 3); however, the WCA region is the wettest in the African continent. The major agroecological zones (AEZ) of Africa, which are closely related to rainfall include the humid, sub-humid – humid, sub-humid dry, semi-arid and hyper arid zones (Figure 4). All of these agroecologies are present in WCA.

Figure 3. Mean annual rainfall (mm) over Africa
**Semi-arid zone:** Rainfall in this zone ranges from 250 - 500 mm with a growing period of 60 - 90 days. This zone includes the northern parts of Senegal, parts of Mali, Burkina Faso, Niger, Chad, Nigeria and Cameroon. The vegetation here is mostly grassland, while *Acacia spp* are the dominant trees. The main food crops grown in the semi-arid agroecology are millet, sorghum, and cowpea, while groundnut is the principal cash crop.

**Sub-humid dry zone:** This zone includes the Sudan savannah with rainfall of 500 - 900 mm and 90 - 165 growing days. The zone roughly covers the Gambia, southern parts of Senegal, Mali, Burkina Faso, Niger, Chad, and the extreme Northern zone of Togo, Benin, Nigeria, Chad and Cameroon. The vegetation is mainly grassland with some shrubs and acacia trees. The main crops grown are millet, sorghum, groundnuts, cotton, maize, beans and rice. A large number of livestock, mostly zebu and zebu-shorthorn crosses, sheep and goats are also part of the farming system in the sub-humid dry zone.
The sub-humid to humid zone: This zone covers mainly the Guinea savannah with average annual rainfall between 900 - 1500 mm, and a growing period of 165 - 180 days. This zone covers the southernmost parts of Senegal, Mali and Burkina Faso, Guinea-Bissau, upper parts of Guinea, and the northern parts of Ghana, Cote d’Ivoire, Togo, Benin, Cameroon and the central parts of Nigeria and Central Africa Republic. Crop farming is the main agricultural occupation here but cattle as well as sheep and goats are also part of the farming system. The major crops grown in the sub-humid to humid zone include maize, sorghum, rice, millet, yam, cotton and groundnut. Forests are confined to the river valleys in the southern parts of this zone.

The sub-humid zone: This zone includes Guinea-Bissau, upper parts of Guinea, the southernmost parts of Mali and Burkina Faso and the northern parts of Ghana, Cote d’Ivoire, Cameroon, Sierra Leone, Benin and the central parts of Nigeria. The average annual rainfall is between 1250 mm and 1500 mm in one season with a 180 – 270 day growing period, which supports a basically grass and shrub vegetation widely infested by the tsetse fly. Cattle, as well as sheep and goats are raised but crop farming is the main component of the farming system. Major annual crops include maize, sorghum, rice, millet, yam, cotton, groundnuts and pulses, as well as tree crops like mango and cashew. Forests are confined to the river valleys in the southern parts of the zone.

The humid zone: This zone consists of two sub zones:

i. The Guinea or derived savannah zone, which has an annual rainfall of between 1500 mm and 1800 mm divided into two alternating dry and wet seasons. The natural vegetation is generally grassland and woody transitional forests. The major crops are maize, yam, rice, millet, sorghum, groundnuts and cotton; sugar cane is grown in the wetter parts. Livestock, mostly trypano-tolerant cattle, sheep and goats are few. This sub zone includes parts of southeast Guinea, northern Liberia, parts of Cote d’Ivoire, middle Ghana, the middle belt of Nigeria and the northern central parts of Cameroon.

ii. The forest zone, where annual rainfall ranges from 1500 mm to more than 2000 mm with a bimodal rainfall pattern. The belt of bimodal rainfall includes east of Sierra Leone, the southern zone of Cote d’Ivoire, Ghana, Togo, Benin, Cameroon, Congo and Gabon. The length of the growing period ranges from 270 to 365 days. The vegetation is dense tropical forest. Major tree crops grown include oil palm, coconut, rubber and cocoa while the main food crops are maize, yam, cassava, cocoyam plantain, banana and beans as well as coffee, mango, citrus and sugar cane.

The eastern part of the coast of Ghana and the coasts of Togo and Benin are distinguished by a rainfall pattern different from the general rainfall distribution along the rest of the West Africa coast. Instead of the normal decrease in rainfall from the coast towards the interior of the continent, the eastern part of the coast of Ghana and the coasts of Togo and Benin receive relatively little rainfall (800 - 900 mm) compared to the 2000 - 3000 mm along the coasts of Cote d’Ivoire, Liberia, Sierra Leone and the western part of the coast of Ghana. This rainfall anomaly over this coastal region is due mainly to local atmospheric circulation, the nature of the coast and some up welling of cold winds (Acheampong, 1982).
Table 1 shows the contribution of individual months to the mean annual rainfall as a function of latitude. From approximately 12° to 18° N August is clearly the wettest month while July and September contribute about equally to the annual rainfall. In the Sahelo–Saharan, Sahel, and Sudan zones, August represents 32 - 40% of the annual mean while July and September each represent about 20 - 24%.

Farther north from 18° to 20° N, July rainfall becomes less important. Between 8° and 12° N, roughly the Soudano–Guinean zone, rainfall is more evenly distributed throughout these three months, the contributions ranging from 17% to 25%. The maximum is still in August towards the north, but shifts to September at around 8° N. Between 4° and 8° N (the Guinea Coast), there is a double maximum in the annual cycle, with the wettest month being June (16 - 24 %) and a secondary maximum occurring in September or October. Latitude between 8° N and 4° N indicates two wet seasons in the humid Guinea zone. In this area, August corresponds to the driest season.

Table 1. Contribution of individual months to mean annual rainfall for different latitudinal sectors in WCA - Numbers are percentages and represent the ratio of monthly mean to annual mean rainfall averaged for stations in the sector.

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<tr>
<td>18° - 20°N</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>41</td>
<td>23</td>
<td>5</td>
<td>2</td>
<td>84</td>
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<tr>
<td>16° - 18°N</td>
<td>1</td>
<td>7</td>
<td>23</td>
<td>40</td>
<td>22</td>
<td>5</td>
<td>0</td>
<td>255</td>
</tr>
<tr>
<td>14° - 16°N</td>
<td>2</td>
<td>8</td>
<td>24</td>
<td>38</td>
<td>22</td>
<td>5</td>
<td>0</td>
<td>498</td>
</tr>
<tr>
<td>12° - 14°N</td>
<td>5</td>
<td>12</td>
<td>23</td>
<td>32</td>
<td>20</td>
<td>6</td>
<td>1</td>
<td>843</td>
</tr>
<tr>
<td>10° - 12°N</td>
<td>8</td>
<td>12</td>
<td>19</td>
<td>25</td>
<td>20</td>
<td>9</td>
<td>2</td>
<td>1368</td>
</tr>
<tr>
<td>08° - 10°N</td>
<td>9</td>
<td>12</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>10</td>
<td>3</td>
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</tr>
<tr>
<td>06° - 08°N</td>
<td>11</td>
<td>16</td>
<td>12</td>
<td>10</td>
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<td>5</td>
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<td>04° - 06°N</td>
<td>16</td>
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<td>9</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>1810</td>
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Source: Nicholson et al. 2000

1.2 Main characteristics of the climate in WCA

The WCA region has wet and dry seasons resulting from the interaction of two migrating air masses. The first is the hot, dry, tropical continental air mass of the northern high pressure system, which gives rise to the dry, dusty, Harmattan winds that blow from the Sahara over most of West Africa from November to March. The maximum southern extension of this air mass occurs in January between latitudes 5° and 7° N (Figure 5). The second is the monsoon tropical maritime, which produces southwest winds. The maximum northern penetration of this wet air mass is in July between latitudes 18° and 21° N. Where these two air masses meet is a belt of variable width and stability called the Intertropical Convergence Zone (ITCZ). The north and south migration of this ITCZ, controls the climate of the region.

In the semi-arid and sub-humid zones, the wet season generally begins in April with the gradual development of south-westerly winds associated with moisture coming in from the Atlantic. The monsoon is characterised by bands of precipitation that originate in the Gulf of
Guinea and then extend northward. In the high atmosphere, WCA climate is characterised by the occurrence of two rapid winds, the African Easterly Jet (at 600 hPa) and the Tropical Easterly Jet (at 200 hPa). Climatology is nevertheless subject to a very high degree of spatial and temporal variability (Lebel et al., 2000), particularly because of the modulation of the seasonal cycle linked to the position and intensity of the ITCZ as well as the distribution and magnitude of rainfall due to squall lines (Leroux, 2000). Consequently, the seasonal characteristics of monsoon rainfall (i.e., onset, length, and cessation of the rainy season), seasonal rainfall amount, and intra-seasonal rainfall distribution during the rainy season show high interannual variability (Fontaine and Janicot, 1996; Le Barbé et al., 2002). A comprehensive investigation of the features of the West African monsoon is necessary to fully understand and predict the seasonal, interannual, and interdecadal variability, anomalies, and drought in WCA.
The lowland climates of WCA are characterised by uniformly high sunshine, particularly the semi-arid and arid zone (2500 - 3000 hours of total annual sunshine duration) and high temperatures throughout the year; mean annual temperatures are usually above 18°C. Areas within 10° north and south of the equator have a mean annual temperature of about 26°C with a range of 1.7 – 2.8°C; the diurnal range is 5.5 – 8.5°C. Between latitudes 10°N and the southern part of the Sahara, mean monthly temperatures can rise up to 30°C, but the annual range is 9°C and diurnal range 14 - 17°C.
2. **Possible causes and measurement of climate variability and change in West and Central Africa**

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### 2.1 Main features of rainfall variability

Variability has been recorded in the climate of West Africa over the last century. The 1930-1960 wet period, the 1970-1980 droughts and the return of rainfall in the 1990s and 2000s illustrate this clearly, along with the subsequent vulnerability of the population particularly in the Sahel zone. Many studies have shown that the average precipitation in WCA underwent major fluctuations in the 20th century. During the 1950s, the precipitation was well above the long-term mean for 1901–1998; from 1960 to 1990 the precipitation regime changed from wet to dry (Nicholson, 1993; Nicholson, 1996; Nicholson and Selato, 2000). According to Le Barbé and Lebel (1997), the precipitation deficit during the dry periods in WCA has essentially been due to a deficit in the number of rainfall events in the heart of the rainy season. Overall, the rainfall for the period 1961–1990 was 30% less than that for 1931–1960 (Hulme, 1992).

The mean decrease in rainfall is about 15 to 30% in the Sahelian zone and 15% in the forest zone. Rainfall deficits in the semi-arid zone were especially large in 1972, 1973, 1983, 1984, 1987, 1990, 1997 and 2004. The 1980s have been declared the driest years in the 20th century, though an increasing trend in precipitation has been observed over the past 15 years (Nicholson and Selato, 2000). Indeed, more recent studies do suggest a return to a closer-to-normal regime in the region since the early 1990s, with precipitation being above the long-term period of 1901–1998 (Nicholson and Selato, 2000). The high degree of inter-annual and spatial variability in precipitation in the Sahel has resulted in some catastrophic famines especially because of repeated droughts (Mohamed et al., 2002). Droughts have caused wide-ranging socio-economic implications for food production, human welfare and political stability (Benson and Clay, 1998).

### 2.2 Possible causes of climate variability

Rainfall over WCA is controlled by global climate teleconnections and regional climate systems, which include Inter-Tropical Discontinuity (ITD), monsoons, subtropical anticyclones, Sea Surface Temperature (SST) anomalies, atmospheric winds, the jet streams, etc. (Folland et al., 1986; Lamb and Peppler, 1992; Vizy and Cook, 2001; Rowell, 2003). The global teleconnections include those associated with El Niño-Southern Oscillation (ENSO), and the North Atlantic Oscillation (NAO). The rainfall patterns of many parts of Africa respond significantly to different phases of the ENSO cycle forcings.

Over West Africa, El-Niño events tend to result in enhanced north-easterlies/reduced monsoon flow, coupled with weakened upper easterlies, and hence dry conditions (Janicot et al., 2001) close to the surface position of the ITCZ, in July - September as well as January - March. A strengthening of the African Easterly Jet (AEJ) or northerly wind anomalies across the Sahara, are shown to be related to drought conditions in the Sahel (July-September) and
Gulf of Guinea area (January-March), once the remote effects of SST anomalies are removed. In general, the wet years in the Sahel tend to be characterised by a pattern of SSTs in which the tropical Atlantic is anomalously warm, compared to dry years, while anomalously cold SSTs prevail in the west of the continent. In the dry years, the AEJ is generally stronger than in the wet years and is displaced towards the equator, while the Tropical Easterly Jet (TEJ) is unusually weak (Nicholson, 2001).

The ocean basin’s warm SST anomalies are major sources of heat energy and moisture which drive the atmosphere and entire climate system of the globe. Studies by Fink et al., (2006) showed that the changes in latent heat release over the West African monsoon region have great impact on the large scale tropical circulation. An earlier study by Palmer (1985) showed that enhanced latent heat release in the central equatorial Pacific Ocean excites the atmospheric Kelvin wave which can propagate across the Atlantic and Africa without complete dissipation, raising equatorial upper-troposphere temperature and geopotentials, generating anomalous westerlies associated with widespread rainfall over Africa. A climate diagnostic study by Njau (2010) showed that upper troposphere thermal regimes are associated with rainfall anomalies such as floods and droughts and confirmed that temperature is the most important parameter in a moist troposphere as it controls the geopotentials, determines the wind field/circulations, cloud development, amount of latent heat release and the entire atmospheric stability that generates spatial and temporal rainfall anomalies over the entire globe.

Drought comes along with a fundamental change of the global SST pattern (Nicholson, 2001; Giannini et al., 2003; Paeth and Hense, 2004). It is also induced by a more direct anthropogenic impact in the form of land use changes, affecting vegetation cover (Clark et al., 2001; Semazzi and Song, 2001), surface albedo and soil moisture (Douville and Chauvin, 2000; Douville, 2002). Nicholson (2001) and Zeng et al. (1999) suggest that rainfall anomalies over sub-Saharan West Africa are primarily triggered by SST changes and are secondarily enhanced in amplitude and period by local feedbacks with vegetation, surface albedo and soil moisture.

Some authors suggest that the impacts of changes in land use and especially deforestation may be among the factors explaining the recurrence of severe droughts in the Sahel (Charney et al., 1975; Xue and Shukla, 1993; Xue, 1997; Zheng and Eltahir, 1998). The process of desertification caused basically by wind erosion and dust transport, also contributes to the degradation of soils in the region (McLeod, 1976). However, some recent remote-sensing studies have shown a trend toward reforestation (Brooks, 2004), along with an increase in precipitation over the past decade. Despite the many factors put forward to explain the changes in precipitation conditions, the dynamics and the variability of the monsoon are highly complex and difficult to understand, particularly because of the nature of the combined interactions between the various spatial and temporal scales (Redelsperger et al., 2002).

2.3 **Methodology for studying climate variability and change**

2.3.1 **Climatic indices used for characterising climate variability and extreme events**

In order to characterise climate variability and change, numerous climate indices are derived from daily precipitation:
(i) **Rainfall index**

Rainfall indices are chosen from among those most commonly used to study variability and changes in precipitation regimes. These indices characterise frequency, intensity, and duration of rainfall amount:

- mean climatology (the mean seasonal conditions) based on the cumulative total precipitation;
- extremes by calculating the 90\(^{th}\) percentile and the occurrence of this extreme;
- duration of dry periods by calculating the frequency of consecutive dry days;
- intensity of precipitation in raindays.

(ii) **Temperature index**

The main temperature indices are expressed by:

- Increase in minimum temperature rate (Tn) for a given long-term data set
- Increase in maximum temperature rate (Tx) for a given long-term data set.
- TN10p : cool night frequency percentage of days when Tn < 10\(^{th}\) percentile of 1961–1990
- TX10p : cool day frequency percentage of days when Tx < 10\(^{th}\) percentile of 1961–1990
- TN90p : hot night frequency percentage of days when Tn > 90\(^{th}\) percentile of 1961–1990
- TX90p : hot day frequency percentage of days when Tx > 90\(^{th}\) percentile of 1961–1990.

### 2.3.2 Potential evapotranspiration (PET)

One of the most important components of the water budget is Potential Evapotranspiration (PET). The process refers to the removal of water from land or water surfaces by direct evaporation and plant transpiration. It depends on temperature, radiation, wind speed, and relative humidity. In WCA, therefore, PET is strongly related to the position of the ITCZ. Potential evapotranspiration rates may exceed on average from 3 mm to more than 10 mm per day according to the season and the latitude. Thus, most of the rainwater is returned to the atmosphere locally by PET. Despite the importance of PET in the WCA water budget, knowledge of PET rates is, at present, only semi-quantitative. Recent advances in instrumentation and measurement techniques have made it possible to compute PET continuously so that an accurate evaluation of PET rates in the WCA can be made.

Several formulae are used to estimate PET. The Penman-Monteith equation has been shown to provide an accurate estimate of PET (Allen et al., 1998). Other models are proposed by Hargreaves (Hargreaves and Allen 2003); Priestley and Taylor (1972); Turc (1961), and Doorenbos and Pruitt (1977). Weather, climatic parameters, crop characteristics, management and environmental aspects are all factors affecting PET. The unavailability of daily data for minimal and maximal temperature, relative humidity, wind speed, and radiation are major constraints in running PET using the available software. An additional problem in West Africa is that there are only a few stations where PET is determined. Because of this lack of data, evapotranspiration is often calculated from other climatic parameters like temperature, relative humidity, wind speed and radiation.
2.3.3 Agro climatic parameter indices used for characterising climate variability

Onset of rainy season

The onset (start of rainy season), cessation, Length of Growing Period (LGP), and dry spell are the major rainy season parameters. Several studies have adopted different definitions for the onset and end of the rainy season (Stern et al., 1982, Sivakumar 1988, Morel, 1992, Traoré et al., 2000, Diallo, 2001). The onset of rainy season, by most agroclimatological definitions (Stern et al., 1982) requires as precondition, a certain amount of rainfall over a number of days, complemented by that of a maximum number of dry days within a period of time, following the potential start. In northern Australia, Nicholls (1984) defined “onset” as the date on which 15% of the mean annual rainfall, at a given station, has occurred.

For West Africa, Dodd and Jolliffe (2001) considered the onset of rainy season to be the first period of 5 consecutive days in which at least 25 mm of rain falls, on the condition that no dry period (7 days or more) occurs over the following 30 days. For the same region, Omotosho et al. (2000) proposed that the onset of the rainy season is the beginning of the first two rains totalling 20 mm or more within 7 days, followed by 2–3 weeks, each with at least 50% of the local crop water requirement.

At the regional AGRHYMET centre (Centre Régional Agro-Hydro-Météorologie), two models, based on slightly different methods, are used to determine the start of the season. The first method, based on soil water balance simulation, is implemented using the Diagnostic Hydrique des Cultures (DHC) model (Girard et al. 1994, Bourneuf et al. 1996). This model uses the daily rainfall data from the regular network of Comité permanent Inter-Etats de lutte contre la sécheresse dans le Sahel (CILSS) member countries. It also uses rainfall estimates from METEOSAT infrared images, the average dekadal values of PET and the soil water holding capacity. The starting date of the rainy season is defined as the day after the 1st of April, when available moisture in the soil top layer (15 cm) exceeds 10 mm and the crop water requirements are satisfied at more than 50% during the following 20 days (Samba, 1998). The second method, implemented with the Zones A Risque (ZAR) model, determines the start of the season based on a rainfall threshold of 20 mm followed by a dry spell of no more than 20 days over the next 30 days. METEOSAT derived rainfall estimates (AGRHYMET, 2002). In addition, the ZAR model gives areas of “failed sowings”, the potential duration of the season based on a fixed average ending date and other information related to the starting date.

Cessation date

According to Sivakumar et al. (1993), the end of the rainy season corresponds to the date after 15th August, when the soil - able to hold 60 mm of available water - is completely depleted, assuming a daily evaporation rate of 5 mm. The date after 1st September, following which no rain occurs for a period of 20 days is also designated as the end of season. According to Traoré et al., (2000), the end of the rainy season occurs after 1st September when a soil - able to hold 80 mm of available water - is depleted up to 4.5 mm, corresponding to 90% of a daily evaporation rate of 5 mm. All these criteria are particularly adapted to the semi-arid zone.
As with the start of the season, the DHC model is used to monitor the crop water requirement status throughout the season. Once a successful planting date is determined for a given location, the potential crop cycle, the duration of the main four growth stages (initial, development, full vegetation and maturation) and the crop water requirements for every 10-day period are determined by assuming a fixed ending date. This ending date is normally the average date after the 1st of September on which available soil moisture in the one meter layer is irreversibly depleted to less than 10% of the soil water holding capacity (Bourneuf et al., 1996). Crop water requirements are determined using the relationship between latitude and the three characteristic values of the crop coefficients derived from measurements on different sites throughout the Sahel (Freteaud et al. 1984).

FAO studies have shown that the Water Requirement Satisfaction Index (WRSI) can be related to crop production using a linear yield-reduction function, which is specific to a crop (FAO, 1977; FAO, 1979; FAO, 1986). Verdin and Klaver (2002) and Senay and Verdin (2003) demonstrated a regional implementation of WRSI in a grid cell based modelling environment. WRSI for a season is based on the water supply and demand that a crop experiences during growing season. It is calculated as the ratio of seasonal actual evapotranspiration (ETa) to the seasonal crop water requirement (WR):

\[
\text{WRSI} = \frac{\text{ETa}}{\text{WR}} \times 100
\]

- WR is calculated from the FAO Penman-Monteith reference evapotranspiration (ETo) using the LSP-based crop coefficient (Kcp) to adjust for the growth stage and land cover condition.
  \[
  \text{WR} = \text{ETo} \times \text{Kcp}
  \]
- ETa represents the actual (as opposed to the potential) amount of water withdrawn from the soil water reservoir (“bucket”).
- The WRSI (Cur WRSI for current WRSI) value for a given pixel represents the season-integrated condition from the start of the growing season until the current modelling period. It is based on the actual estimates of meteorological data to-date. For example, if the cumulative crop water requirement up to this period was 200 mm and only 180 mm was supplied in the form of rainfall, the crop experienced a deficit of 20 mm during the period and thus the WRSI value will be \((180 \div 200) \times 100 = 90\%\).

**Length of the growing season (LGP)**

The length of the growing season is the difference between the end of season and the onset (Stern et al., 2009). According to FAO (1978) the length of the “growing season” or “growing period” (LGS or LGP), is the period (in days) during a year when precipitation exceeds half the PET. A period required to evaportranspire an assumed 100 mm of water from excess precipitation stored in the soil profile is sometimes added. Length of the growing period (LGP) is useful in determining crop cycle lengths and calendars under average conditions.
The calculation of the growing period is based on a simple water balance model, comparing water availability with crop water demand (precipitation with PET), using monthly values.

### 2.3.4 Statistical analysis of climate variability and change

The common statistics used correspond mainly to the mean annual rainfall (or temperature, PET) for multi-year periods at select stations, calculation of the standard deviation, coefficient of variation, and Lamb rainfall index. Time series of Lamb’s rainfall index units indicate anomaly classes: +3, +2, +1 corresponding to extraordinarily wet, very wet and wet years. Zero (0) corresponds to normal conditions while -1, -2 and -3 correspond to relatively dry, very dry, and severe drought condition, respectively. Average decade rainfall anomalies for the 1950s, 1960s, 1970s, 1980s and 1990s, etc., are also used. It can be expressed per individual station or a regional average.

To estimate the trends in the time series, we can apply non-parametric tests: Kendall’s Tau (Kendall, 1975) by calculating the probability of the existence of a trend at the 5% significance level and Sen’s slope estimator (Sen, 1968) to quantify the monotonous trend when detected as being statistically significant at the 95% level.
3 Analysis of past to present and future climate variability

3.1 Present variability of rainfall

The relatively dry conditions early in the 20th century are apparent in most of the time series (Figure 6). Relatively good conditions in terms of rainfall returned during the 1920s and 1930s, followed by widespread drought in the 1940s. The 1950s was probably the wettest period for all of West Africa (Figure 6), during which sub-normal rainfall patterns prevailed in the equatorial regions. In the early 1960s, another dramatic shift occurred in the spatial pattern, which was roughly the inverse of the situation in the 1950s, with lower rainfall in the subtropical latitudes and reduced rainfall in the low latitudes. By the 1970s, increased aridity was widespread, especially in the early years (Nicholson 1994). By the 1980s, rainfall was below the long-term mean, a trend that continued into the 1990s (Figure 6).

Figure 6. Rainfall index fluctuations 1901 to 1995 expressed as a regionally averaged standard deviation (departure from the long-term mean divided by the standard deviation) for five agroecological zones in West Africa

The magnitude of rainfall anomalies for the 1970s and 1980s is indicated in Table 2, which expresses regional average rainfall in the different agroecological zones of WCA. The rainfall was about half a standard deviation (SD) below the long-term mean in the 1970s, but reached approximately 0.8 SD in the 1980s. The change in the humid Guinean regions was more moderate but was also greater in the 1980s.
Table 2. Rainfall anomalies for the decades 1970–79 and 1980–89, expressed as a percent departure from the long-term mean (1901-1991) and as a standardised departure (ratio of the departure from mean to the standard departure; $\sigma$: standard deviation)

<table>
<thead>
<tr>
<th></th>
<th>1970-79</th>
<th>1980-89</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>% $\sigma$</td>
</tr>
<tr>
<td>Sahelo – Sahara</td>
<td>-31</td>
<td>-47</td>
</tr>
<tr>
<td>Sahel</td>
<td>-22</td>
<td>-55</td>
</tr>
<tr>
<td>Soudan</td>
<td>-13</td>
<td>-53</td>
</tr>
<tr>
<td>Soudano–Guinea Zone</td>
<td>-5</td>
<td>-36</td>
</tr>
<tr>
<td>Guinea Coast</td>
<td>-6</td>
<td>-31</td>
</tr>
</tbody>
</table>

The average rainfall deficit of the 1970s and 1980s with respect to the 1950s and 1960s was more than 20% and 30%, respectively, in the northern part of WCA (Figure 7).

Figure 8 shows the most significant climatic change that has occurred in the semi-arid regions of West Africa, particularly since the 1980s. There was a general decrease in seasonal July, August, September rainfall during 1950-1999 in the order of 150-200 mm. In the semi-arid zone, the most seriously affected region, 30-year means have decreased by 20% to 40% between the periods 1931–60 and 1968–97 (see also Gachon et al. (2007)).

Figure 8. Observed seasonal rainfall trends during 1950 - 1999 for all available stations within the northern and southern African monsoon index regions. Station locations indicated by circles, with dry /wet trends denoted by red /blue respectively, and the intensity of trends indicated by a circle’s size. (Source: Hoerling et al., 2006); JAS: July, August, September
This trend has taken the form of a 150 kilometre downward slide in isohyets towards the south for example in Burkina Faso (Figure 9) and in the Sahel, in general (Diouf et al., 2000). The spatial shift of rainfall is however moderate in humid zones for example in the case of Cote d’Ivoire (Figure 10).

Figure 9. Mean rainfall for the period 1951-1980 and 1971-2000 in Burkina Faso (semi-arid to sub-humid dry)
The WCA region, particularly the semi-arid zone, is one of the areas in the world that has had significant climate anomalies in the past century. The dramatic change from wet conditions in the 1950s to much drier conditions in the 1970s and 1980s represents one of the strongest inter decadal signals on the planet in the 20th century (Redelsperger et al., 2006). The drought in this area since the late 1970s has been the most severe and longest on a continental scale in the world during that century (IPCC 2007). Over the Sahel region, rainfall decrease was about 0.8 to 1 mm per day in July – August (Figure 11) according to Hulme (1992b).

Figure 10. Mean rainfall for the period 1951-1980 and 1971-2000 in Cote d’Ivoire (sub-humid dry to humid)
Source - Météorologie Nationale de Côte d’Ivoire

Figure 11. Changes in July – August (JA) total rainfall (mm day\(^{-1}\)), 1967-1998 minus 1948 – 1966. Constructed and supplied by Dr. Mike Hulme at the Climatic Research Unit, Univ. of East Anglia, Norwich, UK.)
The dry period is shown by the Sahelian rainfall index. The reduction is extremely clear in the Sahel with highly deficit periods in 1972-73, 1982-84. Rapid shifts from wet to dry years and vice versa have been recorded during the last two decades in the Sahel region (Figure 12). Since the mid-1990s (Figure 12), a return to better rainfall conditions has been noted (Ali et al., 2008) mostly in the eastern part of Sahel (Figure 13B).

Figure 12. Evolution of the Sahelian rainfall index from 1950-2005
(Source: Ali et al. 2008; AGRHYMET Regional Center, 2010)
A review of the precipitation indices (Figure 14) shows that the decrease in the total cumulative precipitation (PTOT) is attributable chiefly to a decrease in the percentage of rain days (Prcp1) and a tiny increase of dry spell (CDD). Smaller portion of the decline in total precipitation can be attributed to decreases in the precipitation intensity index (SDII). Figure 14 also shows the decrease in the indices for precipitation extremes Prec90p, R3days and R90N. Ultimately, the decreases in precipitation and in intra-seasonal variability (STD) are mainly the result of the statistically significant decrease in the occurrence of rain days. The negative trend for total precipitation is less generalised for the period 1961-2000 than for the 30-year period analysed previously. The decrease in the number of rain days is also smaller. Some climate indices show a positive trend Prec90p and R90N for the period 1961-2000.
Figure 14. Percentages of stations showing statistically significant trends (at the 95% level, with Sen’s slope ≠ 0) for each precipitation index calculated from April to October for the periods: 1961–1990 for the 244 stations available and 1961–2000 for the 76 stations available (from Gachon et al., 2007). **Precp1**: number of days with precipitation ≥ 1 (mm %); **SDII**: mean intensity of precipitation on rain days (precipitation ≥ 1mm) (mm/day); **CDD**: Maximum number of consecutive dry days (precipitation < 1mm) (days); **R3d**: Maximum three-day precipitation (mm); **Prec90p**: 90th percentile of rain day amounts (mm/day); **R90N**: Number of days with precipitation exceeding the 90th percentile with respect to the reference period 1961–1990 (%); **PTOT**: Total precipitation (monthly or seasonal total) (mm); **STD**: Standard deviation (monthly or seasonal, mm/day)

3.2 Present situation of floods

From 1966 to the early 1980s, the number of floods in West Africa was less than two per year. From 1995 onwards, the river and dam flow increased markedly, ranging between 6 and 18 per year (Figure 15). In 2007, 2008 and 2009, floods in West Africa caused severe destruction to infrastructure in addition to large losses to a number of important crops. In
Benin a total of 25,000 hectares of food crops were destroyed in 2008 in addition to 1,204 ha of cotton fields with a total estimated loss of 9.4 billion F CFA. In Burkina Faso, a total of 9,300 ha of cultivated fields were destroyed in 2009.

![Figure 15. Annual number of floods in West Africa 1966 to 2008 (Source: IFCR, 2009)](image)

3.3 Projected rainfall and drought

In general, rainfall projections remain uncertain for WCA. Global Circulation Models (GCM) provide poorly simulated rainfall. Figure 16 shows that the possible 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). However, no conclusions can be drawn regarding rainfall in West Africa. The Sahelian coastline in general, is likely to experience a decrease in precipitation by around -15% to -20% over this century (IPCC, 2007).
Most of the countries in WCA have submitted their Initial National Communications to the United Nations Framework Convention on Climate Change (UNFCCC). These reports present the precipitation and temperature scenario according to the GCM output provided by the IPCC. An example of projected rainfall for 2100 in Sierra Leone is shown in Figure 17. The projections indicate that monthly rainfall values by 2100 under the ECHAM4 and HADCM2 models are similar to current climate rainfall values (1916 - 1990). However, the CSIRO-TR and UKTR models show a decrease in rainfall by about 3% below current monthly rainfall values (Figure 17).
Figure 17. Projected mean monthly rainfall for Sierra Leone from 5 climate models (HadCM3, UKTR, CSIRO-TR, ECHAM4, UKMOEQ); (after the First National Communication to UNFCC, Sierra Leone)

Figure 18 shows that Senegal, Mauritania, Guinea Bissau and Guinea Conakry in West Africa and large parts of Congo and Gabon in Central Africa will experience drought condition in a 2000-2090 projection. In the other parts of WCA, normal wet conditions will be experienced.

Figure 18. Palmer drought index severity projection 2000 to 2090, scenario A2 (from, UKmet Office, 2006: http://www.metoffice.gov.uk/climate/uk/2006/)
3.4 Present trend and variability of the temperature

Temperature is another climate variable in West Africa where particularly the Sahel Saharan, Sahel and Sudanese temperatures have been increasing faster than the global average. The increase has varied between 0.2 and 0.8°C since the end of the 1970s. This trend is stronger in terms of minimum rather than maximum temperatures (Figure 19). In the case of Togo, the mean annual temperature increase was between 0.5°C and 1.1°C from 1961-1985 and 1986-2006 (Table 3).

Figure 19. Minimum and maximum temperature trends in the Sahel-Saharan, Sahel and Sudanese zones in the CILSS countries (from CEDEAO/Club Sahel: OCDE/CILSS, 2008)
Table 3. Mean temperature variation for the period 1961-1985 and 1986-2006 in Togo (from Direction de la Météorologie Nationale Togo, 2007 in First National Communication to UNFCC, Togo)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lome</td>
<td>26.8</td>
<td>27.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Atakpame</td>
<td>25.8</td>
<td>26.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Sokode</td>
<td>26.2</td>
<td>26.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Mango</td>
<td>27.9</td>
<td>29.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

3.5 Future trend and variability of temperature

Climate models are relatively useful when it comes to forecasting temperature changes in Africa. The Inter governmental Panel on Climate Change IPCC (2007) noted that in the 21st 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 the global level (Figure 20). The increase would be less marked in coastal and equatorial areas (+3°C). The highest increase would take place in the western Saharan region (+4°C).

Figure 20. Temperature projection, 2080-2099 compared to 1980-1999
3.6 Variability of potential evapotranspiration (PET)

Table 4 presents the PET (mm/day) calculated using the Penman method. In large parts of WCA, PET is low during the wet season because of the prevailing rains and associated high humidity and cloudiness. In the dry season when the ITCZ is at its southernmost position, the PET remains relatively low in the coastal region. In the semi-arid zone, however, it increases sharply by around 7 - 8 mm per day (Table 4). Potential evapotranspiration (PET) changes during the dry season are associated with high radiation and wind speed.

Table 4. Mean PET (mm per day) during dry and wet seasons in WCA.

<table>
<thead>
<tr>
<th>Agroecological zones</th>
<th>Dry season</th>
<th>Wet season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-arid</td>
<td>8.5 - 6.5</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Sub-humid dry/Sub-humid</td>
<td>7 - 6.5</td>
<td>4 - 3</td>
</tr>
<tr>
<td>Humid /Forest coastal zone</td>
<td>4 - 4.8</td>
<td>3 - 3.5</td>
</tr>
</tbody>
</table>

Sources: IMWI, 2000; FAO, 1998; Sarr, 2003

PET will be affected by climate change. Coulibaly (2007) reported that over the Senegal River Valley +1.5°C mean air temperature changes correspond to a 10% increase in PET. Mean annual PET is in the order of 2000 - 2500 mm per year in the semi-arid zones. It is lower (1200 – 1500 mm) in the humid zone (Figure 21).

Figure 21. Mean annual potential evapotranspiration (PET) in mm (Source: IWMI, 2000)
3.7 Present trend and variability in the onset, cessation and length of growing season

Present variability in the onset and cessation date
In WCA, agricultural production is very vulnerable to variations in the seasonal rainfall onset, cessation and length of growing period, particularly the inter annual variability of onset which is greater than that of cessation dates. Many studies have been done to assess the present and future trend and variability of these parameters in the context of variability and climate change. According to Camberlin and Diop (2003), the cessation date over the 1950 – 1992 period in Senegal shows a significant trend towards earlier dates, with an abrupt shift occurring around 1970. There is also a trend for delayed onset of the rains. For the period between 1950 and 1992, common trends artificially increase correlation coefficients (especially between cessation dates and total rainfall), but for the dry decades between 1970 and 1992, the correlations are much lower for both the cessation dates and the duration. However, from Table 5 it is evident that the correlation between the onset, cessation, duration and total rainfall amounts is not always as high as expected.

Table 5. Correlation coefficients between the inter annual variations of various parameters of the rainy season in Senegal (Source: Camberlin and Diop, 2003).

<table>
<thead>
<tr>
<th></th>
<th>Cessation</th>
<th>Duration</th>
<th>Annual total rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1950 -1992</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset</td>
<td>-0,16</td>
<td>-0,85</td>
<td>-0,40</td>
</tr>
<tr>
<td>Cessation</td>
<td>0,66</td>
<td></td>
<td>0,63</td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td></td>
<td>0,65</td>
</tr>
<tr>
<td><strong>1970 – 1992</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset</td>
<td>-0,08</td>
<td>-0,90</td>
<td>-0,51</td>
</tr>
<tr>
<td>Cessation</td>
<td>0,51</td>
<td></td>
<td>0,17</td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td></td>
<td>0,52</td>
</tr>
</tbody>
</table>

Analyses of onset and cessation date variability in Nigeria reveal late onset of rains in a few places during the period 1941-1970 (Anuforom, 2009). However from the dry period 1971-2000 late onset of rains is now spreading to many parts of the country (Figure 22).
Prior to 1970, early cessation date of rains is noted in a few parts of Nigeria. During the last three decades (1971 – 2000) early cessation of rains affected many parts of Nigeria, particularly the west, east and north east of the country (Figure 23).

In Cote d’Ivoire (sub-humid to humid zone), studies conducted by Guehi Goroza (not dated) showed similar trends as in Nigeria. The late onset of rains was recorded during the period 1971-2000 in the northern, central and southern parts of the country (Figure 24). However, the cessation dates in Cote d’Ivoire seem to remain comparable over the two periods (not shown).
Figure 24. Mean onset date for the decades 1951-1980 (left) and 1971-2000 (right) in Cote d’Ivoire (sub-humid dry to humid agroecological zone): Source - Météorologie Nationale de Côte d’Ivoire

Present Length of growing period

To identify geographic areas where climate change and subsequent impacts on crop and livestock may be relatively large, the length of growing period (LGP) is a useful indicator. It is crop-independent and is an effective integrator of changes in rainfall amounts and patterns, and temperatures (Thornton et al., 2006). In Cote d’Ivoire, contraction in growing seasons was observed in many parts, particularly in the central and southern zone during the period 1971-2000 (Figure 25).

Figure 25. Mean length of growing season variation during the period 1951-1980 (left) and 1971-2000 (right) in Cote d’Ivoire (sub-humid dry to humid agroecological zone): Source - Météorologie Nationale de Côte d’Ivoire
Over the Sahelian region, results show spatial heterogeneity of response in LGP to climate variability and change. The eastern part of the Sahel (Chad) experienced expansion in the growing season, while many other areas particularly in the Western Sahel (Senegal, Guinea Bissau, Mali) recorded shortening of LGP (Figure 26). The trend in prolongation of LGP in the eastern part of the Sahel is linked to better rainfall conditions during the mid-1990s (Ali, 2008). From the Normalized Difference Vegetation index (NDVI), data derived from NOAA-AVHRR satellite over the period 1982-1999, a recent greening over the Sahel region has been observed (Olson, 2005).

Figure 26. Change in the length of growing season (LGP) (1990/1999) over the Sahelian region (Source: ECOWAS-SWAC/OECD, 2008, Atlas on regional integration)

3.8 Future trend of the length of the rainy season

A number of countries in WCA already face semi-arid conditions that make agriculture challenging. Climate change is likely to reduce the length of growing season and force large regions of marginal agriculture out of production. Climate change could adversely affect mixed rain-fed and semi-arid systems, particularly the LGP, e.g. on the margins of the Sahel. Depending on the emissions scenario and climate model used, up to 25% of Africa’s landmass (particularly the semi-arid zone of WCA) may suffer reductions in LGP of 20% or more by 2050 (Figure 27). Currently nearly 280 million people live in these areas and are likely to be impacted by these changes (Thornton et al., 2006).
Figure 27. Agricultural areas within the livestock-only systems (LGA: yellow colour) in arid and semi-arid areas, and rain-fed mixed crop/livestock systems (MRA: green colour) in semi-arid areas, are projected by the HadCM3 GCM to undergo >20% reduction in length of growing period to 2050, SRES A1 (left) and B1 (right) emissions scenarios (Thornton et al. 2006).
4 Capacity for weather and climate monitoring and analysis

4.1 National Meteorological Network

All of the countries in WCA have National Meteorological Services (NMS). However, there is wide variation in the number of stations per unit area and the quality of data. In the French speaking countries of West Africa, daily rain data have been regularly collected by the NMS and delivered to a database built by the Centre Inter- Etats d’Etudes Hydrauliques (CIEH) and the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM, present IRD). The CIEH–ORSTOM database contains data from 1950 - 1984. This database was updated till 1990, with the assistance of AGRHYMET a specialised institution of the Permanent Interstates Committee for Drought Control in the Sahel (CILSS) for the nine member countries of CILSS (Burkina Faso, Cape Verde, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal and Chad); as well as six other countries (Benin, Cote d’Ivoire, Ghana, Guinea, Nigeria, and Togo) in West Africa. The number of stations has varied in time, a significant increase having occurred at the end of the 1940s. It was only at the beginning of the 1950s that a reasonable density was achieved. Appendix Ia and Ib show the state of available rain gauges and synoptic stations in the CORAF/WECARD member countries.

In general, it can be concluded that there has been a significant number of rain gauges in operation in West Africa, since the mid-century, enough to get a good picture of the spatial pattern of rainfall regimes. However, the corresponding daily observations of such rainfall data are not readily available. It is common practice for most NMSs to charge fees for meteorological data (see the costs in Appendix II). It is therefore recommended to involve the NMS in projects or programmes related to climate. It is also recommended to develop a scientific and technical collaboration between NMSs, NARS, and regional and international research centres in order to facilitate the collection for the consequent availability and accessibility of such data.

4.2 Climate and meteorological database management

Several database management software are used by the NMSs in WCA. CLIMBASE (CLIMate data BASE) is a project of the AGRHYMET Meteorological Centre, in Niamey, Niger, aimed at building and organising a historical climate data collected by ground stations in the CILSS countries. All the CILSS countries have access to associated database management software. Sub-regional institutions specialised in agro hydro meteorology and crop protection such as the AGRHYMET Regional Centre have compiled daily weather observations (rainfall, temperature, relative humidity, wind speed and insolation) collected by NMSs of nine countries (Burkina Faso, Cape Verde, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal) that are members of CILSS. This set of data has already been quality controlled and archived using database management software. For its data access interface, the AGRHYMET Regional Centre chose two software applications for data access and management: CLIDATA, for climate data, and Hydromet, for hydrological data. Discovery, an Oracle application, accesses raw data, and Oracle Enterprise Manager (OEM) tools manage the data. The regional climate observation database contains data from 700 stations that have been geo-referenced (Appendix III). The national AGRHYMET
components provide the regional centre with observed ground data (meteorological, pastoral, hydrological, agricultural statistical, etc).

CLICOM: CLimate COMputing (WMO/NOAA, 1988, Lianso 1994) is a project of the World Meteorological Organization (WMO) aimed at developing a standard computer software package to facilitate the storage, retrieval, statistical analysis, transfer and exchange of climate data in the NMSs. It is used by countries such as Benin, Gambia and Guinea Conakry. In Central Africa most of the countries use Climsoft as meteorological database management system endorsed by WMO. Figure 28 shows the geographical distribution of Clidata and Climsoft by countries.

Figure 28. Geographical distribution of meteorological database management software: Clidata and Climsoft (Source: WMO)

4.3 Human resources

NMSs engage various levels of technicians and engineers in the fields of meteorology and agrometeorology. Generally, most of them have some experience in database management, climate analyses, producing climatic and agroclimatic bulletins for users. There is, however, need for on-the-job training in data management and software engineering, climate variability and change analyses, modelling, and validation of models.

The NMSs, particularly those from CILSS countries and some Anglophone countries have skills and expertise related to climate and agro climatic analyses. They are conversant with many tools and software for agroclimatic analyses. They also use GIS, software for mapping (Surfer, Arcview, Arcgis) estimated rainfall from information provided by satellites.
4.4 Agrometeorological products and capacity building services

Most countries in WCA produce agrometeorological bulletins with contents including: rainfall conditions, sowing dates monitoring, successful sowing dates mapping, assessment and monitoring of the vegetation, using the NDVI, crop water requirement satisfaction index, estimated yield, crop phytosanitary monitoring, areas at risk mapping, etc. NMSs bulletins can be accessed at the following website: www.warmis.org

Several centers of excellence in the field of meteorology and climatology are based in WCA, particularly in West Africa. Some of them such as the AGRHYMET Regional Centre, a specialised institution of CILSS and Ecole Africaine de la Météorologie et de l’Aviation Civile (EAMAC) are Regional Training Centers (RTC) for WMO. AGRHYMET is specialised in training, research, and source of information in agro hydrometeorology while EAMAC is specialised in offering training in meteorology related to air navigation. They are both located in Niamey (Niger). In terms of capacity building of the NMSs, the AGRHYMET Regional Centre has contributed from 1975 to 2010 in training many officers in agrometeorology. Across the training programme AGRHYMET has contributed to strengthening the capacities of the CILSS member countries and others countries in WCA such as Benin, Togo Cote d'Ivoire Guinea, even Cameroon, Gabon and Congo republic in several domains such as: database management, GIS and the mapping of natural resources, climate variability and change analysis, water balance and crop modelling, crop monitoring, early warning system and agrometeorological advices for producers. AGRHYMET/CILSS has the mandate to expand and strengthen the training programme and the agro climatic information system throughout the Economic Community of West Africa States (ECOWAS).

The African Centre of Meteorological Applications for Development (ACMAD) also based in Niger, contributes to strengthening capacities of NMSs in climate monitoring and predictions for short-range (daily/weekly), medium-range (10-Day), long-range (monthly) as well as seasonal timescales. In WCA, ACMAD in collaboration with National Meteorological and Hydrological Services (NMHSs) and partners organise Regional Climate Outlook Forums (RCOFS), for the countries in WCA. The forums apart from releasing seasonal climate consensus forecasts provide a regional interaction platform for climate scientists involved in seasonal climate predictions from the regions and renowned centres worldwide as well as users from various sectors and decision-makers. These stakeholders address issues related to seasonal climate forecasts and associated impacts on various socio-economic sectors such as agriculture, food security, water resources, hydropower generation, health and climate disasters, etc.

Normally a Pre-Forum training workshop is dedicated to capacity building in the development and application of climate prediction tools, models downscaling, forecast verification and preparation of the seasonal climate forecast. The centre conducts on-the-job-training in weather and climate forecasting for seconded staff from NMHSs and has a visiting scientists programme. AGRHYMET in collaboration with Abdou Moumouni University of Niamey and ACMAD conduct a 2-year Higher Diploma Course and 3-year Engineer Course in agrometeorology, hydrology, crop protection as well as a postgraduate MSc. degree programme in sustainable crop and environmental protection. Some universities, especially in Nigeria are also active in training in the fields of climatology, meteorology and agro meteorology.
The German Government is supporting the West African scientific community that deals with the impact of climate change by establishing a Science Service Center on Climate and Adapted Land Use (WASCAL) linked with the scientific community in Germany. Its initial geographical target area is the Guinea Savanna agroecological zone within the riparian countries of the Volta River Basin (Benin, Burkina Faso, Cote d’Ivoire, Ghana, Mali and Togo). The initiative involves the construction of a Competence Center in Ouagadougou to be shared with the Volta Basin Authority. This Competence Center will assist partner countries to collect panel data on climate, hydrology, land use, biodiversity and demography and economic development. In addition WASCAL will formulate a research programme to be jointly implemented by a German and regional research consortium. The Core Research Programme targets the advancement of knowledge on the impact of climate change on West African land resources through the promotion of resilience through adapted land use in order to ensure sustainable development.

Also, as part of WASCAL, a series of graduate schools are being sponsored in the participating countries to address the deficit in human resources in the region in aspects dealing with climate change impact in the region. In this regard, a Masters Research Programme (MRP) in Climate Change and Adapted Land Use is being hosted by the Federal University of Technology, Minna (FUT Minna), Niger State, NIGERIA; while the Kwame Nkrumah University of Science and Technology, Kumasi Ghana is focusing on capacity building at the PhD level. The post graduate programme ultimately aims at strengthening the research, educational and policy capacity and competency of West African countries to deal with issues of climate change through adapted land use on a scientific basis in partnership with German institutions. It is expected that these post graduate fellows upon graduation will be competent for engagement by universities, research institutes, and public service.

4.5 Strengths, weaknesses, opportunities and threats in terms of weather, climate monitoring and analysis in the CORAF/WECARD region

Table 6 presents the strengths, weaknesses, opportunities and threats (SWOT) identified in terms of weather/climate monitoring and analysis. Based on this SWOT approach, a set of recommendations are made.
<table>
<thead>
<tr>
<th>Domain</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorological data</td>
<td>- Existing long-term data particularly rainfall and temperature.</td>
<td>Lack of database management (see NMS). Elements such as radiation, wind speed, etc. are often insufficiently recorded.</td>
<td>Setting up of automatic weather station networks.</td>
<td>Withholding and charging high prices for data.</td>
</tr>
<tr>
<td></td>
<td>- Existing daily observed data compiled using database management (Clicom, Climbase, Climdata, Climsoft, etc.)</td>
<td></td>
<td></td>
<td>Data analysis not regularly done.</td>
</tr>
<tr>
<td></td>
<td>- Rainfall data are regularly observed at the main stations.</td>
<td></td>
<td></td>
<td>Meteorological network degradation.</td>
</tr>
<tr>
<td></td>
<td>- Sufficient number of rain gauges in operation since 1950s.</td>
<td></td>
<td></td>
<td>Inadequacy of manpower.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Political instability and civil wars.</td>
</tr>
<tr>
<td>Human capacity</td>
<td>Engineers and technicians in meteorology, agro meteorology, hydrology.</td>
<td>Lack of expertise for example in the domain of modelling.</td>
<td>Availability of regional training and research centres in climatology, meteorology, applied to agriculture. Existing ongoing training. Long-term training programmes.</td>
<td>Lack of manpower in certain key disciplines.</td>
</tr>
<tr>
<td>Equipment and infrastructure</td>
<td>In most of the countries in WCA a database management system is available.</td>
<td>Inadequate infrastructure and equipment.</td>
<td>Automatic weather stations.</td>
<td>Civil and military war.</td>
</tr>
<tr>
<td>Climatic and agro climatic analyses and monitoring</td>
<td>Some expertise on climate and weather monitoring, uses of several methods, tools/software for several climate analyses. Production of agro meteorological products and services.</td>
<td>Products not regularly improved. Agrometeorological product and services do not really reach the users (farmers).</td>
<td>Technical and scientific assistance from sub-regional, regional and international institutions.</td>
<td>Limited access to meteorological data.</td>
</tr>
</tbody>
</table>
5 Conclusions and recommendations

Numerous studies related to the possible causes of spatial and temporal climate variability particularly involving rainfall have been carried out in West and Central Africa. However, there is still a lot to learn about climate variability in the region. It is therefore recommended to focus research efforts on the relationship between rainfall predictions linked to ocean and wind atmosphere and apply them in building seasonal rainfall forecast model.

Meteorological data is not readily available to the public including researchers. There is an increasing tendency for the unregulated sale of data even among public institutions. Relevant discussions aimed at improving access to data need to be held, involving all major stakeholders. In this regard the regional climate observation database of AGRHYMET Regional Centre containing data from 700 stations is crucial. Appropriate links between CORAF/WECARD and AGRHYMET should facilitate access to the AGRHYMET Regional database particularly for research purposes.

The National Meteorological Services (NMS) in WCA have key roles to play in providing meteorological information for decision-making and for planning adaptation and mitigation strategies. Unfortunately, some of these are relatively weak in terms of human resources. However, NMS can actively provide input (data, climate and agroclimatic analysis) and participate in CORAF/WECARD coordinated programmes. It is therefore necessary to strengthen NMS and NARS (agroclimatology/bioclimatology unit) capacities in areas related to identifying climate risks and generating knowledge and managing climate change risks in agriculture, water resources, forestry, health, etc., modelling, impact study in keys sectors (agriculture, natural resources management, biodiversity). Provision of equipment such as computers, automatic weather station, software/tools etc will go a long way in improving the situation.

In general, there has been some improvement in the capacity of NMS both in terms of equipment and expertise; however, there is still room for improvement. Hence there is a need for national governments to support NMS by providing required funds to acquire adequate and appropriate equipment as well as train personnel at all levels. In this regard, it will be worthy to take advantage of the presence of international initiatives. This will require appropriate national and regional collaboration frameworks. CORAF/WECARD could play a significant role in fostering such collaboration.


Anuforom, A. C. 2009. Climate Change Impacts in Different Agro-ecological Zones of West Africa” Paper presented at the International Workshop on Adaptation to Climate Change in West African Agriculture at Ouagadougou, Burkina Faso from 27 – 30 April 2009


Omotosho J.B., A.A. Balogun and K. Ogunjobi. 2000. Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. Int J Climatol 20:865–880


Appendix

Appendix I. State of meteorological database management at the National Meteorological Service (NMS) in CORAF/WECARD region

<table>
<thead>
<tr>
<th>Country</th>
<th>State of the meteorological database</th>
<th>Available software for database management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benin</td>
<td>Good</td>
<td>Clicom</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>Good</td>
<td>Clidata, Climbase</td>
</tr>
<tr>
<td>Cameroon</td>
<td>Good</td>
<td>Clicom, Climsoft</td>
</tr>
<tr>
<td>Congo RD</td>
<td>NA</td>
<td>Clicom, Dataease, Climbase, Climsoft</td>
</tr>
<tr>
<td>Congo Brazzaville</td>
<td>NA</td>
<td>Climsoft</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>Good</td>
<td>Clicom</td>
</tr>
<tr>
<td>Gabon</td>
<td>NA</td>
<td>Climsoft</td>
</tr>
<tr>
<td>Gambia</td>
<td>Good</td>
<td>Clicom, Climbase</td>
</tr>
<tr>
<td>Ghana</td>
<td>Good</td>
<td>Clicom, Climdata</td>
</tr>
<tr>
<td>Guinea Bissau</td>
<td>Insufficient information</td>
<td>Climbase</td>
</tr>
<tr>
<td>Guinea Conakry</td>
<td>Good</td>
<td>Clicom, Climsoft</td>
</tr>
<tr>
<td>Liberia</td>
<td>NA</td>
<td>Not informed</td>
</tr>
<tr>
<td>Mali</td>
<td>Good</td>
<td>Climbase</td>
</tr>
<tr>
<td>Mauritania</td>
<td>Insufficient information</td>
<td>Climbase</td>
</tr>
<tr>
<td>Niger</td>
<td>Good</td>
<td>Climbase, Clidata</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Good</td>
<td>Clicom</td>
</tr>
<tr>
<td>Senegal</td>
<td>Good</td>
<td>Climbase</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>NA</td>
<td>Insufficient information, Climsoft</td>
</tr>
<tr>
<td>Central Africa Republic</td>
<td>NA</td>
<td>Insufficient information, Climsoft</td>
</tr>
<tr>
<td>Chad</td>
<td>Insufficient information</td>
<td>Climbase</td>
</tr>
<tr>
<td>Togo</td>
<td>Insufficient information</td>
<td>Excel, Clidata (occasionally)</td>
</tr>
</tbody>
</table>

NA – information not available
Appendix Ib. NMS meteorological network in the CORAF/WECARD region

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of synoptic and agroclimatic stations</th>
<th>Number of rain gauge stations</th>
<th>Number approximated of stations with more than 50 years of daily observation</th>
<th>Database manager contact, addresses, mail and web site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benin</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Epiphane D. Ahlonsou; Chédé Félicien: <a href="mailto:chedef@yahoo.fr">chedef@yahoo.fr</a></td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>18</td>
<td>150</td>
<td>65</td>
<td>OUEDRAOGO Kouka Ernest, <a href="mailto:ernest_ok@yahoo.com">ernest_ok@yahoo.com</a>; Web site: <a href="http://www.meteoburkina.bf/index.php">http://www.meteoburkina.bf/index.php</a></td>
</tr>
<tr>
<td>Cameroun</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Elarion Sambou: <a href="mailto:Elarions@gmail.com">Elarions@gmail.com</a></td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>14</td>
<td>183</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Congo</td>
<td>16</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Gambia</td>
<td>10</td>
<td>25</td>
<td>4</td>
<td>Fatou Sima (Agrometeorologist) <a href="mailto:sima_fatou@yahoo.com">sima_fatou@yahoo.com</a></td>
</tr>
<tr>
<td>Ghana</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Guinea Bissau</td>
<td>3</td>
<td>30</td>
<td>Not informed (but a few number due to military conflict)</td>
<td>Cherno Luis Mendes, <a href="mailto:Cherno_lm@yahoo.fr">Cherno_lm@yahoo.fr</a>, Direction Général de la Météorologie Nationale Avenida do Brasil, Cx.P. N°. 75 1038 Cedex-Bissau; <a href="mailto:dgmeteobissau@yahoo.fr">dgmeteobissau@yahoo.fr</a></td>
</tr>
<tr>
<td>Guinea Conakry</td>
<td>12</td>
<td>76</td>
<td>17</td>
<td>Direction Nationale de la Météorologie BP 566 Conakry – Rép. de Guinée</td>
</tr>
<tr>
<td>Liberia</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mali</td>
<td>20</td>
<td>200</td>
<td>40</td>
<td>Samaké Mamadou, (agrometeorologist) <a href="mailto:samakem@yahoo.fr">samakem@yahoo.fr</a></td>
</tr>
<tr>
<td>Mauritania</td>
<td>14</td>
<td>250</td>
<td>13</td>
<td>COULIBALY Hamidou; Website: <a href="http://www.onm.mr">www.onm.mr</a></td>
</tr>
<tr>
<td>Niger</td>
<td>15</td>
<td>178</td>
<td>35</td>
<td>Moussa Mouhaïmouni <a href="mailto:Mouh_moussa@yahoo.fr">Mouh_moussa@yahoo.fr</a></td>
</tr>
<tr>
<td>Nigeria</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Not informed</td>
</tr>
<tr>
<td>Senegal</td>
<td>14</td>
<td>200</td>
<td>60</td>
<td>Ilarion Sambou <a href="mailto:hilarion12@hotmail.com">hilarion12@hotmail.com</a> <a href="http://www.meteo-senegal.net/">www.meteo-senegal.net/</a></td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Chad</td>
<td>16</td>
<td>119</td>
<td>30</td>
<td>M’Baiguedem Miambaye <a href="mailto:gmbaiguedem@yahoo.fr">gmbaiguedem@yahoo.fr</a>, tél : 00 235 66 74 27 42 Namodji Lucie, <a href="mailto:namodji@yahoo.fr">namodji@yahoo.fr</a> ;tél: 00 235 66 74 27 42; web site: <a href="http://www.drem.td">www.drem.td</a></td>
</tr>
<tr>
<td>Togo</td>
<td>12</td>
<td>60</td>
<td>NA</td>
<td>Affo Dogo Abalo: <a href="mailto:affodogoabalo@yahoo.fr">affodogoabalo@yahoo.fr</a></td>
</tr>
</tbody>
</table>
Appendix II. Example of cost of meteorological data

Niger

For daily observation
- Price for project, regional, international institution: 35 000 CFA franc per year /per meteorological station
- This means that for a long time series for example 1961-2010, the global cost is: 1 400 000 CFA franc for one meteorological station
- NGOs: 25 000 CFA franc per year /per meteorological station
- National institution such as NARSs: 20 000 CFA franc per year / per meteorological station

NB: 1 euro = 655.957 CFA  http://www.xe.com/ucc/convert/?Amount=1&From=EUR&To=XOF
Accessed 05.10.12

Senegal

For daily observation
- Price for project, regional, international institution: 365 000 CFA franc per year /per meteorological station
- This means that for a long time series, for example 1961-2010, the global cost is: 14 600 000 CFA franc for one meteorological station
Appendix III. AGRHYMET regional rainfall network

The network includes 700 rain gauges in total from which 300 are used in near-real time for the agricultural campaign monitoring in the CILSS countries, among them 80 are synoptic stations.

Source: AGRHYMET