Assessment and modelling of climate variability and change in Cameroon (central Africa)

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Abstract

Cameroon is located on the west coast of central Africa. It is home to about twenty millions inhabitants relying upon rain-fed agriculture for food security. With the increasing pressure of climate change, other activities for sustainable development such as transport, energy, water, livestock and urban settlement are also facing an increasing threat due to extreme climate and weather events. In some cases today’s climate extremes are expected to become tomorrow’s ‘normal’ weather. This assumption stresses the need of understanding the past, the current and hopefully to project local climate behaviour through variability or change assessment and modelling, thereby enabling stakeholders to plan ahead for modifications that may hamper sustainable development projects.

Recent dynamical modelling and climate variability/change assessments from various authors have indicated an observed warming along with a decrease in the inter-annual variability of precipitation, though some isolated incongruities exist as well. The scarcity of in situ meteorological data, predominantly in terms of long term daily data series, is a hindrance for climate research in this part of the world. High resolution climate change information is provided by the regional climate model system ‘PRECIS’ (Providing REgional Climate for Impacts Studies). But since farm and hydro power plants in Cameroon are of a scale below the regional climate’s model resolution the current study utilizes the techniques of statistical downscaling. This helps to connect the gap between the large scale climate scenarios and the fine scale where observations are made (e.g. at the single site of Douala in Cameroon). We use the Statistical DownScaling Model software (SDSM, version 4.2) provided by the Canadian Climate Change Scenarios Network (CCCSN). It is a tool operating with a blended stochastic weather generator together with the transfer functions. NCEP and HadCM3 GCM predictors (regional independent variables) have been calibrated and are used in multiple regression equations on a month-by-month basis to generate future scenarios.

As a meteorological model reanalysis output, data from NCEP was found to perform the best even though only HadCM3 datasets have allowed the future projections up to 2070. Our results indicate, for example, a cooling amongst the overall warming trend during the month of August. Rainfall scenario shows that the decreasing decadal monthly means are not expected to change much until the 2070s but abnormal years of wet ‘dry season’ and dry ‘wet season’ are expected to be frequent in Douala and adjacent areas.
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Chapter One

1. Introduction

The developing world, including the central African region, is currently faced with the high burden of coping with an economy and society that are climate-dependent. Activities such as energy, water, transport, urban settlement, livestock and food security are vital for sustainable development of developing nations and all of them are facing increasing demands under the increasing pressure from climate change.

A report from GICAM (1969), a French acronym of the ‘Cameroon Business Cartel’ highlights the harmful effect of the prevailing rainfall deficit on the agricultural yield over Cameroon in 1967-1968. It clearly stresses the following issues: “The Arabica coffee season of 1967-68... Unfavourably influenced by the drought from December 1966 to March 1967... produced 4000 tons in West Cameroon (6000 tons in 1966-67) and 8000 tons in East Cameroon (14200 tons in 1966-67). The cotton season of 1967-68 registered a new decrease in production (49085 tons of grain against 55810 in 1966-67 and 57444 in 1965-66 due to the shortest rain season recorded in 24 years... the production of industrial palm oil in East Cameroon decreased from 1523 tons in 1965 to 1426 tons in 1966 and 1384 tons in 1967, and that of palm-nuts from 1126 tons to 1107 tons and 1047 tons respectively, in consequence of a bad distribution of the rains in 1967”.

However climate change is not homogenous over the planet and some geographical areas are more sensitive to global warming than others (IPCC, 2007). Extreme climate and weather events are becoming increasingly important for Cameroon because of the inherent vulnerability of its agricultural system and moreover the associated risk of the impending spread of plant, animal, and human diseases that are highly linked to climate variability and change. Meteorological climate is the “average weather” described in terms of the mean and variability of related quantities over a period of time ranging from months to thousands of years. The standard climate period is 30 years, as defined by the World Meteorological Organization (WMO). The Earth’s climates has always changed to a greater or lesser extent; here we take climate change to be a statistically significant variation in either the mean state of the climate, or in its variability, persisting for an extended period, typically decades or longer (Wilby et al., 2001).
If we accept the premise that climate change is happening, then the implication must be that in some cases today’s climate extremes will be tomorrow’s ‘normal’ weather. Much work is currently being undertaken to assess climate change with general circulation models (GCMs) based on scenarios of the future, in particular on the greenhouse gas emission rates and distributions, thereby driving the greenhouse gas concentrations in the atmosphere of the future, which in turn lead to projected climates when these future atmospheric states are averaged over periods of time. It is essential to understand that scenarios are reliable and logical alternative narratives of the future, but they are neither predictions nor forecasts (Nakicenovic et al., 2000).

From the perspective of Cameroon, as is the case with other nations where activity is heavily climate-dependent, there is an urgent need to model climate variability and change, thereby enabling government and policy makers to plan ahead for changes that might minimize any detrimental effects of climate change on the population. As with many countries on the African continent, in situ meteorological data are scarce – particularly so in terms of time series of observations at long-lived observing sites and this hampers local research. However, without research into the development of the local climate it is strongly believed that an increasing poor and unaware population and their assets will be adversely impacted by future climate extremes and disaster (Climate and Development Knowledge Network, 2012).

1.1 Statement of the problem

Countries of central Africa rely economically upon rain-fed agriculture. Since the 1950s there have been noticeable changes in precipitation and temperature extremes, including a tendency towards more periods of long- or short-term dryness in some areas (Aguilar et al., 2009). In Cameroon agriculture employs (both directly and indirectly) about 80% of the population with an estimated 70% of the population actually employed on farms (CIA World Factbook, 2012). Hydro-electricity generation covers the major energy needs of the country but river flows are becoming increasingly unreliable in many catchments (SighaNkamdjou, et al., 1998). The transport sector, tourism and human health are tightly linked to weather and climate fluctuations so that the main problem of the government, national researchers and planners today is to foresee and to integrate climate change into a policy in each of their development projects.
Major efforts are currently underway to perform more Regional Climate Model (RCM) simulations and to release these results to the scientific community. Such dynamical downscaling is based on numerical simulations of physical atmospheric and oceanic processes and involves the nesting of a higher resolution RCM within a coarser resolution GCM. The regional climate model system ‘PRECIS’ (Providing REgional Climates for Impacts Studies (Johns et al., 1997) was created by the Hadley Centre to help generate high resolution climate change information – the software runs on an ordinary PC under the Linux operating system. It is an excellent technological advance and we do expect this type of technology to become faster and more user-friendly in coming years, enabling smaller teams and even specialists from other fields to perform their own dynamic downscaling of global warming impacts for different periods, scenarios and geographical locations like Douala in Cameroun.

Most of the operations in agriculture and hydro power plants in Cameroon involve spatial scales beyond the regional climate’s model resolution. This, together with considerations of computational expense and time requirements is why RCMs have not been used in this study. Instead, the current study employs the techniques of statistical downscaling.

Statistical downscaling methods are needed to link the gap between the large scale climate scenarios and the fine scale where local impacts occur and observations are made. Statistical downscaling first derives statistical relationships between observed small-scale (in our study observed station) variables and larger (GCM) scale variables, using analogue methods (circulation typing), regression analysis, or neural network methods. Future values of the large-scale variables obtained from GCM projections of future climate are then used to drive the statistical relationships and thereby estimate the smaller-scale details of future climate at the observing station.

For the current study, the Statistical DownScaling Model software, (SDSM; Wilby et al. 2007) will be used for our modelling process. The possible main weakness of this method must not be forgotten, that is the assumption that ‘the statistical relationships developed for the present day climate will also hold for the different forcing conditions in the future climates’ (Fowler et al., 2007). The downscaling will be applied at a single site; in the case of Cameroon it is very difficult to apply on a national scale due to the lack of good quality and quantity of data.
1.2 Objectives of the study

The key objective of the study is to explore and gather together some assessments about climate variability and change over Cameroon in the central African region. This project work will help towards the development of early warning systems and risk assessment in Cameroon and central Africa so as to develop capabilities to mitigate the effects of climate uncertainty. It will help to lessen the lack of preparedness and awareness of local communities and will improve the understanding of the Government and non-governmental organizations (NGOs). For teams with limited computing power and few climate experts, statistical downscaling might be one of the most feasible approaches to obtaining climate data for future impact studies. The results obtained here by using statistical downscaling methods to represent local climate variability may help to advance existing climate/weather monitoring and prediction and their applications in Cameroon. It is hoped that the research findings will contribute to policy formulation, and to the national and international planning strategies for sustainable development of Cameroon and adjacent areas.

This study will be accomplished by addressing the following objectives:

- Summarizing the recent climate trends of Cameroon;
- Performing a one site climate projection using the statistical downscaling model SDSM;
- Investigating some projections of Cameroon’s future climate.
Chapter two

2. Geographical area of the study and its current climate

In this chapter, the geography and current climate of the Cameroon are described.

2.1 Climate regimes

Figure 2.1: (Left) The main meteorological stations in Cameroon (source: Cameroon Met. Department) and (right) the location of Cameroon within central Africa (source: http://www.thecommonwealth.org/YearbookHomeInternal/138354/, the Commonwealth Secretariat website). The colours in the left-hand map show four major climatic divisions: yellow (very hot and dry), blue (cooler and fairly moist), brown (warm and very moist), green (moderate temperature and high evapotranspiration).

Cameroon lies north to south from Lake Chad (13°N) to the Congo evergreen forest (1°45´N) in the form of an elongated triangle, bridging the western and the central Africa regions between longitudes 8°24´E and 16°28´E (see figure 2.1). It covers a total area of 475,442km² with a population of about 20 million (CIA World Factbook, 2012). Yaoundé is
the capital of the country, and Douala is the largest city. Four distinct topographical regions have been identified (Genieux, 1958), namely

- the northern savannah sloping into marshland near Lake Chad,
- the central Adamawa Plateau (1,370m above sea level),
- the southern coastal plain (rain forest) and
- the western high forested mountains of volcanic origin (including Mount Cameroon with a peak at 4095m).

A network of rivers (e.g. Sanaga, Nyong) flows west to the Atlantic Ocean, while others (e.g. Mbere, Logone) link the country to the Niger River system and to Lake Chad.

Figure 2.1 shows that Cameroon has four distinct climate zones.

- The coastal zone (brown in the figure) which is warm and the wettest part of the country with a maximum annual total of 4871mm recorded in 1964 during the period 1960-2003.
- A forested area (green in the figure) which has moderate temperatures but a high evapotranspiration rate. The rainfall totals at the southern end of this region are low with the Ebolowa station recording only 2338mm (in 1970) and 2140.5mm falling at Yokadouma (in 1966) as the maximum annual rainfall totals from 1960 to 2003.
- A cooler but still fairly moist region to the north of the forests (shown in blue) due to the western highlands (that extend from the northern parts of the coastal zone towards a high plateau (Adamawa) at the eastern end of this region) that enhances the rainfall. A maximum annual total of 1813mm was recorded here in 1965 during the period 1960-2003.
- A very hot and drier area in the north of the country (coloured yellow in the figure); the annual rainfall total in the north of this area is very low with a maximum of 1193.8mm (falling in 1994) recorded from 1960 to 2003.

2.2 Principal meteorological factors controlling climate of the Cameroon

Like many other tropical regions, the climate and rainfall in Cameroon results from the intricate interactions of many features such as:
• The Inter-tropical Convergence Zone (ITCZ),
• Monsoon winds,
• Meso-scale systems and squall lines,
• Easterly and westerly waves,
• Sea surface temperatures (SSTs) and
• The El Niño/La Niña Southern Oscillations (ENSO).

**Figure 2.2:** Rainfall variability is linked to the position to the equator (Nicholson (2009) modified from Flohn (1965)) with two wet periods close to the equator and only one peak further to the north and the south. The values show the mean monthly rainfall totals (mm) and indicate how the principal rainfall regions move northwards and southwards during the year.

Usually called the Intertropical Convergence Zone (ITCZ or ITZ), this surface area of convergence of the trade winds close to the equator fluctuates north-south following the migration of the overhead sun. It includes a warm and low-pressure area of Intertropical Discontinuity (ITD) which must be differentiated from the zone of convection and maximum rainfall (about 500-1000 km south of the ITCZ) termed the ‘tropical rainbelt’ (Mohr and Thornicroft, 2006). Seasons are typically related to the location and the intensity of the ITCZ in addition to local circulation at smaller scales but, rainfall directly connected to the ITCZ is evident only during abnormally wet years and over a restricted area (northern-most Sahel)
where explicit upper-level features (easterly waves) influenced surface features like the ITCZ and moisture flow (Nicholson, 2009). Year-to-year variation in the north-south movement of the ITCZ can prove a hindrance for crop growth within the region 15°N to 10°S. It passes overhead twice a year in the southern Cameroon (near the equator) resulting in a bimodal rainfall distribution here. In the far north of the Cameroon one peak in the seasonal rainfall pattern prevails (figure 2.2). The seasonal migration has been linked to displacement of the thermally induced equatorial surface pressure trough. This trough moves through greater distances over continents than over oceans. But in the Gulf of Guinea, its movement is restricted by the absence of land masses south of the equator.

Monsoonal flow is caused by the seasonal heating and cooling of large land masses generating a reversal of the meridional pressure gradient and finally the seasonal reversal of the winds in the tropics. In Cameroon, like most of the countries of the Gulf of Guinea, the land is warmer compared to the neighbouring Atlantic Ocean during northern hemisphere summer. The southwest monsoon (West Africa summer monsoon) flows at lower levels, a source of humidity that is to a large extent determined by the large scale atmospheric circulation and sea-air interaction over much of the tropical Atlantic sector (Lamb, 1978 and 1983). As the ITCZ moves down to about 7°N, the northeast winter monsoon (harmattan) invades Cameroon’s territory and most of western and central Africa region, giving rise to a dusty rainless period.

Squall lines are meso-scale systems consisting of a narrow line of thunderstorm cells that may extend for several hundreds of kilometres. Central African squall lines are usually associated with easterly waves and are dependent on, or controlled by, the summer-time monsoon oscillations. When the depth of the monsoon is less than two kilometres, especially north of 11°N, their activity is violent. If the monsoon is deep (over 2 km) leading to monsoon rain, then the squall lines are completely inhibited.

In Cameroon, there are two squall line or thunderstorm seasons for regions from the south of the country up to 11°N but only one to the north (Long et al., 2000). Disturbance lines occur in all months. But in the coastal latitudes, the most vigorous ones develop in May-June and September-October, being rare in July-August. Farther north, for instance in the Lake Chad area, the peak frequency is reached in July-August (Johnson, 1965). These differences are easily reconciled if it is noted that squall lines are more frequent and most developed in those areas where the monsoon is neither too shallow, nor too deep. During
those months when the southwest monsoon extends farthest north, the lower-level south-westerlies are overrun by dry and hot winds from the Sahara, with easterlies in the high troposphere (figure 2.3). Near its northern limits (e.g., Lake Chad area in May-June and September-October), the monsoon is normally too shallow for significant convection to occur, while farther south (e.g., Guinea Coast in July-August) the moist layer is too deep for marked instability to be present. We notice that local evaporation rather than moisture from Atlantic is critical north of latitude 5°N because monsoon depth appears to be relatively constant over this region (Nicholson, 2009). The squall lines occur between these two positions, 'where moderately deep moist air is available and, with the dry overrunning current, pronounced convective instability is present' (Palmen and Newton, 1969, p. 464).

![Figure 2.3](image.png)

**Figure 2.3:** Mean winds (ms⁻¹) in August at 150 and 650 hPa showing the African Easterly Jet and the Tropical Easterly Jet (Nicholson, 2009).

Waves are westward-moving disturbances in the basic easterly current on the equator-ward side of the subtropical high pressure belts. Those occurring in central Africa
originate downstream of the Ethiopian highlands during the summer month in the neighbourhood of the ITCZ. Between 10°N and 15°N, a maximum wind (Tropical Easterly Jet, TEJ) is observed near 200 hPa while another (African Easterly Jet, AEJ) flows at 700-600 hPa. They comprise the southern track with an average wavelength of 2500km (Burpee, 1972; Hulme et al., 1992).

According to Nicholson the main mechanism generating rainfall over northern Cameroon (10°N-13°N), and sometimes equatorwards in the Gulf of Guinea (5°N-10°N), is associated with short-lived anomalies impacting on the core ascent between the TEJ and AEJ axis which controls the broader tropical rainbelt principally in July-August-September season (often extended beyond). The precipitation is strongly enhanced by the combination of the effect of upper-level divergence jet streams with the surface convergence due to the ITCZ and the coastal sea-breeze cell. Therefore, with the reduced latitudinal extent of the rainbelt due to the weakening of the African Westerly Jet (AWJ) and the lack of displacement of the core ascent in the Sahel, a rainfall dipole of opposite or like signs can be evident north and south of about 10°N latitude in Cameroon (Nicholson and Webster 2007, Nicholson 2008).

Studies concluded that interactions between the atmosphere and the oceans can modify the seasonal climate. Janicot (1997) has shown that SST anomalies in the Gulf of Guinea are linked to rainfall variability during boreal summer, from July to September (JAS). Janicot also suggests that a decreasing trend of precipitation is associated with a slow heating of austral seas (the South Atlantic) and also a slow cooling of boreal seas (the North Atlantic).

The El Niño/Southern oscillation (ENSO) is a large-scale, well developed model related to the fluctuations in SST over the eastern equatorial Pacific Ocean with resulting regional climate extremes in many parts of the globe (Nicholson et al., 1997, 2001 and 2009). Numerous investigations of El Niño (warmer than normal SSTs over the eastern equatorial Pacific) and La Niña (the colder than normal sea surface temperature over this same area) depict a characteristic pattern of development, evolution and decay linked to the seasonal cycle in the tropics. Consequently, Central Africa is among those global areas where ENSO events have been reflected in both precipitation and temperature anomalies (Nicholson and Kim, 1997). Consequently, a severe decrease of annual rainfall total has occurred in Cameroon under the influence of El Niño. Generally, seasonal precipitation
during June-July-August (JAS) is usually below normal in the warm ENSO phase but above normal in the cold ENSO phase (Janicot, 1997).
Chapter three

3. A summary of the recent climate trend profile of Cameroon

The monthly rainfall totals used here were obtained from the Cameroon National Meteorological Department for twelve stations in Cameroon with their locations shown in figure 2.1.

3.1 Monthly rainfall variations

![Rainfall graph](image)

**Figure 3.1:** The annual rainfall cycle over Cameroon for the 12 stations in this study. Shown are the monthly averages for the period 1960-2003 with the stations ordered roughly from north to south.

The monthly rainfall distribution over Cameroon (figure 3.1) shows two main seasons:

- The wet period (monthly falls over 100mm) is from about May to September in the northernmost region, and from March to October over the rest of the country. The peak is usually recorded during the July-September period, due to the movement of the ITCZ north of the equator, coupled with the southwest monsoon and the
prevailing regional circulations. Rainfall is mainly generated by omnipresent meso-scale convective systems associated to synoptic easterly waves.

- The dry period from November to April in the north and from December to February for the remaining part can be shifted slightly with an early (late) onset and cessation of rain especially during La Niña (El Niño) year. January is generally rainless in most localities, due to the dry northwest monsoon (harmattan) blowing southwards. The spatial distribution of rainfall (figure 3.1) shows a decrease in mean annual rainfall from the warm and moist low-lying coast of Douala (over 700 mm in August) towards both northern highlands and the southern humid forest plain which are drier (under 300 mm in August).

![Figure 3.2: Monthly rainfall variability over 12 main stations in Cameroon. The variability is shown using the coefficient of variation (%).](image)

The monthly rainfall variability for each station is summarized in figure 3.2 using the coefficient of variation (CV) which is defined as the standard deviation divided by the long-term average. Figure 3.2 shows that, in general, high rainfall variability (CV>50%) occurs during the dry season (November-February) compared to low variability in the wet season (March-October) (CV<50%). The coefficients of variation are more marked in the transition
area with the Sahel region (northern Cameroon) where rainfall variability can exceed 500%. Surprisingly the monthly variation has almost vanished for Maroua (in the vicinity of Lake Chad). It probably reveals the persistence of the prevailing driest rainfall regime over this area partly due to lack of moisture. In fact, because of the higher temperature recorded here the total amount of moisture needed for atmospheric saturation is higher. The local availability of moisture will determine the strength of local climatological features. It can alter the hydrological cycle and various climate feedbacks such as the intensification of latent heat-induced rainfall systems with large amounts of precipitable water (Mason et al., 1994). Thus, here rainfall proves to be the most important monsoon variable because of its associated latent heat release that drives atmospheric circulations, and also because of its critical role in the global hydrological cycle – which in Cameroon is important in power generation (SighaNkamdjou, et al., 1998).

3.2 Seasonal and inter-annual rainfall variations

Examining the change between annual averages of 22 years of rainfall using data sets for 1960-1981 and 1982-2003, reveals that almost all stations (except Bafoussam and Banyo) show a decreasing trend of their annual mean values (table 3.1).

The differences in Maroua, Banyo and Bafoussam are quite small when compared to relative changes at the other rainfall stations. On the other hand Douala and Bertoua exhibit, respectively, a notable decrease of their rainfall averages of about 13.9% and 11.7% which are statistically significant (p-value = 0.0003; 0.003) according to the student t-test difference of means.

Therefore, various authors robustly argue that the climate of this part of central Africa has varied during the 20th century at least insofar as rainfall is concerned. Mahe, L’Hote and co-workers support the fact that a decrease in rainfall has occurred abruptly over Central Africa region in the mid-1970s or at the beginning of the 1980s (Mahe et al. 2001; L’Hote et al., 2002 and 2003). Maybe it is linked to oscillations with a period of about 40 days that have been cautiously interpreted in Cameroon as major rain-generating disturbances (Mbele-Mbong, 1972), or perhaps it is also due to the monsoon depression type rainfall that is recognized over the region in the summer months (June-July-September) when the rainfall peak is observed within each year (Mbele-Mbong, 1972). During the dry years, a weakening of the TEJ and the low level westerly jet is evident between 5°S and
15°N. Their synchronized strengthening leads to anomalous wet conditions due to an increase in the surface pressure gradient. Therefore according to Nicholson the AEJ is ‘a passive player’ which doesn’t change much, but determines the widening of the tropical rain belt in response to the moist low level westerly jet, especially when cold sea surface temperatures are observed in the Gulf of Guinea (Nicholson et al., 2001 and 2009).

Table 3.1: The 12 main meteorological stations and their 1960-82/1982-2023 change in annual mean rainfall

<table>
<thead>
<tr>
<th>WMO station ID</th>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>60-81 annual mean rainfall (mm)</th>
<th>82-03 annual mean rainfall (mm)</th>
<th>Difference (mm)</th>
<th>Relative change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64851</td>
<td>Maroua</td>
<td>10°27′37″N</td>
<td>14°15′26″E</td>
<td>825.0</td>
<td>802.7</td>
<td>-22.3</td>
<td>-2.7</td>
</tr>
<tr>
<td>64860</td>
<td>Garoua</td>
<td>09°20′16″N</td>
<td>13°23′00″E</td>
<td>1095.2</td>
<td>974.3</td>
<td>-120.2</td>
<td>-11</td>
</tr>
<tr>
<td>64870</td>
<td>Ngaoundere</td>
<td>07°21′05″N</td>
<td>13°33′40″E</td>
<td>1554.9</td>
<td>1432.9</td>
<td>-122.0</td>
<td>-7.8</td>
</tr>
<tr>
<td>64880</td>
<td>Banyo</td>
<td>06°44′45″N</td>
<td>11°48′50″E</td>
<td>1717.8</td>
<td>1718.1</td>
<td>0.3</td>
<td>0.02</td>
</tr>
<tr>
<td>64994</td>
<td>Bafoussam</td>
<td>05°28′10″N</td>
<td>10°25′05″E</td>
<td>1655.7</td>
<td>1730.1</td>
<td>74.4</td>
<td>4.5</td>
</tr>
<tr>
<td>64890</td>
<td>Bamenda</td>
<td>05°56′13″N</td>
<td>10°09′43″E</td>
<td>2440.1</td>
<td>2202.9</td>
<td>-237.2</td>
<td>-9.7</td>
</tr>
<tr>
<td>64909</td>
<td>Ekona</td>
<td>04°12′50″N</td>
<td>09°20′30″E</td>
<td>2178.3</td>
<td>1962.6</td>
<td>-215.7</td>
<td>-9.9</td>
</tr>
<tr>
<td>64910</td>
<td>Douala</td>
<td>04°00′16″N</td>
<td>09°43′53″E</td>
<td>4056</td>
<td>3494</td>
<td>-562.0</td>
<td>-13.9</td>
</tr>
<tr>
<td>64950</td>
<td>Yaounde</td>
<td>03°50′24″N</td>
<td>11°31′37″E</td>
<td>1627.6</td>
<td>1545.8</td>
<td>-81.8</td>
<td>-5</td>
</tr>
<tr>
<td>64930</td>
<td>Bertoua</td>
<td>04°35′00″N</td>
<td>13°41′00″E</td>
<td>1615.2</td>
<td>1426.2</td>
<td>-189.0</td>
<td>-11.7</td>
</tr>
<tr>
<td>64972</td>
<td>Ebolowa</td>
<td>02°55′20″N</td>
<td>02°55′20″E</td>
<td>1917.1</td>
<td>1728.9</td>
<td>-188.2</td>
<td>-9.8</td>
</tr>
<tr>
<td>64962</td>
<td>Yokadouma</td>
<td>03°51′00″N</td>
<td>15°06′00″E</td>
<td>1650.8</td>
<td>1472.5</td>
<td>-178.3</td>
<td>-10.8</td>
</tr>
</tbody>
</table>

Inter-annual and seasonal rainfalls over Cameroon fluctuate from relatively wet and dry conditions during the considered period as shown up in figures 3.3 to 3.6. In general, the fluctuations indicate some long-term trends as well. This drying trend accompanied with marked internal variations has already had devastating environmental and socio-economic consequences. Note that in these figures the ‘line of best fit’ has been generated by the ‘R’ software package using a polynomial; in figures where no such line is shown there is no significant trend. Any lines of best fit in the figures are linear in type.
Figure 3.3: Annual and seasonal rainfall variability for Garoua for (upper left) the year, (lower left) May-September wet season, (upper right) January-April dry season and (lower right) the October-December dry season. In all cases the vertical axes shows the rainfall anomaly for each year/season in terms of the standard deviation. The linear trend is shown by the black line and the red lines shows the line of best fit. In all cases the wet decades were 1960-1969 and 1991-1999 and the dry decades were 1970-1989.

Figure 3.4: As figure 3.3 but for Douala. Note that the seasons are (lower left) March-October without trend, (upper right) January-February and (lower right) November-December. Wet decades: 1961-1981 for year to year totals and the same for the rainy season but 1962-1982 for the dry season (January-February). Dry decades: 1982-2000 for year to year totals and the same for the rainy season but 1970-1991 for the dry season (ND).
Figure 3.5: As figure 3.3 but for Bertoua for (upper left) year, (lower left) March to October, (upper right) January-February and (lower right) November-December. In all cases the wet decades were 1961-1980 and 1981-2000 were the dry decades. Note that all the seasons are drying together.

3.3 Recent climate impacts

It is essential to discriminate between factors generating the “mean climate” over Africa, which are quite varied from region to region, and the factors controlling the temporal variability of rainfall. “The latter are much more uniform throughout the continent and must therefore be large-scale aspects of the general atmospheric circulation, such as the Walker or Hadley circulations or monsoon intensities, or ocean influences, such as sea-surface temperatures” (Nicholson, 2000). Nicholson in her study (2001) computes the decline of rainfall in the Gulf of Guinea when compared to 1931-1960, as a drying of 6% for 1970-1979 and of about 7% for 1980-1989. Aguilar (2009) also showed a clear representation of climate change in the region, with obvious warming and the total precipitation decreasing due to changes in the amount of precipitation from heavy events or the length of the maximum number of consecutive wet days. Thus between 1960 and 2003 while the average number of ‘hot nights per year was increasing by 79 (21% of nights), the mean annual rainfall over Cameroon was decreasing by around 2.9mm per month or 2.2% per decade (IPCC, 2007).1

Monsoon variability depends on many factors, from regional air-sea interaction and land processes to teleconnection influences like ENSO. New evidence indicates that increased aerosol loading in the atmosphere (e.g. harmattan haze) may have strong impacts on monsoon evolution through changes in local heating of the atmosphere and land surface (Menon et al., 2002). Therefore, because the variability of regional monsoons is often the result of interacting circulations from other regions, simple indices of monsoonal strength in adjacent regions may give contradictory indications of strength (Webster and Yang, 1992; Wang and Fan, 1999). Why for example, is Lake Chad still shrinking? Today’s Sahelian landscape (including the northern Cameroon) is strongly shaped by man-made factors such as over-grazing that destroys the potential effect vegetation could have on the climate. Growing population in the region together with deforestation increase the use of water and hence partly explain the continuing shrinking of Lake Chad even though amazingly, satellite images of southern edge of the Sahara indicate a small greening.

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1 A ‘hot’ day is defined by the temperature exceeded on 10% of days or nights in the current climate in that region and season.
Chapter four

4. The statistical downscaling model

4.1 SDSM version 4.2 model description

This study uses version 4.2 of the SDSM software. The software was obtained from the Canadian Climate Change Scenarios Network (CCCSN). This software is a tool that uses a blended stochastic weather generator together with the regression method. It generates synthetic weather series using empirical relationships between the given meteorological observations (dependent variables or predictands) and the independent variables (grid-box regional data).

The steps used are briefly outlined here and are then described more fully in the following sections:

(i) Preliminary treatment of the input data, i.e. the station observations, to remove bad data.
(ii) Screening of predictor variables, e.g. checking for suitable large scale GCM-generated fields to be used by the model.
(iii) Model calibration and validation. Observation data for (in our case) 1961-1975 and NCEP/HadCM3 GCM output for the same period are combined to create regression functions for this period. These regression functions and GCM output for 1976-1990 are then used to generate downscaled station data for this period. The downscaled data and actual observations for this period are then compared to ensure that the method is robust.
(iv) Scenario generation, i.e. the creation of downscaled station data for periods up to 2070 in our case.
(v) Statistical analysis.

4.2 Preliminary handling of the input observations

As mentioned earlier the goal of the first step is to do a preliminary handling of the observed dataset to reject some errors that can occur, like negative precipitation values. The observed observational inputs for this statistical method are values of daily precipitation and daily mean temperature for Douala during the 1961-1990 periods. They were obtained from the Cameroon Meteorological Department for the Douala P30 Airport
station (WMO station identifier 64910, latitude 04° 03’16” N, longitude 09°43’53” E, altitude 5m above sea level).

All the normalized daily predictor variables (GCM outputs) were collected for the nearest grid box (these grid boxes are of size 2.5° in latitude and 3.75° in longitude) represented by the grid point (5° N, 11° 15’ E) which were provided for the following two coupled atmosphere-ocean GCM output datasets:

- National Centre for Environmental Prediction (NCEP) re-analysis data set (http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html).
- HadCM3 developed by the Hadley Centre.

The predictors used have been taken from the A2 and B2 scenarios. They reflect the A2 (heterogeneous world with continuous growth of economy and population) and B2 (a world with local solutions of sustainable development and increasing population) scenarios (IPCC, 2001), and were provided by the Canadian Climate Change Scenarios Network (CCCSN). The website from where the GCM data were retrieved is http://www.cics.uvic.ca/scenarios/index.cgi?Scenarios. The GCM datasets were normalized while provided for use (with respect to the 1961-1990 periods).

The HadCM3 GCM and NCEP predictors used are summarized in table 4.1.

Data quality control was carried out by the SDSM software to check whether the station rainfall data series were homogenous and consistent. Any daily totals of precipitation less than 0.1 mm was taken out of the total rainfall quantity. This enables an event threshold to be set to remove any ‘stray’ measurements that may be the result of events such as fog or dew.

No outlier in the observations was found that could represent unusual phenomena, observation, trends or variations susceptible to hamper the normal climate behaviour and variability. When found an outlier must be checked and harmonized according to the data set (using the long term mode value for the specific date). We found 10957 daily mean temperature values with no missing data, ranging from 16.9°C to 32.6°C, and having a mean of 26.6°C. There were 10968 values of rainfall with no missing data. These daily data vary in value from 0mm to 238.4 mm and have a mean of 10.5 mm. After earlier attempts that unsuccessfully used different transformations (these led to an unrealistic drying of the climate of Douala), the normal log transformation for precipitation was used as precipitation
is rather a skewed quantity. Finally, observed daily predictors and predictands were converted into suitable data [*.DAT] files ready to undergo the screening process.

**Table 4.1:** Summary of GCM predictors and observation predictands used in the study. An ‘X’ indicates that a variable was used – the ‘XX’ indicates that it was used for different scenarios.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Douala daily mean temperature</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Douala daily precipitation totals</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Regional mean temperature</td>
<td>temp</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Regional mean sea level pressure at 2m for the A2 and B2 scenarios</td>
<td>mslp</td>
<td>XX</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Relative humidity at 850 hPa for the A2 and B2 scenarios</td>
<td>r850</td>
<td>XX</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>500 hPa geopotential height</td>
<td>p500</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Total number of predictors and predictands</td>
<td>5</td>
<td></td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

**4.3 Screening of the regional climate variables**

To identify appropriate predictors (e.g. mean sea level pressure, relative humidity) to be used in empirical relationship, a correlation analysis was made between 12 possible predictors (chosen among the four main groups of table 4.1) and the observed rainfall at first, and then for the mean temperature for the base-line period 1961-1990.

The 12 predictors considered initially (all normalized relative to 1961-1990) were as follows:

- Mean sea level pressure
- Mean 2m air temperature
- 500 hPa geopotential height,
- 850 hPa relative humidity.

In each case the A2 and B2 scenario values from the HadCM3 SRES and the NCEP datasets were tested.

Correlation is the relationship or association between two (or among more) variables. The correlation coefficient ($r$) measures the strength or degree of linear association between two variables, and is used widely in science including meteorology and climatology. The correlation coefficient ($r$), given $n$ pairs of observations between two sample variables like $x$ for ‘mean sea level pressure’ and $y$ for ‘rainfall totals’ is given by:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

Here the overbar represents the average over $n$ values; the individual values are denoted by the subscript $i$. For clarity the subscript has been removed from all values in the right hand term.

This equation can be viewed as the ratio of the covariance of the two variables to the product of the two standard deviations. Properties of the correlation coefficient include:

- The coefficient has the range $-1 \leq r \leq +1$
- The closer $r$ is to 1 or to $-1$, the stronger the linear relationship between $x$ and $y$
- If $r = 1$ then $x$ and $y$ are perfectly positively correlated. The possible values of $x$ and $y$ all lie on a straight line with a positive slope in the $(x, y)$ plane.
- If $r = -1$ then $x$ and $y$ are perfectly negatively correlated. The possible values of $x$ and $y$ all lie on a straight line with a negative slope in the $(x, y)$ plane.
- If $r = 0$, then $x$ and $y$ are not correlated. They do not have an apparent linear relationship. However, this does not mean that $x$ and $y$ are statistically independent.
- The statistical significance of “$r$” can be estimated using the student t-test:

$$t_{n-2} = r \sqrt{\frac{n-2}{1-r^2}}$$

where $n - 2$ are the number of degrees of freedom. If $t_{n-2}$ is significant, then the calculated “$r$” is significant (different from zero) otherwise it equals zero (not
significantly different from zero). The level of significance is found from lookup tables with t and n-2 as the input.

In addition there are two other statistical quantities that can help us to judge the usefulness of our predictors:

- The coefficient of determination, $R^2$, measures the strength of the relationship between two variables, x and y. This specifies the proportion of the variability in one variable that can be accounted from the relationship with the other variable.
- A $P$-value accompanying a t-test could be considered as the probability of an observed outcome arising by chance. But, a small $P$-value that indicates statistical significance does not specify that an alternative hypothesis is necessarily accurate.

Tables 4.2 to 4.5 give an idea of our different findings. The predictors highlighted in red in the following tables were found to provide the strongest (the best monthly correlation coefficient according to SDSM, at 5% significance level) relationship to Douala international-Airport monthly data, while the blanks indicate insignificant values.

Table 4.2: Results of HadCM3’s explained variance of rainfall analysed ($r$) for 01/01/1961-31/12/1990. The use of a2 and b2 in the predictor name indicates the scenario A2 and B2 respectively. Values highlighted in red indicate the strongest relationship with the observed rainfall.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>H3a2mslp</td>
<td>0.02</td>
<td>0.1</td>
<td>0.09</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3a2r850</td>
<td>0.05</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
<td>0.07</td>
<td>0.15</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3b2mslp</td>
<td>0.01</td>
<td>0.02</td>
<td>0.09</td>
<td>0.1</td>
<td>0.05</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3b2r850</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.1</td>
<td>0.1</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3a2temp</td>
<td>0.1</td>
<td>0.02</td>
<td>0.09</td>
<td>0.03</td>
<td>0.04</td>
<td>0.1</td>
<td>0.03</td>
<td>0.1</td>
<td>0.06</td>
<td></td>
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</tr>
</tbody>
</table>

Table 4.3: Results of NCEP’s explained variance of rainfall analysed($r$) for 01/01/1961-31/12/1990. Values highlighted in red indicate the strongest relationship with the observed rainfall.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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</thead>
<tbody>
<tr>
<td>Ncepmmslp</td>
<td>0.02</td>
<td>0.041</td>
<td>0.02</td>
<td>0.044</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ncepp500</td>
<td>0.03</td>
<td>0.02</td>
<td>0.021</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Ncepr850</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Nceptemp</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.4: Results of NCEP’s explained variance of temperature analysed (r) for 01/01/1961-31/12/1990. Values highlighted in red indicate the strongest relationship with the observed rainfall.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ncepmslp</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.07</td>
<td>0.10</td>
<td>0.10</td>
<td>0.12</td>
<td>0.11</td>
<td>0.13</td>
<td>0.06</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>Ncepp500</td>
<td>0.09</td>
<td>0.04</td>
<td>0.06</td>
<td>0.09</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.09</td>
<td>0.09</td>
<td>0.06</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Ncepr850</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
<td>0.08</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Nceptemp</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table 4.5: Results of HadCM3’s explained variance of temperature analysed (r) for 01/01/1961-31/12/1990. The use of a2 and b2 in the predictor name indicates the scenario A2 and B2 respectively. Values highlighted in red indicate the strongest relationship with the observed rainfall.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>H3a2mslpcm</td>
<td>0.01</td>
<td>0.01</td>
<td>0.011</td>
<td>0.01</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3a2r850cm</td>
<td>0.01</td>
<td>0.01</td>
<td>0.011</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3b2mslpcm</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>H3b2r850cm</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.10</td>
<td>0.01</td>
<td>0.01</td>
<td>0.014</td>
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<tr>
<td>H3a2temppcm</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
<td>0.03</td>
<td>0.08</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The strongest relationship of the HadCM3 regional mean temperature (H3a2temp) suggests that it is the potentially most important predictor for March through November (the entire wet season) while one can consider the highest relationship of the NCEP regional mean sea level pressure (ncepmslp) to set it among the potential predictors for May through November.

It should be noted that the selection of the predictor variables is the most challenging part of the model process – the exact choice of these predictors largely determines the nature of the downscaled climate scenario. Although these predictors, once selected, are used by the model for each month of observation data, their power to determine the future scenario will vary both spatially and, more importantly in our single station case, temporarily. Thus the effect of mean sea level pressure may vary more in the wet season than in the dry season, for example.

In all further tests and usage of the model it is the predictors shown in tables 4.2-4.5 that were used for the meteorological variable/GCM combination shown in the tables.
4.4 Calibration and validation of the model

Using the fifteen year (1961-1975) daily observations of rainfall or mean temperature and all the best predictors (i.e. all those shown in tables 4.2 to 4.5) found for each month through screening, monthly models were constructed by multiple regression equations of ordinary least squares (their data are written to files with file extension. This is the calibration process. The goal in regression analysis is to create a mathematical model that can be used to predict the values of a dependent variable (e.g. monthly rainfall and mean temperature) based upon the values of independent variables (ncepmslp, h3a2mslp, amongst others). In other words, we evaluate (automatically performed by SDSM) the model to generate (downscale) the value of temperature/rainfall (Y) when we know the value of normalized HadCM3 or NCEP GCMs predictors (the Xs). The dependent variable (predictand) is the one to be generated given the computed strength of association among variables. Multiple regression models are typically stated in the form:

\[ Y = \alpha + \beta X_1 + \gamma X_2 + \eta X_3 + \varepsilon \].............. \( (4.3) \)

Here the "residual", \( \varepsilon \), is a random unexplained variation with mean zero.

The coefficients \( \alpha \), \( \beta \), \( \gamma \) and \( \eta \) are determined by the condition that the sum of the square residuals is as small as possible.

The model calibration is performed only with a part of observed daily dataset from 1961 to 1975 (15 years) leaving the remaining set (1976-1990) for the verification after synthetic weather generation.

We have computed our multiple regression equations through an optimization algorithm (ordinary least squares fit) under monthly temporal basis (set as the ‘model type’ in the software). Selecting this model parameter means that different model parameters will be determined for each calendar month. It is possible to also perform the analysis on an annual or seasonal basis (i.e. using a single parameter for all months or a different one for each season, respectively).

However, the documentation suggests that here the seasons are the ‘traditional’ European ones of December-February (winter), June-August (summer) and would not be appropriate for the seasons of Cameroon. Clearly using the ‘annual switch’ would be inappropriate for our study unless only the gross annual features of any scenario were required.
These processes were only conditional for rainfall since there is a direct link between rainfall totals and the number of days of precipitation. In the case of an unconditional model the software assumes that there is a direct link between the predictors (large scale features) and the predictand (e.g. the station temperature). Thus the station temperature may be a function of the GCM temperature.

In the case of a conditional model there may be an intermediate step or process. Thus in our case the station precipitation amounts are taken to depend upon the occurrence of wet days, and the latter are in turn dependent upon the GCM predictors such as humidity and surface pressure as these relate to the large-scale flow that generates the rainfall.

The stability of our model parameters was tested using cross validation (not shown). In this we compared the explained variances ($r$) using each predictor singly as compared to using all the predictors in combination as shown in tables 4.2-4.5 to ensure the robustness of each predictor alone.

Summary statistics for the calibration (using all the chosen predictors) are shown in tables 4.6 to 4.9. The red values in these tables indicate some skill (Chow test values of at least 12) or some positive serial correlation (Durbin-Watson test).

**Table 4.6:** Summary statistics for NCEP’s temperature predictors in each month

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Standard Error (SE)</td>
<td>1.16</td>
<td>1.23</td>
<td>1.26</td>
<td>1.25</td>
<td>1.24</td>
<td>1.28</td>
<td>1.28</td>
<td>1.21</td>
<td>1.24</td>
<td>1.30</td>
<td>1.28</td>
<td>1.31</td>
</tr>
<tr>
<td>Chow test</td>
<td>10.9</td>
<td>5.1</td>
<td>9.92</td>
<td>12.4</td>
<td>9.65</td>
<td>13.3</td>
<td>21.5</td>
<td>19.3</td>
<td>20.6</td>
<td>19.7</td>
<td>22.7</td>
<td>21.5</td>
</tr>
<tr>
<td>Durbin-Watson test</td>
<td>1.41</td>
<td>1.51</td>
<td>1.43</td>
<td>1.37</td>
<td>1.44</td>
<td>1.49</td>
<td>1.36</td>
<td>1.48</td>
<td>1.26</td>
<td>1.5</td>
<td>1.23</td>
<td>1.20</td>
</tr>
</tbody>
</table>

**Table 4.7:** Summary statistics for HadCM3’s temperature predictors in each month

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.08</td>
<td>0.06</td>
<td>0.1</td>
<td>0.07</td>
<td>0.03</td>
<td>0.02</td>
<td>0.05</td>
<td>0.13</td>
<td>0.18</td>
<td>0.15</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Standard Error (SE)</td>
<td>1.14</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.27</td>
<td>1.31</td>
<td>1.27</td>
<td>1.15</td>
<td>1.14</td>
<td>1.2</td>
<td>1.24</td>
<td>1.3</td>
</tr>
<tr>
<td>Chow test</td>
<td>9.2</td>
<td>3.08</td>
<td>1.02</td>
<td>3.25</td>
<td>8.83</td>
<td>14.9</td>
<td>19.0</td>
<td>11.0</td>
<td>7.57</td>
<td>5.48</td>
<td>13.4</td>
<td>16.3</td>
</tr>
<tr>
<td>Durbin-Watson test</td>
<td>1.45</td>
<td>1.61</td>
<td>1.57</td>
<td>1.45</td>
<td>1.40</td>
<td>1.40</td>
<td>1.4</td>
<td>1.67</td>
<td>1.51</td>
<td>1.71</td>
<td>1.29</td>
<td>1.26</td>
</tr>
</tbody>
</table>
Table 4.8: Summary conditional statistics for NCEP’s rainfall predictors in each month

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.01</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
<td>0.1</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Standard Error (SE)</td>
<td>0.49</td>
<td>0.49</td>
<td>0.48</td>
<td>0.47</td>
<td>0.48</td>
<td>0.47</td>
<td>0.48</td>
<td>0.49</td>
<td>0.48</td>
<td>0.49</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Chow test</td>
<td>5.7</td>
<td>5.1</td>
<td>0.5</td>
<td>0.8</td>
<td>1.4</td>
<td>2.0</td>
<td>2.6</td>
<td>1.8</td>
<td>1.4</td>
<td>3.3</td>
<td>2.4</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Table 4.9: Summary conditional statistics for HadCM3’s rainfall predictors in each month

<table>
<thead>
<tr>
<th>Predictors</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Standard Error (SE)</td>
<td>19.7</td>
<td>18.2</td>
<td>26.7</td>
<td>18.9</td>
<td>17.4</td>
<td>18.0</td>
<td>17.0</td>
<td>21.5</td>
<td>25.4</td>
<td>21.6</td>
<td>21.7</td>
<td>17.4</td>
</tr>
<tr>
<td>Chow test</td>
<td>1.6</td>
<td>1.1</td>
<td>1.5</td>
<td>3.0</td>
<td>3.0</td>
<td>1.9</td>
<td>3.2</td>
<td>1.3</td>
<td>1.2</td>
<td>2.1</td>
<td>3.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The standard error (SE) in tables 4.6 to 4.9 is the standard deviation of the difference between the observed monthly rainfall totals and the normalised predictors from SDSM for the period 1976-1990. Note that those for temperature show very little difference from month to month. The same is true for the NCEP-generated rainfall – but not for the HadCM3 rainfall values. However, even a value for SE of 20 mm for rainfall is good when the variation of rainfall is taken into account - and when we consider the difficulties in using GCMs to predict rainfall.

The Durbin-Watson statistic is a statistical test used to detect the presence of autocorrelation in the temperature residuals for a regression analysis. A value of 2 indicates there appears to be no autocorrelation; if less than 2, there is evidence of positive serial correlation. In our case here, no Durbin–Watson test has a result less than 1.0, so it is very probable that we have no autocorrelation and the independence assumption is not violated because none is less than 1.

The Chow (1960) test highlighted in red in tables 4.6 to 4.9 suggests the skill in the model is good in some months (>= 12); it is used to test of whether the coefficients in two linear regressions on different data sets are equal. The smaller values for the result of this test maybe indicate that there is a change in rainfall regime during the validation period of 1976-1990.

NCEP seems to be a better prediction data set than HadCM3 when considering the mentioned criteria, and also performs better in the residual scatter plots – see, for example, figures 4.1 and 4.2. This is not surprising as the NCEP GCM data come from a reanalysis.
rather than a long-range forecast and so should (ideally) reflect the actual observations (Kalnay et al., 1996).

Figure 4.1: The NCEP model shows a symmetrical spread of normalised temperature anomalies (y-axis) in months with a mean temperature between 26.5°C and 28.0°C (x-axis) with values mainly between -4degC and +4degC.

Figure 4.2: The HadCM3 model shows a near-symmetrical spread of residual rainfall (y-axis; values mainly between +3mm/day and -3mm/day) in months with a mean daily downscaled rainfall between 0 and 3.0mm/day (x-axis).
An even spread of residuals, as shown in these figures is desirable and it suggests that the model is performing the downscaling in a satisfactory manner – in our case for both rainfall and temperature. Note that the corresponding figures for NCEP temperature and HadCM3 rainfall are not shown but show the same features.

**Table 4.10:** Temperature characteristics for each of the months of the validation period 1976-1990. (a) and (b) show the station observation values and their variances. (c) shows (b) minus the equivalent NCEP variance. (d) and (e) show, respectively, the differences between the station mean temperature observations and the downscaled values from HadCM3 and NCEP.

<table>
<thead>
<tr>
<th>Month</th>
<th>Obs (°C) (a)</th>
<th>Obsvar (degC)^2 (b)</th>
<th>NCEP var (degC)^2 (c)</th>
<th>HadCM3 diff (degC) (d)</th>
<th>NCEP diff (degC) (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>26.928</td>
<td>2.047</td>
<td>0.641</td>
<td>0.701</td>
<td>-0.339</td>
</tr>
<tr>
<td>Feb</td>
<td>26.891</td>
<td>1.897</td>
<td>0.339</td>
<td>-1.476</td>
<td>-0.491</td>
</tr>
<tr>
<td>Mar</td>
<td>26.896</td>
<td>2.187</td>
<td>0.531</td>
<td>-0.367</td>
<td>-0.23</td>
</tr>
<tr>
<td>Apr</td>
<td>26.837</td>
<td>2.258</td>
<td>0.667</td>
<td>-0.451</td>
<td>-0.41</td>
</tr>
<tr>
<td>May</td>
<td>26.781</td>
<td>1.963</td>
<td>0.334</td>
<td>-2.154</td>
<td>-0.498</td>
</tr>
<tr>
<td>Jun</td>
<td>26.774</td>
<td>1.956</td>
<td>0.301</td>
<td>-3.003</td>
<td>-0.293</td>
</tr>
<tr>
<td>Jul</td>
<td>26.92</td>
<td>2.085</td>
<td>0.371</td>
<td>-3.094</td>
<td>-0.099</td>
</tr>
<tr>
<td>Aug</td>
<td>26.844</td>
<td>2.139</td>
<td>0.691</td>
<td>-6.399</td>
<td>-0.395</td>
</tr>
<tr>
<td>Sep</td>
<td>26.901</td>
<td>2.062</td>
<td>0.508</td>
<td>-7.986</td>
<td>-0.324</td>
</tr>
<tr>
<td>Oct</td>
<td>26.849</td>
<td>2.198</td>
<td>0.539</td>
<td>-5.451</td>
<td>-0.501</td>
</tr>
<tr>
<td>Nov</td>
<td>26.838</td>
<td>1.995</td>
<td>0.307</td>
<td>0.027</td>
<td>-0.29</td>
</tr>
<tr>
<td>Dec</td>
<td>26.914</td>
<td>1.956</td>
<td>0.184</td>
<td>-5.6</td>
<td>-0.112</td>
</tr>
</tbody>
</table>

For the validation step we need to use these predictor regression relationships and assess how the model perform in simulating the daily mean temperature and rainfall values for the period 1976-1990 – the second 15-year period for which we have observations. Ideally, if the relationship between the large scale flow and the station observations is not changing then the downscaled parameters (rainfall and temperature) and the observations should match reasonably well.

The result of downscaling daily mean temperatures and rainfall for Douala reveals that marginal errors are negligible only when the NCEP model is used (see Tables 4.10, 4.11 and figures 4.3 to 4.6). For the rainfall HadCM3 performs rather worse than NCEP in August and September with a deficit of about 187 mm to 222 mm in these months (or about 6-8 mm per day).
Also, from June to October there appears to be a problem with the HadCM3 temperature validation – with table 4.10 suggesting that there is a cooling of about 3 degC at the ends of this period but as much as 7.9 degC error in September (again, a cooling).

This poor performance is also depicted by figures 4.3 and 4.4.

Table 4.10 shows that the NCEP-generated downscaled temperatures have a slightly smaller spread the observations, while (column (e)) they have slightly larger monthly-mean value. In general, however, the agreement is quite good – as would be expected from a model reanalysis.

On the other hand, the HadCM3-generated downscaled values show some serious shortcomings. The September data could be interpreted, for example, as indicating a mean temperature of 19°C with a spread of some 40°C. Clearly, something is wrong. The usefulness of the NCEP results indicate that the method/downscaling model is sound so maybe there are shortcomings in the gridbox data chosen for the downscaling from the HadCM3 dataset? Douala is a station close to the coastline and the GCM gridbox chosen to represent the station contains only land at the lower boundary. However the sharp variation in orography over the Cameroon may not be well-represented by the model and it’s physics.

**Table 4.11:** As table 4.10 but for the rainfall in units of mm/d for the field and the square of this for the variance. Here (b) refers to the variance of the monthly totals (the average of these monthly totals is about 10 times 30 days or 300 mm per month). (c) and (d) are the differences between the observed and downscaled rainfall totals per month.

<table>
<thead>
<tr>
<th></th>
<th>Obs (mm/d)</th>
<th>Obsvar (mm)²</th>
<th>NCEP diff (mm/month)</th>
<th>HadCM3 diff (mm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>8.71</td>
<td>282.1</td>
<td>-0.219</td>
<td>-6.988</td>
</tr>
<tr>
<td>Feb</td>
<td>10.034</td>
<td>419.2</td>
<td>-4.121</td>
<td>0.195</td>
</tr>
<tr>
<td>Mar</td>
<td>10.644</td>
<td>449.9</td>
<td>-2.881</td>
<td>-46.084</td>
</tr>
<tr>
<td>Apr</td>
<td>10.904</td>
<td>432.5</td>
<td>0.24</td>
<td>-3.211</td>
</tr>
<tr>
<td>May</td>
<td>8.396</td>
<td>315.4</td>
<td>-0.295</td>
<td>-15.973</td>
</tr>
<tr>
<td>Jun</td>
<td>9.093</td>
<td>341.5</td>
<td>-3.606</td>
<td>1.883</td>
</tr>
<tr>
<td>Jul</td>
<td>11.938</td>
<td>645.6</td>
<td>3.109</td>
<td>2.874</td>
</tr>
<tr>
<td>Aug</td>
<td>10.272</td>
<td>445.6</td>
<td>3.056</td>
<td>-222.26</td>
</tr>
<tr>
<td>Sep</td>
<td>9.715</td>
<td>472.2</td>
<td>-4.317</td>
<td>-187.582</td>
</tr>
<tr>
<td>Oct</td>
<td>10.569</td>
<td>395.1</td>
<td>5.028</td>
<td>-22.778</td>
</tr>
<tr>
<td>Nov</td>
<td>10.718</td>
<td>384.8</td>
<td>0.445</td>
<td>-3.296</td>
</tr>
<tr>
<td>Dec</td>
<td>9.316</td>
<td>405.8</td>
<td>0.94</td>
<td>-5.727</td>
</tr>
</tbody>
</table>
Table 4.11 shows similar results for the rainfall. It should be noted that during the wet season almost every day has high and relatively consistent rainfall amounts (at least when compared to the monthly mean daily fall) while in the dry season, although most days will be dry or have minimal rainfall amounts, there can be one or two days with very high daily totals – thus the perhaps unexpectedly high variance in the observations during this season.

Table 4.11 shows a reasonable agreement between observations and the NCEP downscaled output – but the same cannot be said of the HadCM3 results. Even in a reanalysis system it might be expected that gridpoint to gridpoint rainfall will differ rather more from the observations that is the case with temperature – this is because the rainfall is a more rapidly varying quantity in space and a model has to represent the conditions over quite a large area (several thousand square kilometres in this case) with a single value.

However, the result that the HadCM3 downscaled output compares quite differently to reality in different months is rather strange. Possibly this is because of the extreme on-off nature of the rainfall already alluded to in some seasons. At the very least it might be worth examining whether using a different set of predictors could be used to achieve better results. It would also be useful to test the model and the method using different station data for the country – Douala is one of the wettest places in the country and maybe the downscaling is being applied near its modelling limit?

**Figure 4.3**: Validation of NCEP and HadCM3 models by investigating their respective errors after subtracting their generated monthly means from the observed daily mean
temperatures at Douala during the validation period (1976-1990). NCEP shows the best fit by the downscaling process.

It is also worth remembering that figures 3.3 to 3.6 suggested a change in rainfall regime during the period 1961-1990. Possibly the downscaling model and the scenarios we will generate in the next chapter might be repeated using the period 1976-1990 to perform the calibration and 1991-2010 to perform the validation.

![Figure 4.4: Validation of NCEP and HadCM3 models by investigating their respective errors after subtracting their generated monthly means from the observed daily rainfall totals at Douala during the validation period (1976-1990). NCEP shows the best fit of by the downscaling process. Note that these differences are per calendar month – so 200 mm equates to about 7 mm per day.](image)

Figures 4.3 and 4.4 highlight the seasonal variation in the validation results from the downscaling model.

To estimate the reliability of generating the future weather using HadCM3 model, a comparison between the 1991-2000 scenarios might help. It might also be interesting to separate out the two different GCM climate scenarios A2 and B2 in future work.

The departure in temperature from observations in the case of the downscaled HadCM3 temperatures suggests that there is little point in using the HadCM3 downscaled temperatures when examining climate projections beyond 2010 using our current setup for the downscaling. However, this will be done – it will be instructive to see if some of the month-to-month variations/discrepancies appear in future periods. However, as the NCEP model does not contain any long-term forecasts, we shall now use the HadCM3 downscaling
to investigate future rainfall projections for Douala, with only a cursory glance at the HadCM3 temperature projections.
Chapter five

5. Results and discussions

5.1. Scenario generation

Regarding the projection of the future climate, the SDSM model was used to generate the future synthetic daily data for various periods (1991-2000 using NCEP and HadCM3 GCM; 2011-2040 and 2041-2070 using only HadCM3). Summaries of the monthly means of rainfall and temperature were then calculated internally by the SDSM software. The changes in the precipitation and mean temperature are best represented through their respective differences relative to the baseline observation period of 1961-1990 (tables 5.1 and 5.2).

Table 5.1: Monthly average of daily rainfall (mm/day) in Douala (observed and downscaled) showing the monthly averages and monthly relative changes (%) for 2011-40 compared to 1961-1990.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>10.22</td>
<td>8.01</td>
<td>1.57</td>
<td>1.85</td>
<td>1.82</td>
<td>-81.9</td>
</tr>
<tr>
<td>Feb</td>
<td>10.49</td>
<td>11.85</td>
<td>4.60</td>
<td>5.03</td>
<td>4.86</td>
<td>-52.05</td>
</tr>
<tr>
<td>Mar</td>
<td>11.63</td>
<td>5.66</td>
<td>1.94</td>
<td>2.22</td>
<td>2.29</td>
<td>-80.91</td>
</tr>
<tr>
<td>May</td>
<td>11.16</td>
<td>4.62</td>
<td>1.37</td>
<td>1.26</td>
<td>1.27</td>
<td>-88.71</td>
</tr>
<tr>
<td>Jun</td>
<td>10.12</td>
<td>8.88</td>
<td>1.80</td>
<td>1.95</td>
<td>2.03</td>
<td>-80.73</td>
</tr>
<tr>
<td>Jul</td>
<td>9.86</td>
<td>14.18</td>
<td>1.46</td>
<td>1.46</td>
<td>1.40</td>
<td>-85.19</td>
</tr>
<tr>
<td>Aug</td>
<td>10.97</td>
<td>9.37</td>
<td>5.63</td>
<td>5.54</td>
<td>5.58</td>
<td>-49.5</td>
</tr>
<tr>
<td>Sep</td>
<td>10.92</td>
<td>25.01</td>
<td>2.39</td>
<td>2.54</td>
<td>2.67</td>
<td>-76.74</td>
</tr>
<tr>
<td>Oct</td>
<td>10.34</td>
<td>6.50</td>
<td>11.91</td>
<td>10.91</td>
<td>10.80</td>
<td>+5.51</td>
</tr>
<tr>
<td>Nov</td>
<td>10.40</td>
<td>18.17</td>
<td>17.80</td>
<td>17.43</td>
<td>17.49</td>
<td>+67.11</td>
</tr>
<tr>
<td>Dec</td>
<td>9.09</td>
<td>6.57</td>
<td>20.02</td>
<td>21.14</td>
<td>21.06</td>
<td>+132.56</td>
</tr>
</tbody>
</table>

Table 5.1 shows the results for the rainfall at Douala without any correction being made for the 1976-1990 ‘validation error’. The downscaled NCEP rainfall values are much closer to the observations (for 1961-1990) than are the HadCM3 values – the latter show some alarming departures from 1961-90 which need investigation. However, there is much
more month-to-month variation in the rainfall even in the NCEP figures for 1991-2000 than in the observations for 1961-1990. In particular NCEP suggests a wet September during 1991-2000. It is also worth noting that for the three HadCM3 rainfall periods (1991-2000, 2011-2040 and 2041-2070) the rainfall amounts in a given month vary very little – suggesting the possibility of no great change in the monthly rainfall amounts in Douala in the future perhaps.

In table 5.1 the final column suggests a drying in the first nine months with a wetting in the final three months of the year. If this is due to shortcomings in the model or the predictors we have chosen it is interesting that there is this difference.

Note the projected wetting of the dry season runs occurs in a season when there appeared to be no problem with the HadCM3 validation tests.

Table 5.2 shows similar results for the projected temperatures – it shows a marked projected cooling in August for HadCM3 relative to NCEP. However, there is little change in future periods compared to 1991-2000 with the HadCM3 data.

**Table 5.2**: Monthly average of daily mean temperature (°C) in Douala (observed and downscaled) showing the monthly values and monthly changes. Notice the projected cooling of August.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>26.55</td>
<td>27.45</td>
<td>28.55</td>
<td>28.58</td>
<td>28.58</td>
</tr>
<tr>
<td>Feb</td>
<td>26.56</td>
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Table 5.2 does not show any problems with the HadCM3 during July and September such as those that we found in the validation step. Other months (such as June), however,
do show a warming relative to 1961-1990 that is difficult to believe – although there is still a warming, even though to a lesser extent.

One possibility is that the observations for Douala are not homogeneous in time. Perhaps for periods during which the station was operating there have been some changes to instrumentation and the degree of urbanisation which mean the observation record has non-meteorological changes in it. It is possible that these are quite large compared to any climate change signal we are trying to detect.

At this level, since previous comparisons indicate that NCEP reanalysis has higher quality estimates than HadCM3, we understand that departures in our HadCM3 future climate projections may be due to the different treatment of multi-decadal natural variability, the temporal structuring of daily climate variables and large-scale forcing of local precipitation, and also by the downscaling method itself. Currently, by artificially inflating the variance of the downscale series to accord with the Douala actual observations, the projection results could be enhanced (Wilby, et al., 2007). Definitely, our statistical downscaling of daily rainfall totals and daily mean temperatures over Douala has enabled us to expect a continuing decline of precipitation during the peak of the wet season, while some classical dry months (October to November) will probably experience more rainfall especially during La Niña years when positive rainfall anomalies develop over the Gulf of Guinea (Nicholson and Selato, 2000).
Chapter six

6. Conclusions and further work

This chapter stresses the conclusions of our study and looks forward to some upcoming research work.

6.1 Conclusions

The purpose of this study was to assess rainfall variability and change over Cameroon, using 44 years of monthly data sets for 12 meteorological stations. Because of the lack of significant means to run a dynamical model in our country and the lack of expertise in agricultural and hydropower institutions to exploit such models that are very much the domain (still) of the climate expert, we choose to run a one site statistical downscaling model for ‘Douala’ to simulate future climate.

This choice is also supported by the availability of current projections of the 21st century future climate on the basis of the IPCC (2001) outputs, according to which rainfall should still decreasing over West Africa in the decades to come, and should not change much or perhaps slightly increase in some parts of Central Africa. We have also realized that in Cameroon, despite many local discrepancies a general rainfall decline is still going on.

The monthly rainfall variability for each station reveals that high rainfall variability (>50%) occurs during the dry season (November-February) compared to the wet season March to October (<50%). Moreover, these coefficients of variability are more marked in the transition area with the Sahel region (northern Cameroon) where rainfall variability can exceed 500%. To my surprise monthly variation almost vanished for Maroua, the warmest area in Cameroon (in the vicinity of Lake Chad). So, as far as monsoon variability is linked to many factors, from regional air-sea interaction and land processes to teleconnection influences; man-made action was pointed to when searching for the vanishing of Lake Chad, for example (Naah 1990).

Assessing whether there is evidence that rainfall accumulations have changed from the (1960-1981) to 1982-2003 decades, the F-test of variance gives an idea that there is no
difference between the studied period variances. Almost all stations reveal a p-value greater than 0.05 not sufficient to claim the 95% statistical significance of the test. This suggests that the rainfall variance is quite constant over Cameroun for many decades at least in terms of the annual totals. But, these variations can actually vary locally, within the months, seasons and from year to year. Douala and Bertoua exhibit respectively a forthright decrease of their rainfall averages for about -13.9% and -11.7% with an undeniably significant statistical test (p-value = 0.0003; 0.003).

Using the SDSM model, and after computing our multiple regression equations via an optimization algorithm (ordinary least squares fit) under conditional processing for rainfall, both HadCM3 and NCEP clearly show a reasonable performance if allowance is made for the discrepancies (as yet still unexplained) between the calibration results for 1961-1975 and the validation results for 1976-1990. (The project did not allow for the time that would be needed to explore the use of different predictor variables.) The HadCM3 downscaled results give little signal in terms of a temperature change into the future – except during August – although this result may be partially due to the discrepancies found at the validation stage.

The downscaled results suggest a slight trend towards decreasing overall rainfall amounts (see table 5.1) – certainly towards the end of the year. Given the current climate, this implies that Douala on the edge of the Gulf of Guinea and other cities in its neighbourhood will continue to be vulnerable to warming, floods and landslides during the peak of the wet season (JAS) when the soil is saturated by continuous downpours. It seems likely that wet ‘dry season’ and dry ‘wet season’ events are projected to continue to be common in Douala in the future.

The results obtained above were a little disappointing. Perhaps the main conclusion that this work shows is that the use of a statistical downscaling model is a complicated area of work. This project has enable the author to get a feel for the problem – but clearly several more iterations even for the current station are needed and there is a need to thoroughly explore the many features and options of the model.
6.2 Further work

Results presented in this report show reveal issues that a more comprehensive study should aim to address:

1. Why are there apparent issues revealed during the calibration-validation phase of the study? Does this suggest that a different (maybe a later) calibration period be used (1976-1990) with validation using data for the period 1991-2005 – using daily data that was not available to this study. This might get around any suggestion of a change in climate/rainfall regime (chapter 3) during 1961-1990. Such regime changes may possibly be detected using variables other than rainfall or temperature, e.g. by using wind observations. Possibly also, information about such changes might be obtained from measurements of SSTs for the Gulf of Guinea – these should be available given availability of satellite-derived SST measurements. SST changes might impact of local/coastal rainfall generation.

2. A close examination of the daily temperature and rainfall series needs to be carried out to check for instrumental changes – or changes due to urbanisation. This can be done using nearby sites with overlapping data periods.

3. Clearly the study needs to be carried out with additional rainfall and temperature station data from different sites. Is there an issue with the study having used a relatively wet tropical rainfall station in which one or two days of rain (especially in the dry season) can alter the perceived average conditions of that month? Note that any station observation series that are used should be homogenous and self-consistent to remove any spurious trends.

4. A more extensive study of the available predictor variables needs to be carried out. The study does suggest that improvements might be made here – as the numbers shown in tables 4.2 to 4.5 show only a small variation – and are actually somewhat smaller than those shown in the software documentation. However, the latter point may be down to the region of the world used in our study. Given the inherent issues associated with statistical downscaling it may that some climate regimes are better suited to the method.
5. If there is a change in climate regime it might be possible to detect this by examining in detail (on a daily/monthly basis perhaps) the GCM output on a gridpoint basis for the grid squares containing the Cameroon.

6. Once resources allow it would be very useful to run some RCM simulations for central Africa and to analyse any changes to rainfall and temperature that they produce, as well as repeating item 5 above using this more detailed dataset.

In Cameroon the majority of the population lives in rural areas and main cities like Douala. They depend on rain fed agriculture for their subsistence but also the government is deeply concerned for sustainable development planning purposes, especially in each agro pastoral and hydropower generation locality. Therefore, the downscaling and projection of future rainfall and temperature with GCM outputs to several models have to be done for all Cameroon meteorological stations in order to intimately depict local discrepancies beyond the rainfall decrease which is still going on over the area.

Such work could only be done realistically once some of the issues found in this document (chapters 4 and 5) have been addressed. It would be also be useful to attempt to assess the usefulness of the current SDSM software for use in an equatorial regime. Here, geostrophy breaks down due to a lack of Coriolis force and, compared to mid-latitudes. Whereas in mid-latitudes local weather is often highly-dependent upon large-scale features, possibly in the Cameroon case this is not always so – there is very little variation in observed temperatures, for example.

If local weather and climate changes are not found in points 4 and 5 then, despite its known limitations, statistical downscaling methods could be used in hydrological and other impact assessment studies with very rapid and promising results when representing microclimates, where the dynamical downscaling has extra restrictions.

The most advantageous solution to assess climate change impacts at a local or regional scale would be the combination of the dynamical and statistical approach in order to have an easy to use tool that can represent regional and local climate variability and produce climate change scenarios. It is hoped that a sound dynamical downscaling will be undertaken for the whole country. The regional climate model ‘PRECIS’ (Providing Regional Climates for Impacts Studies) developed by the Hadley Centre would help the Cameroon
Meteorological Department to generate high resolution climate change information and limited area models (LAM), based on the fact that its main innovation allows us to run the model on a ‘ordinary’ PC running under the Linux operating system.

In addition Cameroon should continue to maintain its current network of stations with long-term climate records – and possibly even create a few more.
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References


