Space–time rainfall variability in West Africa derived from observations and GCMs

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Abstract The CATCH project quantifies the impact of climate variability on water resources in West Africa by using observed and simulated rainfall scenarios as input for hydrological models. The reliability of the rainfall of a global circulation model (GCM) (LMD-6) was investigated over the CATH region (0° to 5°E and 6° to 15°N). Observed daily rainfall data between 1960 and 1990, spatially averaged over the five selected GCM cells, were compared with the GCM rainfall to identify which variability is reproduced. This includes the seasonal cycle, the inter-annual variability and daily rainfall characteristics. Substantial discrepancies between the observed and simulated rainfall regime of West Africa were found.

Key words global circulation model (GCM); rainfall; simulation; observation; variability; season; climate; West Africa

INTRODUCTION

The rainfall regime of West Africa is characterized by multiscale variability (e.g. Lebel et al., 2000; Le Barbé et al., 2002) that has great impact on the water resources. Rainfall regimes need to be considered to understand the links between rainfall and water resources variability in various climatic regions. One special concern is the possible modification of these rainfall regimes due to climate change. Observations of present rainfall regimes and plausible scenarios for future rainfall regimes derived from general circulation models (GCMs) have to be jointly considered to characterize the possible impact of climate variability on water resources. There are, however, good reasons to check the reliability of GCM simulations since their coarse resolution has involved a simplified parameterization of rainfall-producing processes and an inadequate scale for representation of rain fields. Therefore various intercomparison studies have been launched recently (e.g. Phillips et al., 2000). This study contributes to the validation of the GCMs representation of the rainfall regime in West Africa as a preliminary step for coupled climate and water resources studies.

SYNTHESIS OF WEST-AFRICAN RAINFALL VARIABILITY

High resolution data, such as those collected in HAPEX-Sahel in the 1990s and within the framework of the CATCH project (Couplage de l’Atmosphère Tropicale au Cycle Hydrologique) since 1997, are needed to characterize the West African variability at the...
convective scale. However, daily rainfall data recorded by the operational, low-density networks are the only source of information for analysing the rainfall variability at regional and synoptic scales over several decades. One objective of CATCH is to explore the scale-dependency of the rainfall variability in this region, by focusing on a regional window extending from 0° to 5°E and from 6° to 15°N. One initial step was to evaluate how the various scales of variability are reproduced by climate models. The LMD-6 is used here as GCM (Polcher & Laval, 1984; Lebel et al., 2000). Its output was analysed and compared to raingauge observations over the period 1960–1990. This was done for five grid cells covering the whole range of the West African climate, from the Guinea Gulf to the northern edge of the Sahel. Each cell covers 70,000 km² (Fig. 1) and contains between 28 and 50 daily reading gauges (Table 1). In Table 1 and thereafter these grid cells are referred to by using the latitude of their centre (e.g. cell 13.6).

Analysis of observed daily rainfall shows (a) a noticeable differences in the inter-annual rainfall variability between the north and the south, (b) a decrease of the mean annual rainfall from south to north, (c) a shift in the seasonal cycle from a two-season regime in the south to a single rainy season in the north, and (d) most rainfall is between 1 to 10 mm day⁻¹.

RAINFALL SIMULATED WITH THE LMD-6 GCM

The LMD-6 GCM is a grid point model (Polcher & Laval, 1994) that uses a regular discretization in longitude and latitude and an irregular one along the vertical axis (15 sigma levels). Its resolution in the study region is about 1.65° (latitude) by 3.75° (longitude) (Table 1). This model version uses the land surface scheme SECHIBA (Ducoudré et al., 1993; de Rosnay & Polcher, 1998). The model was forced with Seawater Surface Temperatures (SSTs) observed over 34 years, starting in 1960. Five runs were carried out (i.e. A, B, C, D and E) to separate in the simulated climate the part forced by the ocean from the chaotic nature of the atmosphere. The only differences between the runs are the initial conditions on 1 January 1960.

First the rainfall signals simulated by the GCM for the five runs were intercompared at various scales. The following results were obtained:
(a) the mean annual latitudinal gradient is well reproduced by the five runs (A–E), which are very close to each other (Fig. 2(a));
(b) the relative homogeneity of the mean annual rainfall simulated by the five runs (Fig. 2(a)) hides significant differences between the simulated seasonal cycles (Fig. 3(a)). These differences are especially important in the peak of the rainy season when land surface processes play an important role in the atmosphere–land exchanges. On the opposite there is a large similarity between the five runs at the beginning and the end of the rainy season (Fig. 3(a)), when the large-scale forcing is dominant (which does not mean that the monsoon onset is well reproduced as will be discussed below). The differences between the runs are still more noticeable when looking at the inter-annual variability (Fig. 3(b)).

In conclusion, people need to consider that the model behaviour is chaotic during the rainy season. In the next section the LMD-6 GCM behaviour will be characterized by averaging the output of the five runs.
Fig. 1 Location of the CATCH region in West Africa.
Table 1: Name and location of the LMD-6-GCM grid cells (CATCH region).

<table>
<thead>
<tr>
<th>Name</th>
<th>East longitude (°)</th>
<th>North latitude (°)</th>
<th>Number of raingauges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Cell 13.6</td>
<td>0</td>
<td>3.75</td>
<td>12.8</td>
</tr>
<tr>
<td>Cell 12</td>
<td>0</td>
<td>3.75</td>
<td>11.2</td>
</tr>
<tr>
<td>Cell 10.4</td>
<td>0</td>
<td>3.75</td>
<td>9.6</td>
</tr>
<tr>
<td>Cell 8.8</td>
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<td>3.75</td>
<td>8.0</td>
</tr>
<tr>
<td>Cell 7.2</td>
<td>0</td>
<td>3.75</td>
<td>6.4</td>
</tr>
</tbody>
</table>

COMPARISON OF THE LMD-6 GCM AND THE OBSERVED RAINFALL IN THE CATCH REGION

The performance of the GCM is assessed by comparing the observed rainfall, spatially averaged over a GCM cell, with the corresponding GCM rainfall, computed as the average of the five runs. This comparative study covers 31 years (1960–1990) and includes three time-scales: the mean climate, the inter-annual variability and the daily rainfall characteristics.

Fig. 2 Mean annual rainfall from south to north: (a) five runs simulated with the LMD-6 GCM, and (b) average of the five simulations and observed values.

Fig. 3 Five runs of simulated rainfall for cell 10.4, period 1960–1990: (a) mean seasonal cycles, and (b) annual rainfall.
Seasonal cycle

Generally, the whole dynamics of the rainy season onset is not reproduced satisfactorily by the model. The seasonal differences between the GCM outputs and the observations are clear (Fig. 4(a)), thus confirming the conclusions of Lebel et al. (2000). The rainy season starts too early and finishes later than observed. The model produces noticeable amounts of rain during the dry season. The overestimation is of the same order for all grid cells, except the southern ones (8.8 and 7.2). For these two cells, the first rainy season is simulated unrealistically strong, with an overestimation of the rainfall by a factor of about 3. In all cells (except 7.2) the observed peak of the rainy season is underestimated. The general discrepancy in the coastal cell may be attributed to the impact of SSTs fluctuations. The major intra-seasonal characteristics, however, are reasonably found for the CATCH region: the peaks of the rainy season are reproduced as well as the shift towards a single one while moving from the south to the north.
Mean annual rainfall

Generally, the decrease of the mean annual rainfall is reasonably simulated by the model when moving from south (coast) to north. However, the local effect of the Atacora mountainous range on the rainfall regime between $9^\circ$N and $11^\circ$N is not detected (Fig. 2(b)). This is probably due to the coarse resolution of the model. Comparison with observed data presents a systematic overestimation of the mean annual rainfall. On the coast (cell 7.2), this overestimation can reach 1000 mm year$^{-1}$ (80%).

Daily rainfall

The GCM produces a smaller number of non-rainy days than observed (Table 2). Obviously, this implies that the number of simulated rainy days is higher. The number of days with daily rainfall above a certain daily total (threshold) clearly shows this for all cells (Table 2). The analysis of the distribution of GCM daily rainfalls is supported by Lebel et al. (2000). The difference between the daily GCM and the observed rainfall is caused by rainfall greater than 10 mm day$^{-1}$ (Table 2). The relative error is

<table>
<thead>
<tr>
<th>Cell</th>
<th>Number of days observed</th>
<th>Number of days simulated</th>
<th>Observed (mm year$^{-1}$)</th>
<th>GCM (mm year$^{-1}$)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>5286</td>
<td>2413</td>
<td>0.00</td>
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</tr>
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<td>10.4</td>
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<td>8.8</td>
<td>3120</td>
<td>1039</td>
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<tr>
<td>7.2</td>
<td>2397</td>
<td>528</td>
<td>0.00</td>
<td>0.00</td>
<td>14.98</td>
</tr>
</tbody>
</table>
23% (totals of classes \( h < 1 \) and \( 1 < h < 10 \)) in the Sahelian region (cell 13.6) and 21% in the south (cell 7.2). The most important reason for the differences, however, are the days with rainfall more than 30 mm day\(^{-1}\). For these days the relative error is 2685% and 1843% for the cells 13.6 and 7.2, respectively (Table 2). In the Sudanian zone (cells 7.2 and 8.8), rainfall is not only produced by convective events, but also by monsoon-type of rain systems. Thus, the failure of the GCM to properly reproduce the statistical distribution of the daily rainfall in this region may be linked to the existence of complex physical processes that are not well accounted for by the convection schemes used in the GCM.

CONCLUSIONS AND DISCUSSION

Important discrepancies were found between the observed rainfall regime of West Africa and the regime simulated by the LMD-6 GCM. From an energetic and climatic point of view, the unreliable simulation of the seasonal cycle over the whole climatic transect is a serious shortcoming. An oversimplified representation of the land processes in GCMs may be one reason for these differences.

Two major problems for water resources assessment are:
(a) the overestimation of the seasonal rainfall during the first rainy season on the coast by a factor 3, and
(b) the unrealistic frequency distribution of the daily rainfalls.

The latter is a serious drawback if one considers daily rainfields as proxy of event rainfields. As long as GCMs produce unrealistic rainfields at the daily scale, it is difficult to use disaggregation algorithms to generate fields of rainfall events for hydrological models as proposed by Lebel et al. (1998). Regional climate models might produce more realistic rainfields at the daily and convective scales than those obtained from GCMs (Zheng et al., 1999), due to their finer resolution.

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REFERENCES


