
Further analysis of simulated interdecadal and interannual variability of summer rainfall over tropical north Africa

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The comments of Sud and Lau (hereafter SL) raise a number of important questions. In particular they raise the issue of validating hypotheses such as a strong oceanic forcing on seasonal rainfall variability, and validating the models used to support such hypotheses. Two points are worth making in this vein. First, that the model(s) should first be verified as state-of-the-art for the problem under consideration. This can be done by studying the model’s mean climate over the region of interest, its teleconnections to other regions, and by comparing its interannual skill with other models and with empirical relationships. Second, a representative sample of simulated data is required to support the hypothesis. Ten years, as used by Rowell et al. (1995) (hereafter RFMW) and by SL, are not sufficient to estimate accurately the portion of seasonal variability due to SST forcing, but, if sufficiently representative, should be enough to provide general support for such a hypothesis. Thus to further verify RFMW’s hypothesis of tropical north African rainfall variability, a multi-decadal suite of simulations is required, which employ a general circulation model (GCM) with reasonable dexterity over the north African region. Such a model has recently become available at the Hadley Centre, and, although it inevitably has some residual weaknesses, two 46-year runs have been done enabling a more considered response to be made to SL’s comments. These long runs also allow separate study of decadal and interannual timescales, an important distinction made in the empirical analysis of Ward (1994) and RFMW, and furthermore they allow consideration of the representativity of the 10-year samples of RFMW and SL.

The simulated data to be analysed derive from a 2-member ensemble of 46-year runs with version 2b of the Hadley Centre climate model; HADAM2b (Hadley Centre Atmospheric Model). This is a development from HADAM 1, from which data were first submitted to AMIP and used by SL, amongst others. The poor performance of HADAM 1 over the Sahel had already been noted by RFMW. The developments leading to HADAM 2b include improvements to the cloud and precipitation parameterizations, the addition of orographic form drag in the calculation of momentum roughness length, an extension to the gravity-wave drag parameterization, a 4-layer rather than a 1-layer soil hydrology scheme, and some tuning of the horizontal diffusivity (see Hall et al. (1995) for further detail). Each experiment consists of a multi-decadal simulation of the period October 1948 to December 1994, forced throughout by observed sea surface temperatures (SSTs) and sea-ice extents from a globally complete data-set constructed at the Hadley Centre and known as GISSST 1.1 (Global sea-ice and SST) (Parker et al. 1995). The two simulations differ only by their initial atmospheric conditions; these are the model output on 1 October from the last two years of a 10-year run of HADAM 2b, forced by climatological SSTs and sea ice.

Following RFMW, and the comments made above, it is important first to verify the statistics of the model’s mean climate and variability. Table 1 illustrates this on a seasonal and monthly basis for the three regions used by RFMW, by comparing the simulated rainfall with an updated version of the gridded observed rainfall data described by Hulme (1994). At a seasonal timescale, although the Sahel and Guinea...
Coast are about 15–20% too dry, the mean rainfall and its coefficient of variation (i.e., standard deviation scaled by the mean) are otherwise well simulated by HADAM 2b in each region. The evolution of the seasonal cycle (at monthly resolution) is, however, less well simulated, with July and August rainfall being too similar in all regions, and the variability of September means being too high in the Sahel and Soudan. However, from the results of the following paragraphs, it seems unlikely that these deficiencies have much impact on the seasonal mean response to SST forcing.

The second stage of model verification is to show in a statistical sense that the patterns of SST anomalies to which the model is responding are realistic. This is examined separately on decadal and interannual timescales, by filtering both the rainfall and SST data. A Chebychev filter is used (following Walraven 1984), with the same 50% amplitude cut-off as RFMW: 11.25 years. Figure 1 shows the correlations between each of the filtered rainfall time series and the filtered GISST data (except for the low-frequency Guinea Coast, which is omitted because decadal fluctuations account for little of its total variability); these can be compared with the observational analysis of RFMW (their Fig. 7). On both decadal and interannual timescales the patterns of correlations are similar to those observed, except for the high-frequency correlations between parts of the equatorial Atlantic and the Sahel or Guinea Coast. Further statistical testing of the high-frequency relationships shows that there are only small isolated regions (including the equatorial Atlantic) with a greater than 95% probability that the observed and model correlations derive from different populations (using a $\chi^2$ test on $z$-transformed correlations); these may however have occurred by chance. A point of greater concern is a general tendency around the globe for the model correlations to be slightly lower than those observed, and this suggests that the amplitude of the SST response over tropical north Africa is partitioned incorrectly with the random component of the variability. However, if instead the model correlations are plotted using ensemble means (not shown), the comparison with observations is improved, suggesting that this may be a useful approach to dampen the artificially excessive internal variability. As a final check on the model, it is also worthwhile verifying the fraction of total seasonal variance explained by the low-frequency component. For the model, this fraction is 55%, 50% and 14% for July to September (JAS) rainfall in the three respective regions (using ensemble mean data), and, for observations, it is 61%, 59% and 11%, respectively (1949–94); such differences seem unlikely to be statistically significant, although more runs would be needed to test this objectively.

A cautionary note on the interpretation of the relationships displayed in Fig. 1, worth mentioning here and neglected by RFMW, is that the process of filtering should only be viewed as providing clues towards the identification of the forcings and mechanisms of climate variability. Although the dominant frequencies of influential SST patterns will be reflected in the spectrum of the forced variable, it should be remembered when searching for mechanisms that the atmosphere ‘sees’ only the relative amplitude of the spatial patterns of SST, but knows little of their temporal context beyond a few months.

Given the above background to the strengths and weaknesses of this most recent Hadley Centre model, its performance at simulating the time series of rainfall variability over tropical north Africa can now be assessed and compared with the results of SL and RFMW. Figure 2 illustrates the 46-year time series of observed and modelled JAS rainfall anomalies for the three regions, and Table 2 presents the correlation skill of these model time series, along with confidence intervals to give an idea of sampling error (taking account of serial correlation following Bartlett (1935) and Folland et al. (1991)). Note that model ensemble means have been used to counter the excess random variability found in the individual runs. The first column of Table 2 shows that moderate simulation skill was achieved by the model over the last 4 to 5 decades, and this is also reflected in Fig. 2. For all regions these are lower than the skill estimates of RFMW, but higher than those of SL over the Sahel and Soudan (for all but one model) and close to the median of AMIP models over the Guinea Coast. The confidence ranges are however rather large, particularly for the Sahel and Soudan where serial correlation increases uncertainty. Next, the two right-hand columns of Table 2 can be used to assess the sensitivity of these skills to analyses based
only on subsets of years. For the RFMW's years, the fourth column of Table 2 hints that this selection may tend to inflate model skill, as suggested by RFMW and SL (although the skill differences are not actually significant). Conversely, the fifth column of Table 2 indicates that the AMIP sample of years may underestimate model skill for two of the regions, suggesting that this period is rather unrepresentative of the longer record (not surprising for the Sahel at least, as also noted by SL). It is therefore possible that some of the better models analysed by SL may in fact be capable of somewhat higher skill if run for a few decades. Note also, that HADAM 2b is substantially less skillful over the Guinea Coast than many of the AMIP runs shown by SL, suggesting a partly incorrect SST response in this region. Lastly, Table 2 shows results for the low-frequency and high-frequency components of the time series. At decadal timescales the correlation skill is clearly enhanced over the Sahel and Soudan, and this presumably reflects reduced random chaotic noise owing to the effects of temporal averaging, coincident with an at least moderate influence of SSTs. In the high-frequency analysis, skill over the Sahel and Soudan is lower than in the unfiltered data, because part of the total SST response has been filtered out, yet the effects of random ‘noise’ (a purely high-frequency phenomenon) are retained; it is mainly from this part of the spectrum that the AMIP years were sampled.

Reflecting on the above results, we are now in a better position to discuss SL's comment that 'a majority of GCMs in the AMIP suite, including the first AMIP version of the UKMO-GCM, were unsuccessful in unequivocally supporting the HC's [Hadley Centre's] hypothesis'. Three points can be made:

1. The above analysis shows (and as SL suggest), the ten AMIP years are rather unrepresentative of a longer multi-decadal record, since they sample only a small part of the low-frequency fluctuations of the Sahel and Soudan rainfall.

2. It is also possible that the ten years of RFMW are not wholly representative of the four decades from which they were sampled, and as RFMW state, this may have resulted in an overestimate of skill owing to the emphasis on extreme years.

3. Most important, many of the models used for AMIP seem not to be 'state-of-the-art' for the purpose of verifying the hypothesis of a strong influence of SSTs on seasonal rainfall variability over tropical north Africa. This is demonstrated by the fact that the majority of the models were unable to match the statistically significant skill found in a few models (SL's Fig. 3). It is possible that tropical north Africa is a particularly sensitive area to model errors, and indeed this is the experience of the UKMO, as discussed by RFMW. There are many potential reasons for this, including interaction between clouds and radiation (RFMW), unrealistic moisture convergence as a symptom of other problems (SL), and the suitability of interactive soil moisture schemes (SL). Erroneous land surface interactions may also be the cause of the climate drifts which SL suggest could be a problem in some models.

In conclusion, the results of a new pair of multi-decadal ocean-forced simulations presented here add further support to the notion that SSTs have a moderate to strong influence on tropical North African seasonal rainfall variability at decadal and interannual timescales. It is also valuable to note that the influence of SSTs at decadal timescales is supported by a recent intercomparison of simulated Sahel rainfall in the multi-decadal runs of nine different GCMs (Lievezey et al. 1995), which all showed a downward trend from the 1950s to the 1980s. On the other hand, it must also be stated that the true potential predictability of seasonal rainfall over tropical North Africa, cannot yet be assessed with high accuracy. Meanwhile, the results presented in Table 1, and the known 'simulation' skill of empirical models (e.g. correlations of 0.78, 0.77 and 0.74 for the Sahel, Soudan and Guinea Coast, respectively; Ward, personal

<table>
<thead>
<tr>
<th>Area</th>
<th>All years (unfiltered)</th>
<th>All years (low-freq.)</th>
<th>All years (high-freq.)</th>
<th>RFMW Years</th>
<th>AMIP Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahel</td>
<td>0.63 ± 0.02</td>
<td>0.87</td>
<td>0.37 ± 0.56</td>
<td>0.78 ± 0.39</td>
<td>0.12 ± 0.63</td>
</tr>
<tr>
<td>Sudan</td>
<td>0.59 ± 0.06</td>
<td>0.81</td>
<td>0.37 ± 0.56</td>
<td>0.74 ± 0.26</td>
<td>0.50 ± 0.83</td>
</tr>
<tr>
<td>Guinea Coast</td>
<td>0.49 ± 0.06</td>
<td>0.66 ± 0.90</td>
<td>0.51 ± 0.36</td>
<td>0.60 ± 0.07</td>
<td>0.12 ± 0.63</td>
</tr>
</tbody>
</table>
Figure 1. Standard correlation between filtered July to September (JAS) SST anomalies (on the model grid) and filtered JAS rainfall anomalies, using each model run separately. (a) Low-frequency Sahel, (b) low-frequency Soudan, (c) high-frequency Sahel, (d) high-frequency Soudan, and (e) high-frequency Guinea Coast. Shading in (a) and (b) indicates correlations greater than 0.7 and less than −0.7 (note that it does not indicate an assessment of significance). Shading in (c) to (e) indicates where correlations are significantly different from zero at the 95% level.

SST communication 1995) can be used as an approximate minimum estimate of potential predictability (i.e. correlation ≈ 0.7), whereas the runs of RFMW probably represent an absolute maximum estimate of potential predictability (correlation ≈ 0.9). A cautionary note however, is that these estimates derive from a period of large decadal variability over the Sahel and Soudan, and it is likely that during periods of lesser decadal variability (e.g. 1920–1950), predictability would be lower. These remaining uncertainties can only be narrowed by improving the GCMs used in multi-decadal ensembles, although it may be that such improvements are particularly elusive for the Sahel. As SL state, objective criteria are required to define the ‘ideal’ model; this note has suggested an assessment of the rainfall–SST correlation patterns, along with a careful analysis of the model’s climate statistics.

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Figure 1. Continued.
Figure 2. Time series comparing observed (solid bars) and simulated (ensemble mean) (hatched bars) July to September mean rainfall anomalies for each year from their respective 1951–80 climatologies (Table 1). Also shown are the filtered low-frequency time series for observed (continuous line) and simulated (dashed line) data. (a) Sahel, (b) Soudan and (c) Guinea Coast.
References


