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# Climate variability in central equatorial Africa: Influence from the Atlantic sector

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[1] We document a strong teleconnection between Central Equatorial African (CEA) rainfall (and Congo River discharge) and the large-scale circulation over the North Atlantic, throughout the boreal winter/spring season. Positive rainfall anomalies over CEA (at interannual and multi-annual timescales) are related to anomalous westerly mid-tropospheric zonal winds over the CEA/Atlantic region. These anomalies appear to be part of a coherent structure of zonal wind anomalies extending to the polar regions of the North Atlantic, similar to that associated with the NAO pattern. Idealised model simulations suggest that at least over the tropical and subtropical latitudes of the Atlantic/African sector such a signal may be associated with SST forcing from the Tropical North Atlantic (TNA) region. We conclude that TNA SSTs may force these circulation anomalies over CEA at multi-annual timescales but at interannual timescales they may be relatively independent of TNA SSTs. *INDEX TERMS:* 1833 Hydrology: Hydroclimatology; 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 9305 Information Related to Geographic Region: Africa. **Citation:** Todd, M. C., and R. Washington (2004), Climate variability in central equatorial Africa: Influence from the Atlantic sector, *Geophys. Res. Lett.*, *31*, L23202, doi:10.1029/2004GL020975.

## 1. Introduction

[2] Central Equatorial Africa (CEA) is the third most extensive region of deep convection, globally, after the West Pacific warm pool region and Amazonia. Tropospheric heating associated with this convection is a primary driver of the tropical general circulation. Broadly, the CEA region (see box in Figure 1) represents the Congo River basin (roughly 12°S–7°N, 15°E–32°E), which includes the world's second most extensive region of tropical rain forest. However, our understanding of the climate processes in CEA is limited. Indeed, the literature on African climate variability is strongly biased towards West Africa (including the Sahel), East Africa and Southern Africa. Thus, the CEA region represents a notable gap in our understanding of the tropical climate system.

[3] Remarkably few studies have attempted to characterise either the meso-synoptic scale processes that determine rainfall over CEA [e.g., *Laing and Fritsch*, 1993], or the nature of variability at longer timescales. A limited number of publications have assessed the extent to which CEA climate variability at interannual timescales is influenced by the state of the global oceans, specifically through correlation of rainfall with tropical sea surface temperatures (SSTs). There is evidence of a positive association between rainfall over CEA and tropical southern Atlantic SSTs [*Hirst and Hastenrath*, 1983; *Nicholson and Entekhabi*, 1987; *Camberlin et al.*, 2001]. Evidence for the impact of ENSO on CEA is rather limited. *Camberlin et al.* [2001] document a negative association of Nino-3 Pacific SSTs and rainfall in the extreme western part of CEA, whilst *Amarasekera et al.* [1997] note a weak negative correlation between annual Congo River discharge and East Pacific SSTs. Nevertheless, the observational studies overall indicate that teleconnections from the global tropical oceans to CEA region are actually rather weak [e.g., *Camberlin et al.*, 2001]. Century long GCM simulations forced with historical SSTs show that model CEA rainfall is also relatively insensitive to SST forcing [*Washington*, 2000]. In this paper we document a strong teleconnection between CEA climate variability during the boreal winter/spring season and the large-scale atmospheric circulation in the north Atlantic/African sector. We evaluate the mechanisms driving this response using an idealised GCM experiment and conclude that the role of SST forcing is time dependent.

## 2. Data and Methods

[4] A major reason for the lack of previous studies of CEA climate is the paucity of high quality long-term datasets [e.g., *Camberlin et al.*, 2001]. In this study we derive an index of CEA rainfall from the 0.5° gridded monthly rainfall product of *New et al.* [1999], averaged over the region 10°S–5°N, 15–30°E for the period 1901–98. Rain gauge density over much of CEA is relatively poor, so we also analyse a long-term record (1903–89) of monthly discharge data from the River Congo (Q), observed at Kinshasa, Democratic Republic of Congo (4.3°S, 15.3°E). The Congo River is the world's second largest in terms of both discharge (mean annual discharge is around 40,000 $m^3 s^{-1}$) and basin area (approximately 3.8M $km^2$) and drains most of the CEA region (roughly 12°S–7°N, 15–32°E). The Congo discharge data, therefore, represent an independent measure of effective precipitation integrated over most of CEA.

[5] As an equatorial region, CEA experiences a marked semi annual cycle in rainfall. Mean rainfall averaged over the CEA region, peaks in the transition months of OND (160 mm $month^{-1}$) and MAM (about 146 mm $month^{-1}$), with minima in the high season months of JAS (73 mm $month^{-1}$) and DJF (123 mm $month^{-1}$), although rainfall is clearly substantial in all seasons. The semi annual cycle is associated with the north/south movement of the ITCZ

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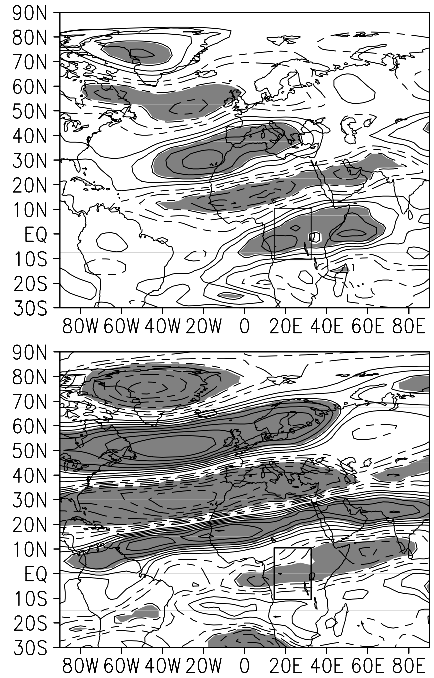


**Figure 1.** (top) Correlation of AMJ Q and FMA 500 hPa zonal wind (1948–89), (bottom) correlation of FMA NAO and 500 hPa zonal wind (1948–98). Positive (negative) contour values are solid (dotted), contour interval is 0.1, zero contour is omitted. Shaded regions denote correlations significant at the 0.05 level. All wind data from the ERA40 reanalysis dataset. Box in Figure 1 (top) shows CEA region.

across tropical Africa. Congo River discharge shows peaks in the AMJ and NDJ seasons indicating a lag in the surface hydrological system of 1–2 months. In this study we focus our analysis on the boreal winter/spring seasons. We presents results based on the FMA (AMJ) wet rainfall (discharge) season, as an exemplar of results which are actually consistent over the entire boreal winter-spring CEA rainfall period (December–April). The correlation between CEA rainfall during FMA and Q during AMJ is 0.64 over the period 1903–89, and is robust at both interannual and multi-annual timescales ($r = 0.6$ and $r = 0.75$, respectively, see Results section for details of data filtering). It should be noted that all our results are largely insensitive to whether CEA rainfall or Congo River discharge is used as the measure of CEA climate.

[6] To assess the association of CEA climate and the large-scale circulation we use the standard techniques of correlation and composite analysis. Information on the large-scale atmospheric circulation is obtained from two independent reanalysis datasets. The National Center for Environmental Prediction (NCEP) reanalysis dataset extends from 1948 [*Kalnay et al.*, 1996] and the European Centre for Medium Range Weather Forecasts (ECMWF) ERA-40 (http://www.ecmwf.int/research/era/index.html) from 1958. We use the *Smith and Reynolds* [2004] SST data (1950–89) and an index of North Atlantic Oscillation (NAO) (1901–89) from *Jones et al.* [1997]. All correlations calculated on unfiltered data are preceded by removal of linear trends. There are known discontinuities in the NCEP data over Africa [*Camberlin et al.*, 2001], notably in 1967-8, associated with abrupt changes in the amount of data assimilated. To account for this problem we also conducted our correlation analysis separately on NCEP data for the 1948–67 and 1968–98 periods (not shown). The results are largely the same for both periods such that we are confident that the results for the entire period are robust.

## 3. Results and Discussion

[7] The teleconnections linking CEA climate with the North Atlantic sector are characterised by a remarkably strong positive correlation between mid-tropospheric zonal winds over CEA and AMJ Q (Figure 1, top) (similar for FMA CEA rainfall, not shown). These correlations extend throughout the troposphere but peak near 500 hPa and are evident in both the NCEP and ERA-40 reanalysis data. The zone of high correlation over CEA is part of a coherent structure of five bands of alternating sign extending from the polar North Atlantic to equatorial Africa.

[8] This structure is strongly characteristic of the NAO (Figure 1, bottom), but with correlations of opposite sign. Our analysis shows a strong negative association between the NAO and both CEA rainfall and Congo discharge, during the boreal winter/spring period (Table 1). This exists for both interannual and multi-annual timescales. Despite its equatorial location, the climate of CEA in this season appears more sensitive to influences from the North Atlantic than to ENSO, the dominant mode of tropical climate variability (Table 1). *McHugh and Rogers* [2001] document a similarly strong association between boreal winter rainfall over neighbouring southeast Africa (0–16°S, 25–40°E) and the NAO. It appears, therefore, that the NAO is associated with variability in the climate of an extensive region of tropical Africa from the Atlantic to the Indian Ocean.

[9] The NAO itself is intimately connected with Tropical Atlantic climate variability, involving associated fluctuations in SSTs and trade winds over the Tropical North Atlantic (TNA) (see, e.g., *Marshall et al.* [2001] for a review). Indeed, a direct response to the NAO is the well-established Atlantic 'tripole' pattern of SST anomalies, the leading mode of SST variability in the North Atlantic. The TNA region (5–20°N, 15–40°W) represents the southernmost, subtropical centre of action [*Venzke et al.*, 1999]. An important question arises, therefore, whether the observed atmospheric response associated with CEA rainfall anomalies, and linked to the NAO, might itself be a response to SST anomalies in the TNA region.

[10] We now consider this possibility. The nature of ocean-atmosphere interaction over the Atlantic region is thought to be time-dependent, so we consider behaviour at different timescales. The spectra of CEA rainfall and Congo

**Table 1.** Correlation Between NAO and Indices of CEA Climate[a]

| | Unfiltered | HF | LF |
|---|---|---|---|
| AMJ $Q_C$ vs FMA NAO (1903–1988) | −0.45** | −0.37** | −0.56 |
| Annual Q (Jul–Jun) vs FMA NAO (1903–1988) | −0.34** | −0.37** | −0.43 |
| FMA CEA rainfall vs. FMA NAO (1901–98) | −0.37** | −0.38** | −0.41 |
| AMJ Q vs FMA Nino3 SST | −0.20 | — | — |
| FMA CEA rainfall vs FMA Nino3 SSTs | −0.09 | — | — |

[a]Correlations for unfiltered and interannual (HF, <4 years) timeseries significant at the 0.01 level indicated by **. No significance testing conducted on multi-annual (LF, >4 years) timeseries. All unfiltered data have linear trends removed prior to analysis.

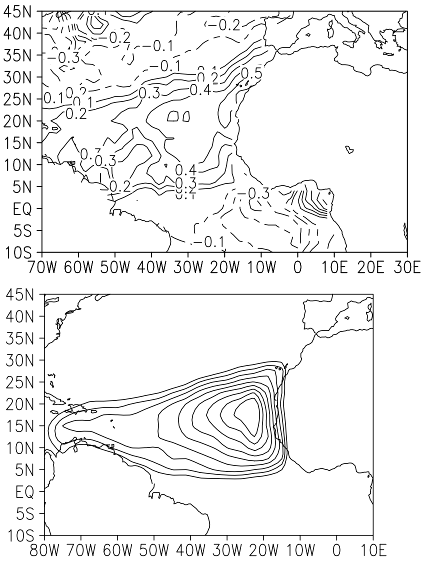

**Figure 2.** (top) Correlation of LF AMJ Q and LF FMA SST. Positive (negative) contour values are solid (dotted), contour interval is 0.1, zero contour is omitted. (bottom) SST anomalies (K) used in idealised AGCM experiments. Contour range is from 0.8 K to 2.4 K with interval of 0.2 K.

discharge during winter/spring (not shown) show power in the multi-annual (7–9 years) band and the interannual band (2–4 years), whilst that for TNA SSTs is characterised by power on multi-annual to decadal scales [*Melice and Servain*, 2003; *Andreoli and Kayano*, 2004]. On the basis of the CEA rainfall and AMJ Q spectra, we have filtered the discharge, rainfall and SST data to retain the interannual, high frequency (HF) component (<4 years) and the multi-annual, low frequency (LF) component (>4 years). Our analysis indicates that there is indeed a strong, significant positive association of TNA SSTs with AMJ Q (Figure 2, top) (and with CEA rainfall, not shown) apparent in the LF band (Figure 2, top, r = 0.47) but not in the HF band (not shown). It is interesting to note that at interannual timescales TNA SSTs are related to ENSO (as well as to the NAO) and the absence of an associated between TNA SST and CEA climate in the HF band may explain the weak association of ENSO and CEA (Table 1).

[11] To investigate further the hypothesis that the observed atmospheric response at LF may be a result of TNA SST forcing we performed idealised experiments with the UK Hadley Centre Atmospheric Model (HadAM3). The model resolution is 2.5° latitude by 3.75° longitude with 19 vertical levels. Model integrations were started on 1st November and ended on 30th April. The lower boundary consisted of the seasonally varying SST climatology onto which a constant SST anomaly structure was imposed from 1st December to 30th April (Figure 2, bottom). The SST anomaly structure is defined from composites of observed SSTs based on a sample of high minus low extreme years (the upper and lower 10th percentile) from the timeseries of observed TNA SSTs. To identify any 'signal' of SST influence within the internal atmospheric variability an ensemble of 10 model integrations was performed in which each ensemble member differed only in the initial starting conditions. Resulting ensemble mean anomalies were calculated relative to the mean of the 10-year control run. Local significance was derived using a t-test.

[12] The response of the model atmosphere to the positive TNA SST anomalies (Figure 3, bottom) shows significant zonal wind anomalies extending in the characteristic meridionally banded structure across Africa and the Atlantic region, consistent with the observations (Figure 1). The magnitude of the response at high latitudes is weaker than that associated with the NAO such that TNA SSTs appear to force the atmosphere most strongly in the tropics and subtropics (consistent with *Sutton et al.* [2000]). The model rainfall response shows significant positive anomalies over the CEA region of up to 40 mm month$^{-1}$ (Figure 3, top). It is noteworthy that the large-scale circulation structure associated with observed CEA rainfall variability (Figure 1) is similar at both interannual and multi-annual timescales (not shown). However, our results in Figure 2 (top) suggest that SST forcing from the TNA region is likely to be apparent largely at multi-annual timescales. At interannual timescales this type of response may be relatively independent of SST forcing.

[13] Finally, we comment on the mechanisms through which the observed large-scale zonal wind structure over CEA might influence rainfall processes. Composite zonal wind anomalies based on samples of wet minus dry years (determined from the upper and lower 10th percentiles of the CEA rainfall series) show westerly zonal wind anomalies over CEA (centred near 4°S), throughout the troposphere, with a maxima of 4.0 ms$^{-1}$ near 550 hPa (Figure 4, bottom). The anomaly structure for ERA-40 data is essentially the same (not shown). Therefore, for wet minus dry periods

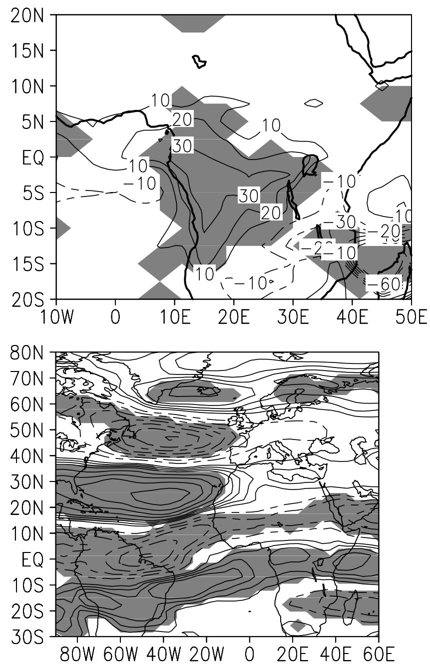

**Figure 3.** Mean difference between 10-member ensemble HADAM3 experiment with TNA SST anomalies and model control run, (top) FMA precipitation mm month$^{-1}$, contour interval is 10 mm month$^{-1}$ (bottom) FMA 500 hPa zonal wind (ms$^{-1}$), contour interval is 1.0 ms$^{-1}$. Positive (negative) contour values are solid (dotted), zero contour is omitted, shading indicates anomalies significant at 0.05 level.

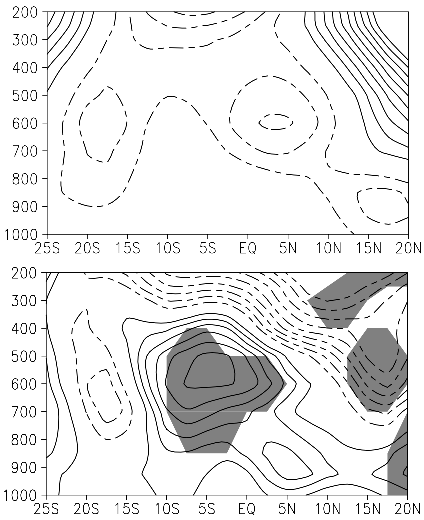


**Figure 4.** Latitude/height plot zonal wind ($ms^{-1}$) averaged over 15–30°E during FMA (top) the long-term mean (contour interval is 2.5 $ms^{-1}$) (bottom) anomalies for wet (1969, 1968, 1970, 1963, 1957) minus dry (1992, 1949, 1958, 1967, 1983) CEA rainfall periods (contour interval is 0.5 $ms^{-1}$). Positive (negative) contour values are solid (dotted), zero contour is omitted, shaded area indicates anomalies significant at the 0.05 level. All data from the NCEP reanalysis dataset.

over CEA vertical wind shear is increased above 500 hPa and reduced below this level. We may speculate that these wind shear anomalies play a critical role in modulating the development of deep convection in the region during boreal winter/spring [e.g., *Rowell and Milford*, 1993]. *Nicholson and Grist* [2003] suggest that there may be a fundamental association between rainfall, the ITCZ and the strength of the twin African Easterly Jets (AEJ-North and AEJ-South) over CEA. During the Boreal spring over the CEA region the AEJ-N is centred on the 600 hPa level, near 4°N (with mean velocity up to 8 $ms^{-1}$) and the weaker AEJ-S near 17°S (with mean velocity up to 6 $ms^{-1}$) (Figure 4, top). Figure 4 (bottom) shows that the position of the AEJ features remain relatively constant between composite samples, although the AEJ-N is substantially weaker by about 2.0 $ms^{-1}$ and the AEJ-S stronger by about 1.0 $ms^{-1}$ during wet conditions compared to dry. This structure of observed zonal wind anomalies is very similar to that of the HadAM3 experiment described above (not shown). Further research is clearly required to determine the relationship between wind shear, and strength of the AEJ features and the meso-scale convective systems, likely to be the dominant rainfall producing system over CEA [*Laing and Fritsch*, 1993].

## 4. Conclusions

[14] Our understanding of the climate of Central Equatorial African region is arguably weaker than that of any other tropical continental region. In this paper, we document a strong teleconnection between CEA rainfall and the large-scale circulation over the North Atlantic throughout the boreal winter/spring season, including the spring CEA wet season. Positive rainfall anomalies over CEA are related to anomalous westerly mid-tropospheric zonal winds over the CEA/Atlantic region. This is part of a structure extending to the polar regions of the North Atlantic, similar to that associated with the NAO pattern. Observations and idealised model simulations suggest that over the tropical and subtropical latitudes of the Atlantic/African sector such a signal may be associated with SST forcing from the Tropical North Atlantic region, at least for low frequency multi-annual variability. We can conclude that (i) the large-scale circulation structure associated with CEA rainfall variability is similar at both interannual and multi-annual timescales (ii) the mechanisms forcing this large-scale structure over CEA may time-dependent, such that at multi-annual timescales they may be forced by TNA SSTs but at interannual timescales they are relatively independent of SST forcing. Finally, there is a need for further research to understand the relationship between the large-scale flow and associated vertical shear, the AEJs and the occurrence of meso-scale convective clusters.

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