Article

# ing the Impacts of Global Warming on Water Budget

# Simulating the Impacts of Global Warming on Water Budget Components in Nigeria

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**Abstract:** This study assessed the temporal-spatial variations in the water budget components across Nigeria and examined the potential impacts of future global warming on available water for agricultural uses in the country. To achieve these objectives, daily data of precipitation, runoff, evapotranspiration and ground water (top soil and root-zone water) from RegCM3 simulations over the region for 1981-2000 (baseline) and 2031-2050 (future) periods were used. The climate model projections suggested significant increase in future temperature ( $1.6^{\circ}$ C in the North,  $1.4^{\circ}$ C in the Mid-Belt and  $1.2^{\circ}$ C in the South zones) across the entire country. The annual projection in precipitation was predicted to decrease slightly (-0.5%) in the North zone but expected to increase by 2.26% and 1.50% in the Mid-belt and South zones respectively. Positive changes (+5 to +60%) in monthly precipitation were generally predicted in dry season and negative changes (-2 to -36%) in wet season across the zones. Significant future increase in temperature and reduced precipitation, particularly during the wet season, were found to have negatively impacted groundwater. The study concluded that future distortion in various water budget components could have negative impacts on crop production in the region.

Keywords: water budget components, climate change, Nigeria.

# **1. Introduction**

Recent advances in modelling and improved understanding of the physical processes of climate systems have made projections of future climate more reliable (Christensen *et al.*, 2007; Pirani, 2011; Taylor *et al.*, 2012). Now, results of downscaled Global Circulation Models (GCM) have been used for regional studies of the impact on the hydrological cycle by integrated hydrological models (e.g. Van Roosmalen *et al.*, 2007, 2009; Goderniaux *et al.*, 2009; 2011) including water quality issues (Sonnenborg *et al.*, 2012).

Evidences from climate projections have shown a temperature increase of 0.74°C in the average surface temperature of the earth during the 20th century (IPPC, 2007; UNEP, 2007) and a further increase of 1.4 to 5.8°C by 2100 is projected due to greenhouse gas emissions (McCarthy et al., 2001). The studies show that climate change has impacted rainfall/precipitation in many parts of the world (Ducci and Tranfaglia, 2008) and has caused significant reductions in a number of regions impacting on the availability of both surface and groundwater resources (Loaiciga et al., 1996). Future climate model projections also suggested further impacts of climate change on future rainfall as many regions of the world will experience more rainfall while others will experience lower rainfall (Van Roosmalen, 2007; 2009). Future change (increase or decrease) in precipitation and the potential impacts on groundwater recharge or discharge may also deteriorate dependent or associated ecosystems and agricultural production (Aldous et al., 2011; Barron et al., 2012; Hinsby et al., 2012). Also, the climate in Africa is predicted to become more variable, and extreme weather events are expected to be more frequent and severe, with increasing risk to health and life. This includes increasing risk of drought and flooding in new areas (Few et al. 2004; Christensen et al., 2007) and inundation due to sea-level rise in the continent's coastal areas (Nicholls, 2004; McMichael et al., 2006). It is speculated that Africa will face increasing water scarcity and stress with a subsequent potential increase of water conflicts as almost all of the 50 river basins in Africa are trans-boundary (Ashton, 2002). As such, agricultural production, which relies mainly on rainfall for irrigation, will be severely compromised in many African countries, particularly for subsistence farmers in sub-Saharan Africa.

Literature suggest that recent researches on climate change effects on groundwater system is still relatively scarce (Marshall and Randhir, 2007). Particularly, our current understanding of the effects of the projected future climate change on the water budget components across the various zones of Nigeria is still inadequate. It is however, speculated that both the temperature rise and rainfall decline due to climate change may affect various components of the water budget directly and indirectly (Zagonari, 2010). For example, sharp decrease/increase in water availability could be complicated by greater uncertainty in the spatial and temporal distribution of rainfall and surface water resources (Niasse, 2004). This is so because, the water resources of a region are highly dependable and sensitive to climate variability and change; due to inter-connection between the climate system, hydrological cycle and water resources system (Oyebande *et al.*, 2002). The primary aim of this study, therefore, is to assess the potential impacts of future climate change on available water for agriculture in Nigeria. The specific objectives are to (i) use climatic data from regional climate model RegCM3 simulations to investigate the recent past (1981-2000) and future (2031-2050) climate changes in Nigeria; (ii) examine the variations in water budget components (precipitation, runoff, evapotranspiration, and top soil as well as root zone water) across the country; and (iii) assess the impact of future climate change on available water for agricultural uses in the region.

# 2. Methods and Materials

#### 2.1. The Study Area

The study area is Nigeria. The country is located approximately between latitude 4° and 14° North of the Equator, and between longitudes 2° 2' and 14° 30' East of the Greenwich meridian (Fig. 1). In this study, the country is subdivided latitudinally into three zones consisting of the South (4°-8°N), Mid-belt (8°-11°N) and the North (11°-14°N) zones (after Abiodun *et al.*, 2012a; Ohunakin *et al.*, 2015).



Figure 1: Map of Nigeria indicating the south, mid-belt and the north zones

#### 2.2. Data Source and Analyses

EH50M global climate model was downscaled over Nigeria for the present-day (1981 - 2000) and future (2031 - 2050) time periods using the International Centre for Theoretical Physics (ICTP) Regional Climate Model version 3 (RegCM3). The daily simulated data of surface air temperature, precipitation, run-off, evapotranspiration, top soil water (0-10 cm) and root zone soil water (below 10 cm depth) were extracted and analysed to obtain their monthly, seasonal and annual statistics (such as the mean and standard deviation). The present-day (1981-2000) mean climate were subtracted from their future (2031-2050) means and the differences obtained were then expressed as the percentage of the present-day means. The future change in a climatic variable is assumed to be significant if its absolute value is higher than the natural variability (*i.e.* standard deviation) of its present-day value (after Abiodun *et al.*, 2012b).

#### 2.3. Model Simulations

The ICTP RegCM3 was developed at the Earth System Physics (ESP) section of the Abdus Salam International Centre for Theoretical Physics (ICTP). It is a three-dimensional primitive equation atmospheric model and an evolution of the NCAR-RegCM2 model originally developed by (Dickinson, 1984; Giorgi et al., 1993a; b) and augmented by (Sun et al., 1999). Comprehensive description of RegCM3 and the main model components are discussed in (Pal et al., 2007). The climate model configuration, physics options and set-up which are identical to those documented in Abiodun et al. (2012b). For the future climate simulations, elevated greenhouse gases under Intergovernmental Panel on Climate Change A1B future scenario were used. The model extends from the surface to 50 hPa with 18 vertical grid points. The selected climate model domain widens far beyond the study area from about 3°S to 27°N and 28°W to 28°E with 40 km horizontal grid spacing. This allows the primary features that control the annual cycle of the West African monsoon to be fully captured and minimizes inconsistencies between boundary conditions and the model. RegCM3 simulations had been validated over Nigeria and West Africa at large (e.g. Jenkins, 1997; Sun et al. 1999; Afiesimama, et al., 2006; Abiodun et al., 2012a) and found to simulate well the climate of Nigeria at high resolutions as employed in this study. The model is found to accurately simulate regional temperatures pattern over West Africa with cold bias of about 2°C particularly during the wet season. Despite the fact that it generally underestimates the peaks of rainfall, it is a fairly good resource for climate data over Nigeria (West Africa) particularly where and when the surface observed data is not available.

### **3. Results**

#### 3.1. Present-day Climate

Monthly mean air temperature and solar radiation over the three climatic zones of Nigeria from 1981 to 2000 are shown in Figure 2. Maximum mean air temperatures of 27 (South), 30 (Mid-belt) and 32°C (North) were obtained in March/April over the country (Fig. 2a). The least temperatures of 24, 23.5 and 25°C were obtained in the month of July/August over the South, Mid-belt and North zones respectively. The patterns of monthly variations (annual cycle) in solar radiation were similar to that of temperature over the country. It attained its peak values [180 (South), 230 (Mid-belt) and 240 Wm<sup>-2</sup> (North)] in March/April and the least [160 (South), 165 (Mid-belt) and 170 Wm<sup>-2</sup> (North)] in July/August (Fig. 2b). Figure 3 depicts the annual cycle of precipitation in the country. The results indicated that it rained throughout the year (no completely dry month) in the south zone. However, December to February (3 months) were dry in the Mid-belt while November to March (5 months) were dry in the North. The distribution of precipitation in the south was bimodal with the peaks of about 150 mm in June and 250 mm in September. But in the Mid-belt and North zones, precipitation distributions were unimodal with the peaks of 255 mm (Mid-belt) and 245 mm (North) in the month of August. The seasonal variations in the surface run-off are presented in Figure 4. The results showed that the run-off was practically zero in December to February over the South. It then began to increase from 4 mmday <sup>1</sup> in March to reach its peak (54 mmday<sup>-1</sup>) in September. The run-off started to increase from zero in April to reach its peak (50 mmday<sup>-1</sup>) in August. The start of run-off started later (May) in the north zone with the peak (38 mmday<sup>-1</sup>) in August. Figure 5 describes the monthly variations in topsoil water. In the South, the topsoil water appeared to reach its peak (33 mmday<sup>-1</sup>) in June; dropped slightly to (32.5 mmday<sup>-1</sup>) in August and attained its least value (15 mmday<sup>-1</sup>) in January. Similar patterns were obtained over the other two zones, but the peaks of about 33 mmday<sup>-1</sup> were obtained in the month of August and the least (about 10 mmday<sup>-1</sup>) in February. The annual cycle of root zone water, as shown in Figure 6, mimics that of topsoil water over all the zones. The peaks in the month of September were 580 mmday<sup>-1</sup> (South), 520 mmday<sup>-1</sup> (Mid-belt) and 430 mmday<sup>-1</sup> (North) while the least were 460 mmday<sup>-1</sup> (South), 330 mmday<sup>-1</sup> (Mid-belt) and 280 mmday<sup>-1</sup> (North) in March/April. Figure 7 shows that evapotranspiration rate in the South zone was 430 mmday<sup>-1</sup> (the lowest) in the month of February and 110 mmday<sup>-1</sup> (the peak) in May. Similar trends were obtained in the Mid-belt and North zones with the peaks [100 mmday<sup>-1</sup> (Mid-belt); 90 mmday<sup>-1</sup> (North)] in July/August and the least [48 mmday<sup>-1</sup> <sup>1</sup> (Mid-belt); 15 mmday<sup>-1</sup> (North)] in February/March.

The annual mean statistics in Table 1 indicated that the mean temperature for the present-day (1981-2000) were 26.7°C (North), 25.1°C (Mid-belt) and 24.4°C (South). The mean annual rainfall and solar radiation were 731.0 mm: 222.4W/m<sup>-2</sup>, 1143.7 mm: 203.6W/m<sup>-2</sup>, and 1576.0 mm: 185.5W/m<sup>-2</sup> in the North, Mid-belt and South zones respectively.

The annual surface run-off, evapotranspiration, topsoil and root zone water were 8.5: 51.4: 18.1: 322 mmday<sup>-1</sup>, 16.4: 71.8: 21.2: 417.5 mmday<sup>-1</sup> and 28.2: 88.7: 28.2: 519.1 mmday<sup>-1</sup> over the North, Mid-belt and South zones respectively.



**Figure 2:** Seasonal variation in (a) temperature and (b) solar radiation over Nigeria under the presentday climate (1981-2000).



Figure 3: Seasonal variation in precipitation over Nigeria under the present-day climate (1981-2000).



Figure 4: Seasonal variation in surface runoff over Nigeria under the present-day climate (1981-2000).



Figure 5: Seasonal variation in top soil water over Nigeria under the present climate (1981-2000).



Figure 6: Seasonal variation in root soil water over Nigeria under the present climate (1981-2000).

**Table 1.** Present (1981-2000) and future change (2031-2050) in annual mean temperature (TMN; °C), solar radiation (SRD; Wm<sup>-2</sup>), precipitation (PREC; mm), surface runoff (ROFF; mmday<sup>-1</sup>), root zone water (RWATER; mmday<sup>-1</sup>), top soil water (TWATER; mmday<sup>-1</sup>) and evapotranspiration (EVAP; mmday<sup>-1</sup>) over various climatic zones of Nigeria.

Zone			Parameter						
			TMN	SRD	PREC	ROFF	RWAT	TWAT	EVAP
North	Present	x	26.7	222.4	731.0	8.5	322.0	18.1	51.4
		Σ	0.54	3.99	93.83	0.95	10.54	0.62	2.77
	Future	x	28.3	222.3	727.4	8.5	322.0	18.3	53.10
		Σ	0.99	3.82	93.69	0.93	10.52	0.69	3.07
	Change in $\overline{x}$		1.6	-0.1	-3.6	0.0	0.0	0.2	1.7
	% change		5.99	-0.04	-0.50	0.00	0.00	1.11	3.31
Mid-belt	Present	x	25.1	203.6	1143.8	16.4	417.5	21.2	71.8
		σ	0.55	3.89	107.30	1.28	12.50	0.82	1.18
	Future	$\overline{x}$	26.5	203.9	1169.6	16.8	416.4	21.4	73.9
		σ	0.91	3.94	108.47	1.41	12.10	1.02	1.78
	Change in $\overline{x}$		1.4	0.3	25.8	0.4	-1.1	0.2	2.1
	% change		5.58	0.15	2.26	2.44	-0.26	0.85	2.93
South	Present	$\overline{x}$	24.4	185.6	1576.0	28.2	519.1	26.4	88.7
		σ	0.42	3.03	109.52	2.20	11.83	0.62	1.10
	Future	$\overline{x}$	25.6	184.6	1599.6	29.9	515.9	26.5	89.6
		σ	0.61	2.83	117.57	2.50	11.43	0.68	1.34
	Change in $\overline{x}$		1.2	-1.0	23.6	1.7	-3.2	0.1	0.9
	% change		4.92	-0.54	1.50	6.03	-0.62	0.38	1.02

 $\bar{x}$  = Mean value;  $\sigma$  = Standard deviation



**Figure 7:** Seasonal variation in surface evapotranspiration over Nigeria under the present climate (1981-2000).

#### 3.2. Future Changes in Climate and Water Budget

Results of the regional climate projection suggested that the annual mean temperature will increase by 1.6°C (5.99%), 1.4°C (5.58%), and 1.2°C (4.92%) in the North, Mid-belt and South zones respectively (Table I). The annual precipitation was found to decrease slightly by -3.6 mm (-0.5%) in the North but increased by 25.8 mm (2.26%), and 23.6 mm (1.5%) in the Mid-belt and South zones respectively. Also, the topsoil water and evapotranspiration were simulated to increase by 0.2 mmday<sup>-1</sup> (1.11%) and 1.7 mmday<sup>-1</sup> (3.31%) in the North; 0.2 mmday<sup>-1</sup> (0.85%) and 2.1 mmday<sup>-1</sup> (2.93%) in the Mid-belt and 0.1 mmday<sup>-1</sup> (0.38%) and 0.9 mmday<sup>-1</sup> (1.02%) in the South. However, annual solar radiation was predicted to increase by 0.3 Wm<sup>-2</sup> (0.15%) over the Mid-belt; but simulated to decrease by 0.1 Wm<sup>-2</sup> (-0.04%) and 1.0 Wm<sup>-2</sup> (-0.54%) over the North and the South zones respectively. Although, there was no changes in the future run-off and the root zone water over the North zone, the model predicted increase of 0.4 mmday<sup>-1</sup> (2.44%) and 1.7 mmday<sup>-1</sup> (6.03%) in the former but decrease of 1.1 mmday<sup>-1</sup> (-0.26%) and 3.2 mmday<sup>-1</sup> (-0.62%) in the later over the Mid-belt and South zones respectively.

Figure 8 shows the future percentage changes in seasonal temperature and solar radiation across the country. The model consistently predicted temperatures rise of about by 3 to 8% in all the months. The least (3%) changes were obtained in November over the Mid-belt and the South zones while it occurred earlier (October) in the North.



**Figure 8:** Future percentage change in monthly (a) temperature and (b) solar radiation over Nigeria (2031-2050).

Decrease of about 2 to 3% in solar radiation was suggested in the peak of the wet season (July-Sept) and dry season (Feb-Mar) in the South. It however suggested an increase of about 1 to 4% in May/June and October over the zone. Over other two zones, the model suggested a rise of about 1 to 4% mostly in the wet season (May-July) and a decrease of 1-5% in dry season. For the precipitation, as shown in Figure 9, the changes were found to range from -2 to -35% in May-September but +2 to +60% in October and November as well as most other months in the dry season. The patterns for the seasonal changes in surface run-off and topsoil water were similar to that of the precipitation with negative changes [-2 to -50% (run-off); -1 to -9% (topsoil);] in May-September but positive [+5 to +85% (run-off); +1 to +9% (topsoil)] in October and November as well as most other months in the dry season (Figs. 10 and 11). Figures 12 and 13 illustrate the results of the future changes in the seasonal root zone water and evapotranspiration respectively. Over the Mid-belt and the North zones the changes in root zone water were generally negative (-0.5 to -2.5%) in the wet season but positive (0.2 to 1.7%) in the dry season (Fig. 12). Over the South zone, however, the changes in root zone water were generally negative (-0.2 to -1.8%) except for the month of April and November. Except in the month of May, future changes in seasonal evapotranspiration were simulated to increase between 2 to 36% (Fig. 13) across all the zones. These values were higher in the dry than the wet season.



Figure 9: Future percentage change in monthly precipitation over Nigeria (2031-2050).



Figure 10: Future percentage change in monthly surface runoff over Nigeria (2031-2050).



Figure 11: Future percentage change in monthly top soil water over Nigeria (2031-2050).



Figure 12: Future percentage change in monthly root soil water over Nigeria (2031-2050).



Figure 13: Future percentage change in surface evapotranspiration

# 4. Discussion

Results of the present-day climatology indicated that the interior zones were drier (less precipitation) than the coastline (south zone). It rains throughout the year in the south and the length of wet season reduces northward. The south has bimodal distribution of precipitation with primary and secondary peaks in June and September. However, the Mid-belt and North zones have unimodal precipitation distributions with the peak in the month of August. This pattern of distribution is consistent with the seasonal variation of the West African monsoon system which closely follows the latitudinal movement of solar radiation and the associated heat-low (Abiodun *et al.*, 2012a). Surface run-off, evapotranspiration, topsoil and root zone were higher in the coastline and decreased northward. These are consequences of northward decrease in annual total precipitation. In addition, the annual cycles of these water budget components follow closely that of precipitation. However, annual mean solar radiation and warmth (temperature) were higher in the interior than the coastline areas. The influence of the tropical maritime air mass from Gulf of Guinea and the thick vegetation moderate temperature fluctuations along the coastal region (Charney, 1975; Folland, *et al.* 1986; Adefolalu, 2007). Similarly, lower solar radiation recorded in the south could be attributed to the contribution of denser cloud cover over the zone as reported by Ohunakin *et al.* (2015). These results were in

agreement with the findings of similar studies over the region (e.g. Omotosho and Abiodun 2007; Abiodun *et al.*, 2008; Abiodun *et al.*, 2012a; Sylla *et al.*, 2010a).

Results of the regional climate projection suggested an increase in annual temperature, precipitation, topsoil water and evapotranspiration over all the zones. The future global warming was projected to increase inland from the coast. The lower warming in the south could be attributed to the influence of relatively cool moist air from the ocean and increased cloud cover over the coastal region (Sylla et al., 2010a). The rise in temperature values over the country are consistent and within the range of those previously reported in the literature (IPPC, 2007; Abiodun et al. 2012b; Olusina and Odumade 2012; Sylla et al. 2010b). The fact that the future changes in mean temperatures were greater than their standard deviations for the present-day (Table I) suggests significant future change in temperature over the country due to global warming. Although, the projected rise in evapotranspiration was only significant over the Mid-belt zone, these changes could be attributed to the possible increase in temperature while that of topsoil water could be due to the excepted rise in precipitation. The results of seasonal changes demonstrated declines in future precipitation, (-2 to -35%) in May-September. This is an indication of possible reduction in future precipitation, particularly in the north where the wet season is short. It however suggested a rise (+2 to +60%) in October and November (transition period) as well as most other months in the dry season. These are indications of false start of rainfall or longer length of growing season, particularly in the south. Yields of some crops are found to be more sensitive to rainfall anomalies such as changes in annual rainfall, peak and retreat of rainfall as well as false start of rainfall (Bosello and Zhang, 2005; Agbola and Ojeleye, 2007). Similarly, a false start of planting, encouraged by a false start of rainfall, may be followed by prolonged dry spells whose duration of 2 weeks or more may be critical to crop emergence and/or growth (Olaniran, 1983). Soil erosion from excessive rainfall during the crop growing period might also lower the yield due to nutrient losses through leaching. It must be noted, however, that future changes in annual precipitation were found to be insignificant. This might be as a results of the fact that the 20-year simulation used in this study is too short to account for all the natural variability; but it would account for inter-annual variability and, to some extent, the decadal variability a reported in Abiodun et al. (2012b).

Thus, increase in temperature along with reduced precipitation, particularly during the wet season as projected, will likely result in the loss of arable land in the region due to decreased soil moisture, increased aridity, increased salinity and groundwater depletion (Bals *et al.*, 2008). The future change in rainfall/precipitation amount can affect soil erosion rates and soil moisture, both of which are important for crop yields. These results affirms the assertion that the hydrological regimes in which crops grow will surely change with global warming (Oyiga *et al.*, 2011).

The future changes in seasonal evapotranspiration were simulated to increase (2 to 36%) across all the zones. These values were higher in north than other zones and in dry than the wet season. This can be attributed to the spatial distribution of solar radiation and cloudiness over the country.

Solar radiation was projected to increase slightly by 0.15% over the Mid-belt but expected to decrease by 0.04% and 0.54% over the North and the South zones respectively. The reduction in solar radiation over south zone could be ascribed to the projected rise in future precipitation and cloudiness. Seasonally, solar radiation was speculated to decrease by 2 to 3% in the peak of the wet season (July-Sept) and dry season (Feb-Mar); but suggested to increase by 1 to 4% in May/June and October in the South. Over other two zones, the model suggested a rise of about 1 to 4% mostly in the wet season (May-July) and a decrease of 1-5% in dry season. These results corroborate the findings of Ohunakin *et al.* (2015) who used different but the same RegCM simulation data in their study. Although, the model predicted no changes in the future run-off over the North zone, it however suggested an increase in run-off over the Mid-belt and South zones. The pattern for the seasonal changes in surface run-off was similar to that of the precipitation with reduction (-2 to -50%) in May-September but increment (+5 to +85%) in October and November as well as most other months in the dry season. Some of the implications are reduction in the soil fertility and land degradation due to flooding and erosion in the south and mid-belt zones.

Finally, the annual and seasonal changes in topsoil water were simulated to follow the same patterns with the run-off over the country. This signals good water availability for crop with shallow (0-10 cm) fibrous root. However, the model consistently predicted decrease in root zone water over the Mid-belt and South zones. The results of the future changes suggested reduction in the seasonal root zone water over the Mid-belt and the North zones particularly in the wet season but an increase in the dry season. Over the South zone, there were reduction in root zone water except for the month of April and November. Since some major crops rely on root zone water (> 10 cm depth), reduction in available water for crop at certain times during the growing season will negatively affect food supplies as reported by FAO (2008). Nigeria as well as other countries in Sub-Sahel Africa depends on rain-fed agriculture and, the distortion of the rainfall pattern would limit crop production and this would bring untold physical and socio-economic hardship to the rural farmers in the region (Oyiga *et al.*, 2011).

# **5.** Conclusion

This study has examined the impact of future global warming on water budget components in Nigeria using the climatic data from regional climate model RegCM3 simulations. The climate model projections suggested warmer climate in the future across the entire country. It predicted increase of

1.6°C, 1.4°C and 1.2°C in the North Mid-belt and South zones respectively. The model also projected slight decrease in future annual precipitation in the North but speculated a rise in other zones. There were also signals indicating false start of rainfall and/or longer length of growing season in the country. Thus, increase in temperature along with reduced precipitation, particularly during the wet season as projected, were attributed to the observed groundwater depletion. Solar radiation was projected to increase slightly by 0.15% over the Mid-belt but expected to decrease by 0.04% and 0.54% over the North and the South zones respectively Due to the potential influence of solar radiation and cloudiness, the future changes in evapotranspiration were simulated to increase (2 to 36%) across all the zones and seasons. The model also suggested an increase in run-off over the Mid-belt and South zones. This implies reduction in the soil fertility and land degradation due to flooding and erosion. Although, the annual and seasonal changes in topsoil water were simulated to rise over the Mid-belt and South zones, some crops may suffer for reduction in the seasonal root zone water particularly in the wet season. Thus, future distortion of the various water budget components could have negative impacts on crop production in the region.

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