

Oceanic Oscillations and Congo River Basin Climatology

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DOI: 10.5281/zenodo.12192494

Introduction

According to the IPCC's 2021 report, anthropogenic climate change is and will increasingly have a significant impact on natural systems that support human wellbeing. The occurrence of extreme weather events induced by climate change has already had adverse effects on terrestrial, freshwater, ocean, and coastal ecosystems. These extreme events have also reduced food security; contributed to migration and displacement; threatened livelihoods and the health and security of people, and increased inequality. Global temperature increases have affected sea surface temperature (SST) at the boundary between the ocean and atmosphere. SST directly influences the climate system, particularly atmospheric circulation, rainfall patterns, and storm intensity.

According to the US Environmental Protection Agency (EPA, 2001), SST has been rising from 1880 to 2020, with the most rapid increases occurring in the last 3 decades. Currently, SST is rising at a rate of 0.14°F per decade. SST varies regionally, with some regions facing warmer and others cooler temperatures (EPA 2001). Warmer waters tend to promote the development of stronger storms in the tropics. As oceans absorb excess heat, they release more water vapour, affecting rainfall patterns. This can lead to droughts, heavy precipitation, sea level rise, and stronger storms (ECMWF, 2023).

The Congo River Basin (CRB) is the second largest river basin in the world, extending over a 3.4 million km² area in central Africa. Jarugula & McPhaden (2023) note that the Inter Tropical Convergence Zone (ITCZ) movement affects the Congo River discharge (CRD) in a bimodal fashion. Maximum peak precipitation during November–December is followed by a secondary maximum during April–May, with a minimal amount during March and August. Resulting fluctuations in discharge from the Congo River, driven by those changes in precipitation pattern, affect seasonal changes in sea surface salinity in the Eastern Tropical Atlantic. Such salinity changes can impact SST variability, evapotranspiration, the eastern equatorial Atlantic local climate, and West African monsoon onset. However, Jarugula & McPhaden (2023) also note that the Indian Ocean Dipole has a large impact on SST in both the western Indian and the eastern equatorial Atlantic Oceans. These and other studies inspired us to examine oceanic oscillations to the east and west of Africa to explore how they might interact with CRB precipitation patterns.

Material and Methodology

Study Region

The Congo Basin is the world's largest carbon sink, absorbing 1.5% of annual global CO₂ emissions (White et al., 2021) and playing a vital role in moisture recycling. Nevertheless, it remains underrepresented in the scientific literature compared, for instance, to the Amazon (Alsdorf et al., 2016). The CRB is home to a diverse population of soil microorganisms, fungi, plants, and animals, as well as a growing human population. Yet it is still unclear how increased land use impacts its forest reserves and ecosystem services. Loss of carbon-rich swampy forest and peatland reserves (28% of the world's tropical peat carbon, see Crezee et al. 2022) could turn this global carbon sink into a potent carbon source; loss of moisture recycling services threatens the lives and livelihoods of millions through fire, floods, droughts, and crop failure.

Prior Work

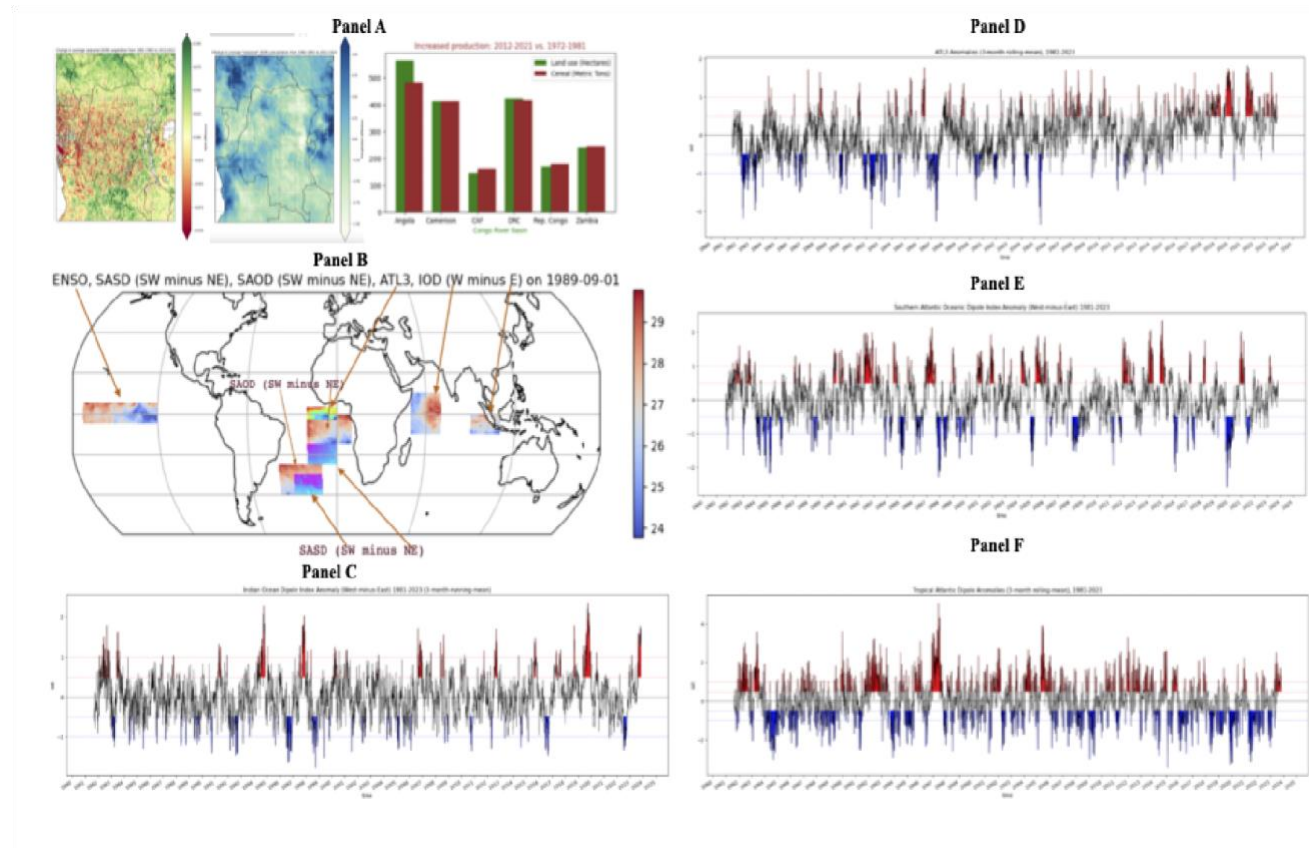
We received the complete shape file for the CRB from Prof. Raphael M. Tshimanga du Centre de Recherche en Ressources en Eau du Bassin du Congo (Raphael M. Tshimanga, personal communication, 10/10/23). During the Climatedata Academy (CMA) 2023 Summer School, our team examined the interaction of precipitation and vegetation changes in the CRB and discerned a clear trend towards decreased precipitation and decreased vegetation over time. Our preliminary analysis compared NDVI vegetation data for the 1982–1992 period with that of the 2012–2022 period, and we examined the CHIRPS precipitation data for the same time periods. The NDVI data showed a substantial decrease in vegetation across the CRB, while the CHIRPS data showed significant decreases in precipitation for much of the CRB (Panel A).

These preliminary findings raised the question of whether the drop in both vegetation and precipitation was due to global and local temperature increases, demographic and land-use change, specifically deforestation, and how these factors interacted with ENSO to produce extreme events. The picture became more complex when we looked at World Bank data for agricultural land use and crop production in CRB countries. Comparing cereal production and cropland for the 2012–2021 period vs. 1971–1981 showed dramatic increases in agricultural land use and resulting food production, raising questions about what exactly was driving the NDVI and CHIRPS changes.

Data

We downloaded data from NOAA's mean SST data (oisst.v2) for the full set of years from 1981–2023. (<https://downloads.psl.noaa.gov/Datasets/noaa.oisst.v2.highres/>). The Woods Hole Oceanographic Institute (WHOI) website article, "El Niño & Other Oscillations" (<https://www.whoi.edu/know-your-ocean/ocean-topics/how-the-ocean-works/ocean-circulation/el-nio-other-oscillations/>) identifies multiple oceanic dipoles and indices (Yu et al. 2022) and teleconnections between them. Several recent studies of teleconnection have indicated interactions between ENSO and other oceanic oscillations. Some of these oscillations directly influence CRB precipitation patterns, either individually, or in teleconnection patterns. These oscillations include: Indian Ocean Dipole (IOD) (Jaragula et al., 2023, Zhang & Han 2021); Southern Atlantic Oceanic Dipole (SAOD) (Santis et al., 2020; Bier & Ambrizzi 2019); South

Atlantic Subtropical Dipole (SASD) (Wainer et al., 2014); Tropical Atlantic Interannual Variability (ATL3) a.k.a. the 'Atlantic Niño' (Rodríguez-Fonseca et al. 2009, Zhang L et al. 2023); Tropical North Atlantic Index (TNAI) (Polo et al., 2008); Tropical South Atlantic Index (TASI); South Atlantic Tropical (SAT) Index; and North Atlantic Tropical (NAT) Index.



Panel A: Preliminary analysis of changes in NDVI vegetation data (left) and CHIRPS precipitation data (right) from 1981-1992 vs 2012-2022, showing substantial decrease in vegetation in the Congo River Basin and substantial drop in precipitation, and increased crop land and cereal production during a comparable period. **Panel B:** Showing the regions of the world's oceans used to calculate SST variability for ENSO, SASD, SAOD, ATL3, and IOD. **Panel C:** Indian Ocean Dipole (IOD) Anomalies (West-minus-East, 3-month running average (1981-2023)) **Panel D:** ATL3 Anomalies (3-month running mean), 1981-2023 **Panel E:** Southern Atlantic Oceanic Dipole (SAOD) Anomalies (West-minus-East), 1981-2023 **Panel F:** Tropical Atlantic Dipole Anomalies (TNA-TSA, 3-month running mean), 1981-2023

Following the literature, we identified the ocean coordinates used for these indices and dipoles (Panel B).

Methods

We used Python libraries such as Xarray, pandas, Numpy, Matplotlib, and others in Jupyterhub for this analysis, together with scripts provided by the Climatedata Academy or customised versions of the same. For prior work, we used NDVI (vegetation) and CHIRPS (precipitation) (both masked with the CRB shape file) and World Bank (crop/land-use) data. We downloaded sea surface temperature data from NOAA, then identified the ENSO, IOD, SASD, SAOD, and ATL3 sea surface regions.

Results

We plotted the ENSO climatology and ENSO extreme events for the full NOAA 1981–2023 dataset, extending the time period used in the CMA summer school to the full available dataset from NOAA; the approach was similar to our summer school tutorial. We then plotted anomalies for the Indian Ocean Dipole (IOD), also known as the Dipole Mode Index (DMI). The IOD is calculated by subtracting IOD east: 90°E–110°E, 10°S–0°S from IOD west: 50°E–70°E, 10°S–10°N (Panel C).

The 'Atlantic Niño' or ATL3 index is the area-averaged SST anomaly over 20°W–0°, 3°S–3°N, covering the tropical Atlantic Ocean area with the largest interannual variance (Panel D) (Exarchou et al., 2021).

The South Atlantic Subtropical Dipole Index (SASD) is calculated by subtracting the area-averaged SST at SASD's southwest pole (30°W–10°W, 30°S–40°S) from the area-averaged SST at SASD's northeast pole (20°W–0°, 15°S–25°S) (Panel E).

Another southern Atlantic dipole index, the Tropical Atlantic (TASI) SST anomaly index, is an indicator of the surface temperatures in a broad swath of the tropical South Atlantic Ocean.

(<https://stateoftheocean.osmc.noaa.gov/sur/atl/sat.php>) It is calculated by subtracting the Tropical South Atlantic (TSA) 30°W–10°E, 20°S to 0° from the Tropical North Atlantic (TNA) 55°W–15°W, 5°N–25°N. The TSA SST anomaly index captures surface temperatures, i.e., the meridional surface temperature gradient, in the Gulf of Guinea, the eastern tropical South Atlantic Ocean. The TNA SST anomaly index captures surface temperatures in the eastern tropical North Atlantic Ocean. The north-south difference, i.e., TNA SST minus TSA SST across the equator, captures the tropical Atlantic Sea surface temperature dipole, the Tropical Atlantic (TASI) SST anomaly index (Panel F).

Discussion

The Subtropical North Atlantic (SNA) sea surface temperature (SST) has been shown to influence Congo River Basin precipitation, with Tropical Atlantic (TA) SST representing a second mode with maximum loadings over the Congo River Basin and the northern Sahel (Polo et al., 2008). Polo et al.'s work is part of a broader expansion of research into understanding the teleconnections between multiple oceanic oscillations globally and their effect on precipitation and related weather patterns in various regions around the world.

The Indian Ocean Dipole (IOD), first identified in 1999 (Saji et al., 1999), has been shown to have positive and negative phases that are semi-independent of ENSO, and to influence the ATL3-'Atlantic Niño' (Zhang & Han, 2021). A positive phase IOD involves warmer than normal western equatorial/tropical Indian ocean SSTs, and cooler than normal in the eastern Indian Ocean (near Java/Sumatra). Positive IOD often brings floods to East Africa while bringing droughts to eastern Asia/Australia. Positive IOD drives significant increases in CRB rainfall, affecting the Congo River discharge and altering eastern tropical Atlantic salinity, driving further feedback in precipitation over the

basin. Conversely, during negative IOD years, moisture transport weakens over the CRB (Jarugula & McPhaden, 2023).

Related work has found that positive IOD-enhanced rainfall in the western tropical Indian Ocean weakens easterly trade winds over the tropical Atlantic, triggering the Atlantic Niño by causing warm anomalies in the central and eastern equatorial Atlantic basin (Zhang & Han 2021). Zhang & Han (2021) found that the canonical Atlantic Niño/eastern Atlantic Niño dominated before 2000 (1970–1999). Since 2000, the warm SST anomalies now extend from the western coast of South Africa to the central equatorial Atlantic Ocean. This is most likely due to increasing global temperatures. These findings and others suggest further exploration of oceanic oscillation teleconnections may help develop a better understanding of Congo River Basin climatology.

Conclusion

Our preliminary work here indicates that while climate change is driving increasing ocean temperatures globally, the sea surface temperature changes within the identified oceanic oscillation indices and dipoles are diverse and not linearly related to global sea surface temperature increases. This diversity and non-linearity invite further investigation, both in terms of the teleconnection between the different oceanic oscillations, and their interactions with Congo River Basin climatology.

References

- Alsdorf D. et al. (2016) Opportunities for Hydrologic Research in the Congo Basin, *Reviews of Geophysics* 54, 378–409. <https://doi.org/10.1002/2016RG000517>
- Bier & Ambrizzi et al. (2019) South Atlantic Dipole Changes From 1851 to 2010, <https://ui.adsabs.harvard.edu/abs/2019AGUFM.A21J2742B>
- Crezee B et al. (2022) Mapping peat thickness and carbon stocks of the central Congo Basin using field data, *Nature Geoscience* 15, 639–644, <https://doi.org/10.1038/s41561-022-00966-7>
- Exarchou et al. (2021) Impact of equatorial Atlantic variability on ENSO predictive skill, *Nature Communications*, DOI: <https://doi.org/10.1038/s41467-021-21857-2>
- ECMWF (2023) Climate indicators: Sea Surface Temperature <https://climate.copernicus.eu/climate-indicators/sea-surface-temperature>
- EPA (2001) Climate Change Indicators: Sea Surface Temperature [https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature#:~:text=Sea%20surface%20temperature%20increased%20during,decade%20\(see%20Figure%201\)](https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature#:~:text=Sea%20surface%20temperature%20increased%20during,decade%20(see%20Figure%201))

Jarugula, S., McPhaden, M.J. (2023) Indian Ocean Dipole affects eastern tropical Atlantic salinity through Congo River Basin hydrology. *Communications Earth & Environment* 4, 366 (2023).

DOI: <https://doi.org/10.1038/s43247-023-01027-6>

Polo I et al. (2008) Tropical Atlantic Variability Modes (1979–2002). Part I: Time-Evolving SST Modes Related to West African Rainfall, DOI: <https://doi.org/10.1175/2008JCLI2607.1>, Page(s): 6457–6475

Rodríguez-Fonseca B et al. (2009) Atlantic Niños telecommunication with ENSO: Are Atlantic Niños enhancing Pacific ENSO events in recent decades, *Geophysical Research Letters*

DOI: <https://doi.org/10.1029/2009GL040048>

Santis W et al. (2020) Memory Effect of the Southern Atlantic Subtropical Dipole,

DOI: <https://doi.org/10.1175/JCLI-D-19-0745.1>

Saji, N., Goswami, B., Vinayachandran, P. et al. (1999) A dipole mode in the tropical Indian Ocean.

Nature, 401, 360–363, DOI: <https://doi.org/10.1038/43854>

Wainer, I., Prado, L., Khodri, M. *et al.* Reconstruction of the South Atlantic Subtropical Dipole index for the past 12,000 years from surface temperature proxy. *Sci Rep* 4, 5291 (2014).

DOI: <https://doi.org/10.1038/srep05291>

Yu L et al. (2022) A change in the relation between the Subtropical Indian Ocean Dipole and the 3 South Atlantic Ocean Dipole indices in the past four decades, *acp-2022-562-ATC3*,

DOI: <https://doi.org/10.5194/acp-23-345-2023>

Zhang L, Han W et al. (2021) Indian Ocean Dipole leads to Atlantic Niño, *Nature Communications*.

DOI: <https://doi.org/10.1038/s41467-021-26223-w> Zhang L et al (2023) Emergence of the Central Atlantic Niño, *Science Advances*, *sciadv.adi5507*, DOI: [10.1126/sciadv.adi5507](https://doi.org/10.1126/sciadv.adi5507)

Index of /Datasets/noaa.oisst.v2.highres:

<https://downloads.psl.noaa.gov/Datasets/noaa.oisst.v2.highres/>

<https://downloads.psl.noaa.gov/Datasets/noaa.oisst.v2.highres/>

<https://stateoftheocean.osmc.noaa.gov/sur/pac/nino4.php>

<https://stateoftheocean.osmc.noaa.gov/sur/atl/tasi.php>

<https://stateoftheocean.osmc.noaa.gov/sur/ind/swio.php>

<https://stateoftheocean.osmc.noaa.gov/sur/ind/dmi.php>

<https://stateoftheocean.osmc.noaa.gov/sur/ind/setio.php>

<https://stateoftheocean.osmc.noaa.gov/sur/ind/wtio.php>

Tropical Atlantic and Indian Ocean sea surface temperature forecasts.

<https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/atlantic-indian-ocean>

