CLIM 680 Project Website

The "East African Climate Paradox" How does the Coupled Model Intercomparison Project Phase 6 (CMIP6) compare to (CMIP5) under Representative Concentration Pathways (RCPs) 4.5 and 8.5.

1. Introduction:

The Intergovernmental Panel on Climate Change (IPCC) estimates that the impacts of global warming are likely to reach 1.5°C between 2030 and 2052 relative to the pre-industrial levels under the "business as usual" scenario (IPCC, 2021). The resultant response of climate systems will be depicted by features such as increased intensity of precipitation extremes, a sharp decline in the number of wet spell lengths, and an increase in dry spell lengths (Giorgi, 2019)with widespread impacts on human and natural systems (IPCC, 2014b). Africa is one of the most susceptible areas to climate variability and change (IPCC, 2021). Understanding ongoing and projected climate variability and change is essential for long-term planning at the global, regional, and local scales and is particularly important for countries/regions whose economies are heavily reliant on rain-dependent sectors. East Africa (Fig.1) is one such region and is highly vulnerable to the effects of climate variability and change (IPCC, 2007). This region's economy is strongly reliant on rain-fed agriculture (World Bank, 2008).

There are two rainy seasons for East African precipitation March to May (MAM), and October to December (OND) (Williams and Funk, 2011) Seasonal rainfall during MAM is the main crop-growing season in EA; thus, excess or depressed seasonal rainfall during this season results in food insecurity in the region (World Bank, 2008; Muhati *et al*., 2018). The rainy season of MAM has been documented to exhibit a decreasing pattern while the OND rainy season has shown an increasing tendency (Ongoma and Chen, 2017; Makula and Zhou, 2021). Current observations show that the region is experiencing high rainfall variability, with the main concern being the reduction in the MAM seasonal rainfall (Tierney *et al*., 2015).

Since 1985, the rains have declined, with major consequences for livelihoods (Tierney *et al*., 2015; Ongoma and Chen, 2017). In contrast, climate model projections show increased long-range rainfall: this has been termed the 'Eastern African climate change paradox. (Muhati *et al*., 2018; Wang *et al.*, 2018) (Fig.3). Wang *et al.* (2018) observed that the "East African climate paradox" was due to the possible interaction of anthropogenic aerosol emissions with climate, natural variability and sea surface temperatures, acting singularly or in concert in altering the East African rainfall regime. He concluded that the observations might be due to a mismatch of time scales, between decadal-scale variability and longer-term climate changes in East Africa. This project examines the improvement in Coupled Model Intercomparison Project Phase Six (CMIP6) models against the predecessor CMIP5 in simulating mean and extreme precipitation over the East Africa region. The specific questions to address are: (a) To what extent can the CMIP6

GCMs (General circulation models) reproduce the observed mean climatology and seasonal rainfall extremes over the EA region? and (b) Does the CMIP6 GCMs cure the East African Paradox as compared to observational Precipitation data?

2. **Data**:

This study utilizes historical **(9 models)**and future multimodel simulations **(9 models)** from the newly released CMIP6 (Eyring *et al*., 2016). Monthly mean rainfall data from the 18 CMIP6 models were considered. The study considered a base period of 1980–2014 and three future periods, near **2015-2100** (**2021–2040**), mid (**2041–2060**) and far (2080–2099) future, to analyse future rainfall changes in the region based on the RCP4.5 & 8.5), middle-of-the-road and scenario (O'Neill *et al*., 2017). The study used only the first realization (r1i1p1f1) from each model. I extract data between specified latitudes and longitudes

ds = ds.sel(lat=slice(6, -12), lon=slice(28, 42))

The model output data were accessed from the Earth System Grid Federation from the Earth System Grid Federation (ESGF; https://esgf-index1.ceda.ac.uk/search/cmip6-ceda/). Therefore, to validate the model data, the study utilized the latest gridded rainfall observations from the Climate Research Unit (CRUTS4.05; Harris et al., 2020). The datasets were obtained from the Centre for Environmental Data Analysis (CEDA) at https://catalogue.ceda.ac. uk/. The study also used the North Atlantic Oscillation Indices, which is a climate phenomenon that affects weather patterns in the North Atlantic Ocean region, including parts of North America, Europe and North Africa. In this case, NAO indices were applied to ensemble means for 9 Global Historical precipitation data for the period **1950-2014** to establish anomalies at a Global scale.

Models

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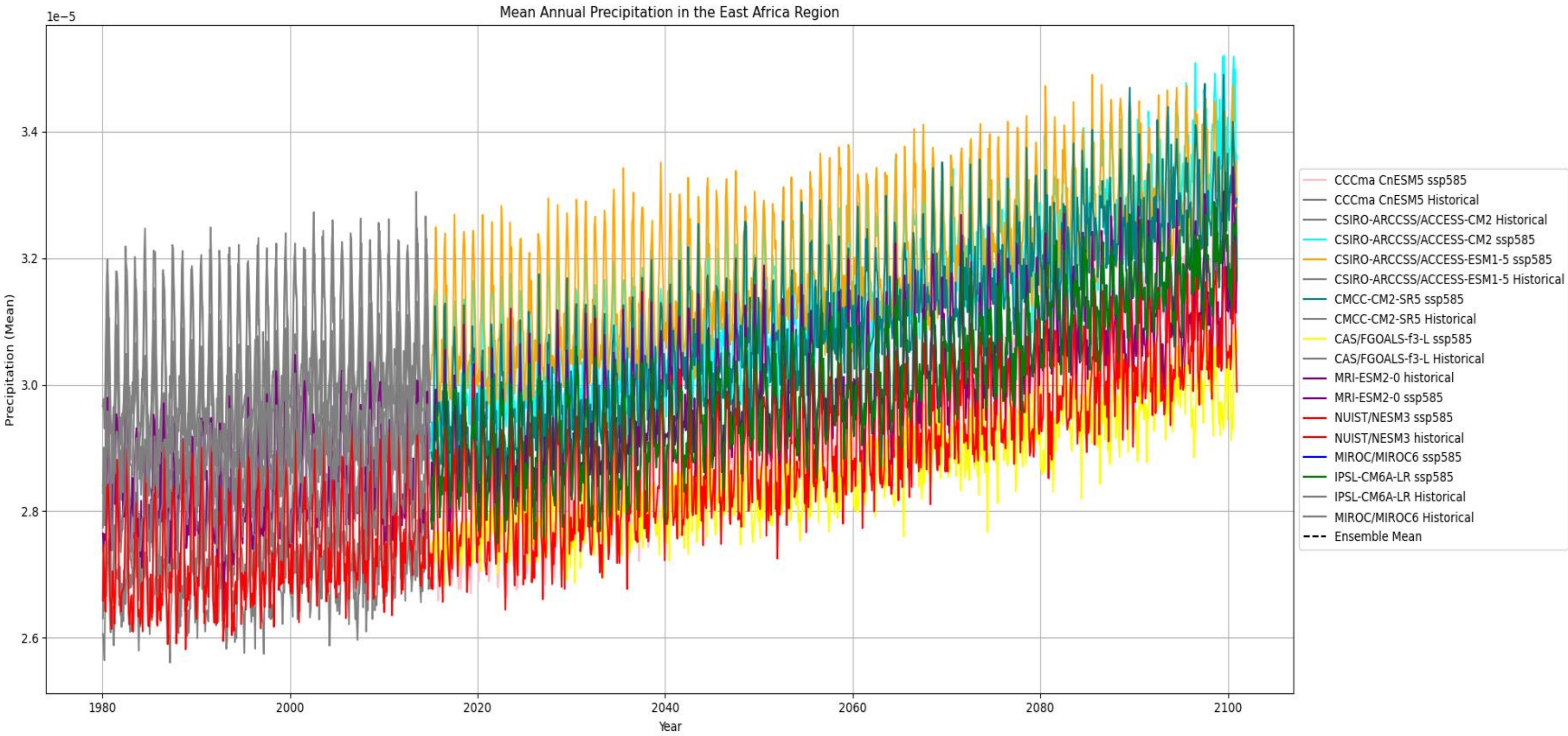
5.**Data Analysis**:

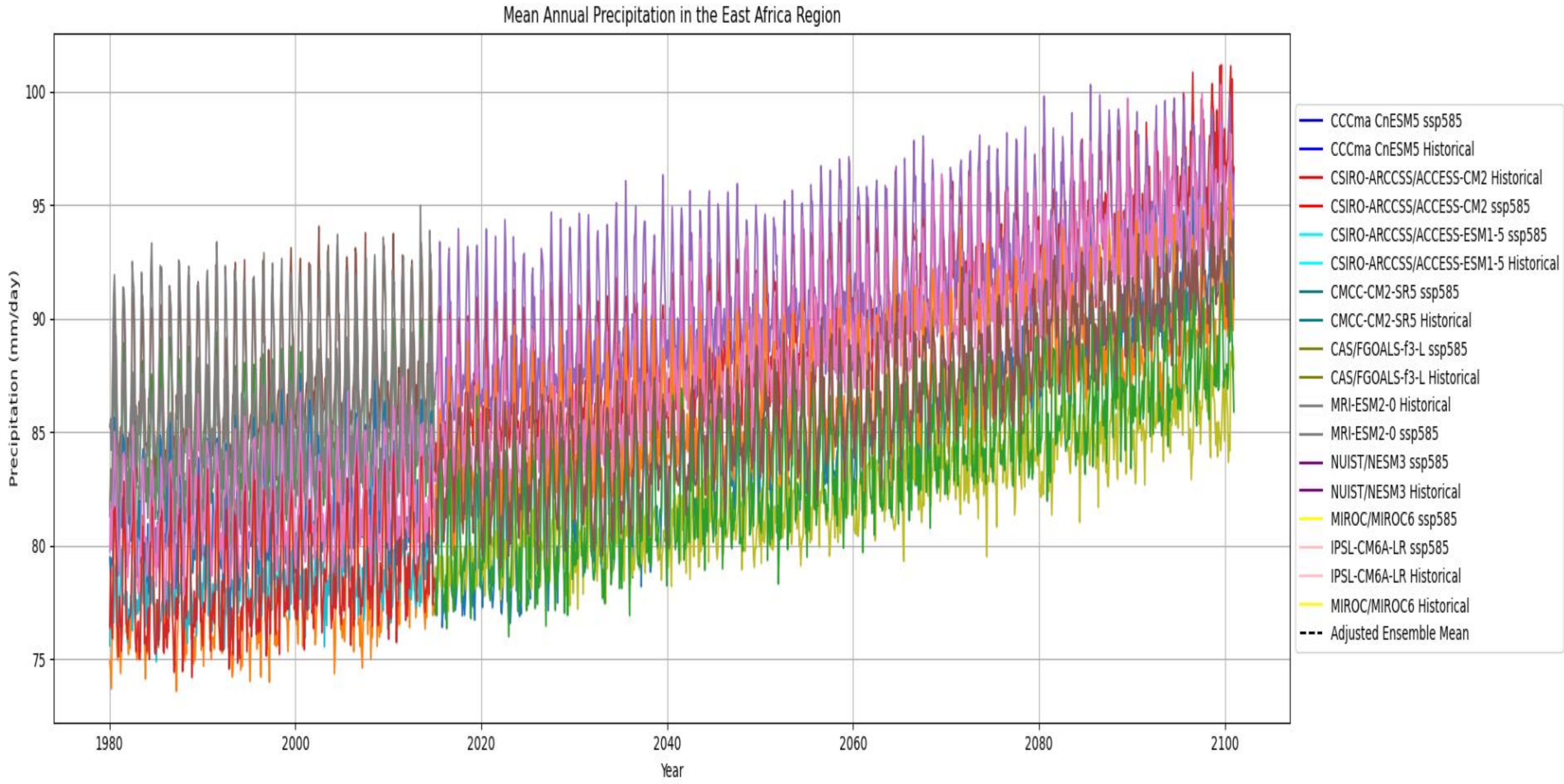
- Precipitation data was treated to, Monthly mean analysis(1980-2014), (2015-2100)
- Trend analysis,
- Annual mean analysis,
- Significant differences in decadal mean rainfall,

- Decadal mean analysis, seasonal mean analysis
- Ensemble means
- Nao Climate Indices

Precipitation output before Bias correction



Precipitation output after Bias correction



NAO Statistics

NAO Positive Timesteps: 147
NAO Neutral Timesteps: 528
NAO Negative Timesteps: 181
NAO Positive Time Range: 1950-10-01T00:00:00.000000000 to 2014-12-01T00:00:00.000000000
NAO Negative Time Range: 1950-07-01T00:00:00.000000000 to 2014-08-01T00:00:00.000000000
NAO Neutral Time Range: 1950-01-01T00:00:00.000000000 to 2014-11-01T00:00:00.000000000
Precipitation Time Range: 1950-01-01T00:00:00.000000000 to 2014-12-01T00:00:00.000000000
High Precipitation Statistics (1950-2014):
Max: 42.503048
Min: -36.26456
Low Precipitation Statistics (1950-2014):
Max: 29.899004
Min: -33.102478
Neutral Precipitation Statistics (1950-2014):
Max: 32.06158
Min: -29.267128

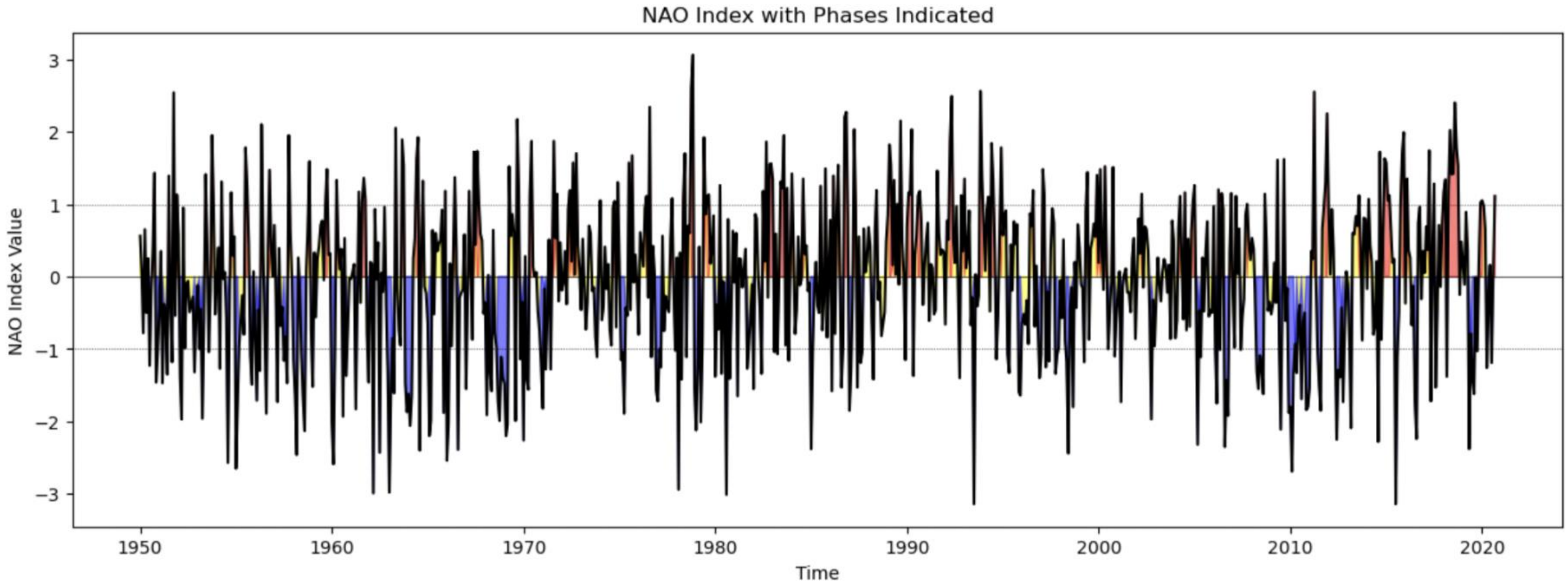
Ensemble Means

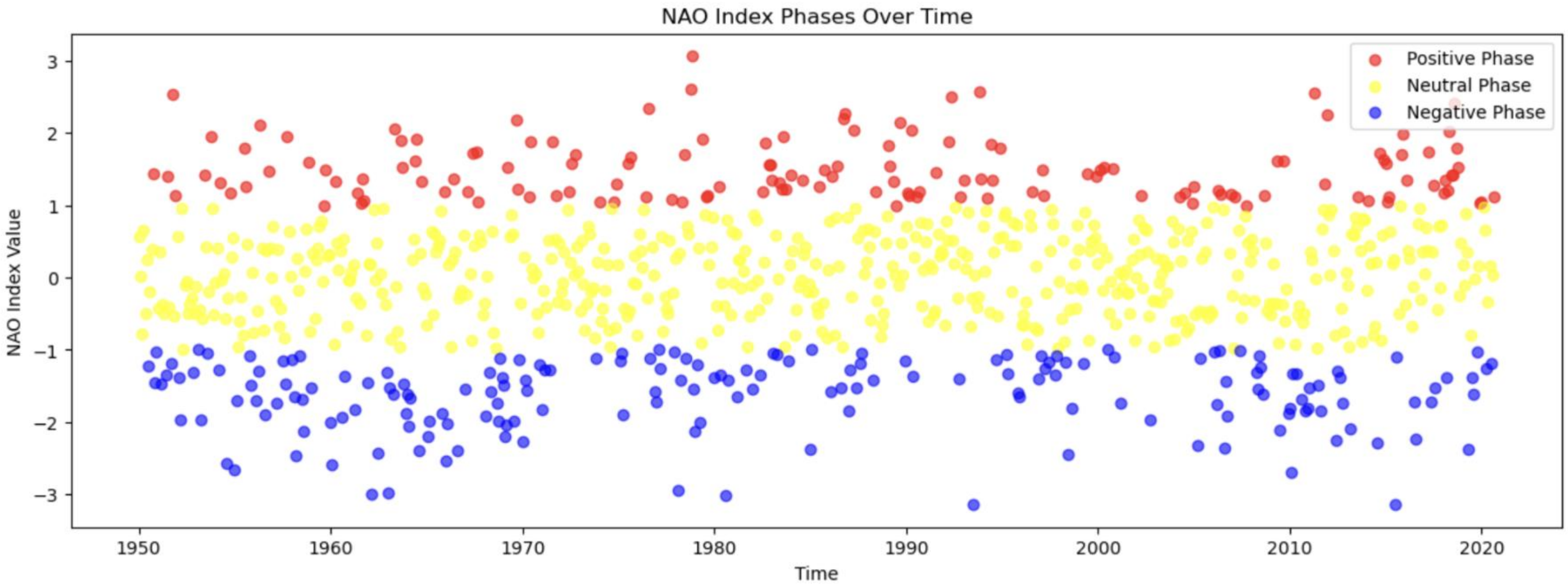
Processing model: MRI-ESM2-0 Historical...
Processing model: NUIST/NESM3 Historical...
Processing model: IPSL-CM6A-LR Historical...
Processing model: MIROC/MIROC6 Historical...
Ensemble mean values:
Month 1: 104.269714
Month 2: 105.979172
Month 3: 133.800552
Month 4: 140.417801
Month 5: 78.571121
Month 6: 44.603432
Month 7: 37.446186
Month 8: 39.721603
Month 9: 45.091084
Month 10: 59.994701
Month 11: 90.533920

Month 12: 106.965141

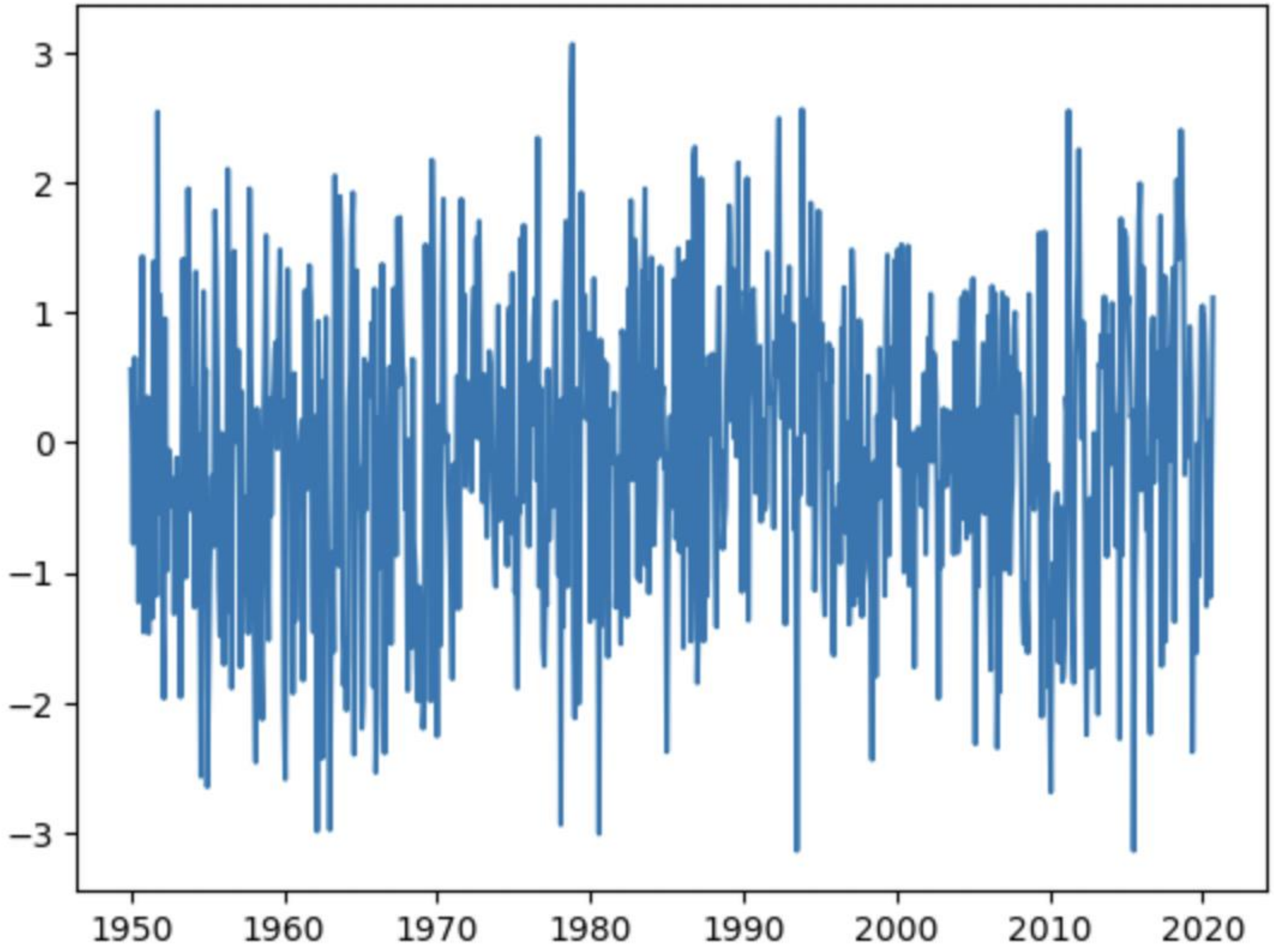
NAO statistics Ensemble

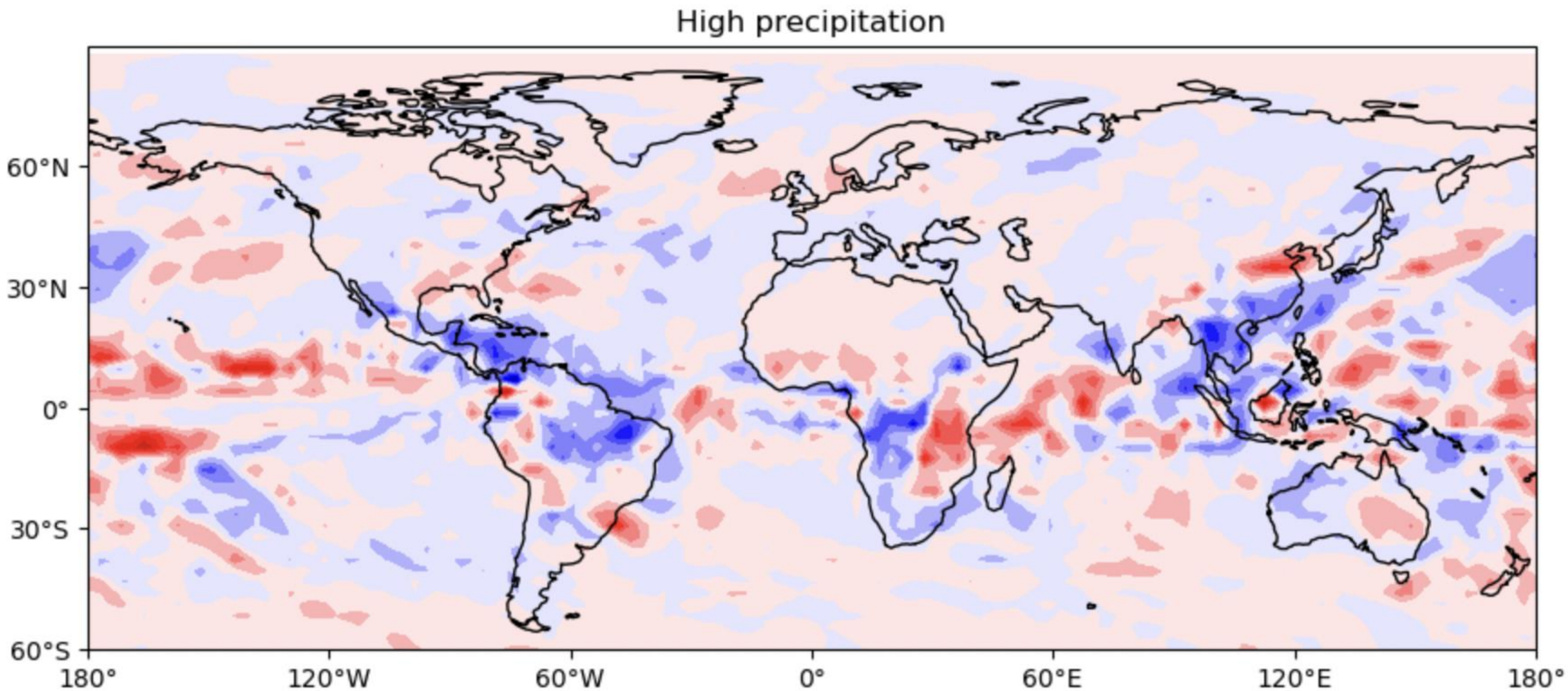
NAO Positive Time Range: 1950-10-01T00:00:00.000000000 to 2014-12-01T00:00:00.000000000
NAO Negative Time Range: 1950-07-01T00:00:00.000000000 to 2014-08-01T00:00:00.000000000
NAO Neutral Time Range: 1950-01-01T00:00:00.000000000 to 2014-11-01T00:00:00.000000000
Precipitation Time Range: 1950-01-31T00:00:00.000000000 to 2014-11-30T00:00:00.000000000
High Precipitation Statistics (1950-2014):
Max: 170.04909
Min: 0.00059128227
Low Precipitation Statistics (1950-2014):
Max: 156.96751
Min: 0.0022904137
Neutral Precipitation Statistics (1950-2014):
Max: 161.08954
Min: 0.0018590583

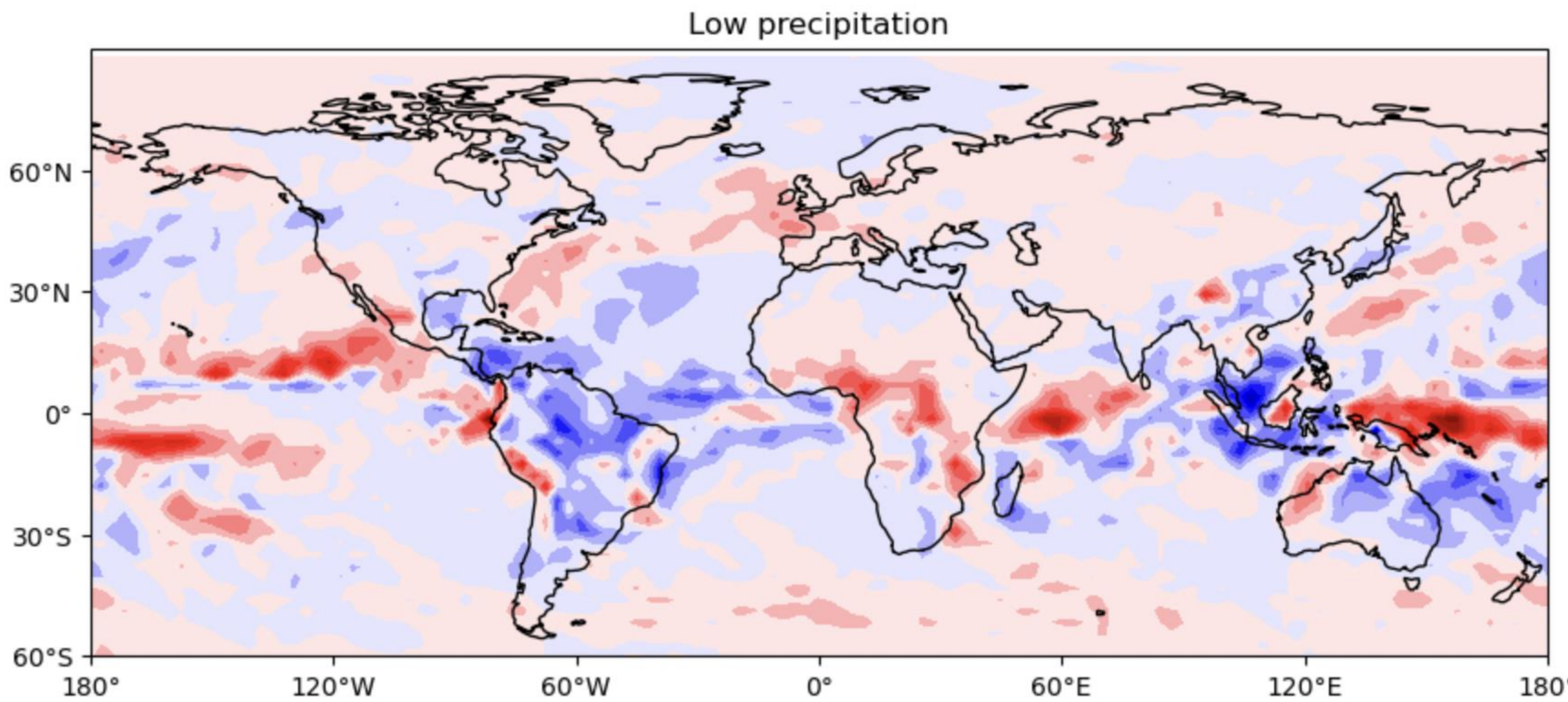

NAO Index with Phases Indicated
NAO Index Value
Time
3
2
1
0
−1
−2
−3
1950
1960
1970
1980
1990
2000
2010
2020

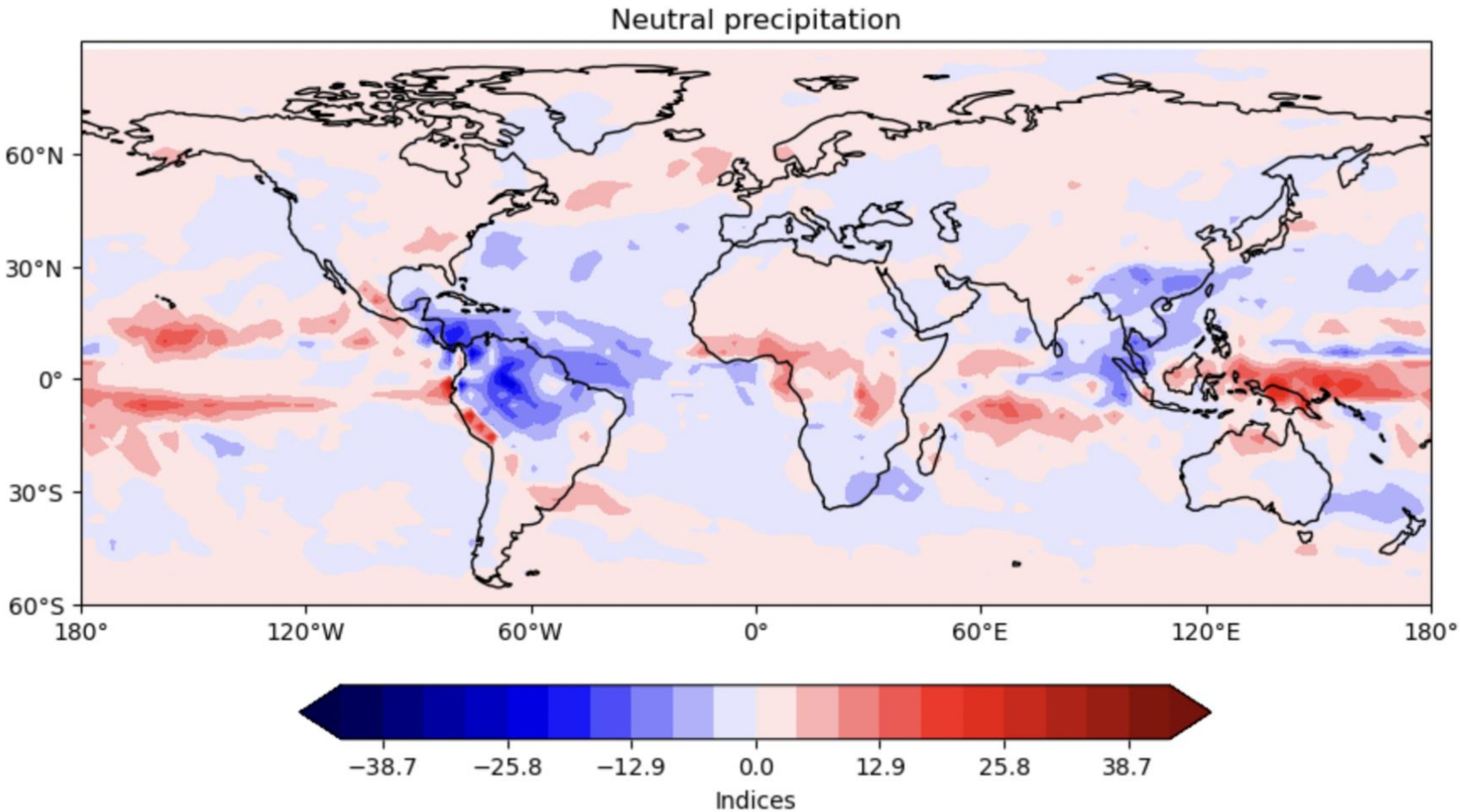

NAO Index Phases Over Time
Positive Phase
Neutral Phase
Negative Phase
NAO Index Value
Time
3
2
1
0
−1
−2
−3
1950
1960
1970
1980
1990
2000
2010
2020

1948-1-01

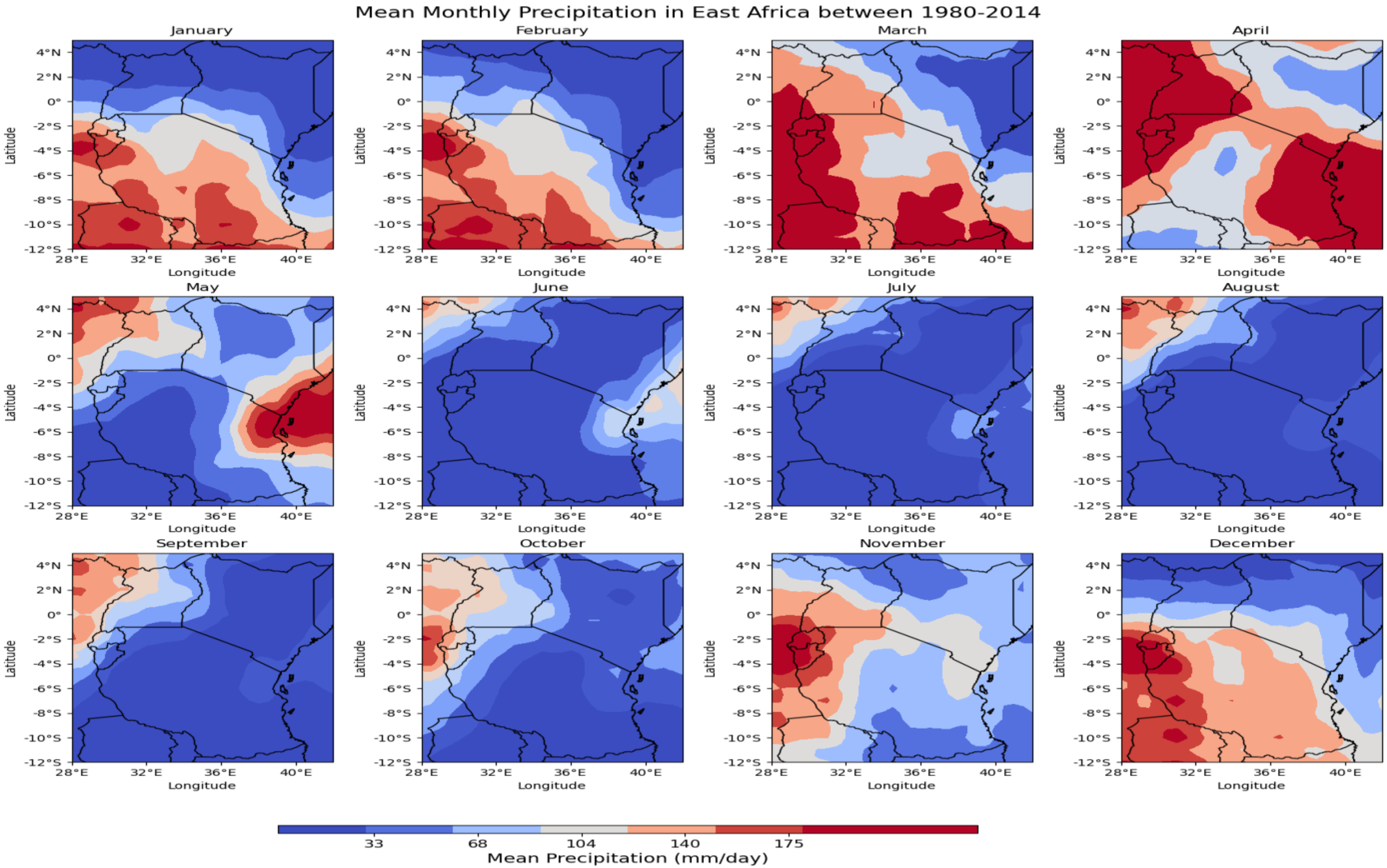



High precipitation
60°N
30°N
0°
30°S
60°S
180°
120°W
60°W
0°
60°E
120°E
180°


Low precipitation
60°N
30°N
0°
30°S
60°S
180°
120°W
60°W
0°
60°E
120°E
180°



Neutral precipitation
60°N
30°N
0°
30°S
60°S
180°
120°W
60°W
0°
60°E
120°E
180°
−38.7
−25.8
−12.9
0.0
12.9
25.8
38.7
Indices


Mean Monthly Precipitation in East Africa between 1980-2014
January
February
March
April
May
June
July
August
September
October
November
December
Latitude
Longitude
4°N
2°N
0°
-2°S
-4°S
-6°S
-8°S
-10°S
-12°S
28°E
32°E
36°E
40°E
33
68
104
140
175
Mean Precipitation (mm/day)

Results

1. CMIP6 has no overall advantage over CMIP5 in simulating total precipitation over the region. CMIP6 has inherent biases dry (wet) over most parts of the region during the MAM (OND) rainfall season.
2. While the CMIP6 can reproduce the bimodal precipitation patterns better than the CMIP5 models.
3. Consequentially, CMIP6 can reproduce the mean climatology of the region albeit overestimating the OND rainfall mean.
4. For the secular change of precipitation, the individual means and ensemble means cannot be wholly relied upon for projecting rainfall trends because they exhibit a wetting anomaly despite observations suggesting a drying anomaly.
5. Spatially, the CMIP6 simulation of precipitation will be biased towards a dry (wet) simulation over most parts of East Africa with the driest (wettest) biases over south-eastern Tanzania (Lake Victoria basin) during MAM (OND) season.
6. CMIP6 projects an increase in the MAM and OND precipitation averaged over East Africa by the end of the 21st century higher in the SSP5-8.5 **than the SSP2-4.5**.
7. While this observation is consistent with CMIP5 and related studies, caution should be exercised in interpreting this projection considering CMIP6 has a weakness in the simulation of extreme rainfall events and the bimodal season precipitation means.

Conclusion

Based on this study, it can be concluded that CMIP6 is marginally better than CMIP5 in the simulation of the East African rainfall patterns. It means that the “East African Paradox” observation will not have been addressed.

References

Year	Author	Title	Journal	Web link
2023	Lupien	Past climate unravels the eastern African paradox.	*Nature.*	https://www.nature.com/articles/d41586-023-02297-y
2022	Mölg ,	A mid-troposphere perspective on the East African climate paradox.	*Environ. Res. Lett.*	https://iopscience.iop.org/article/10.1088/1748-9326/ac8565/meta
2021	Pedersen +	An assessment of the performance of scenarios against historical global emissions for IPCC reports.	*Glob. Environ. Change.*	https://www.sciencedirect.com/science/article/abs/pii/S0959378020307822
2019	Giorgi,+	The response of precipitation characteristics to global warming from climate projections.	*Earth Syst. Dyn*	https://esd.copernicus.org/articles/10/73/2019/
2021	IPCC	IPCC. Summary for Policymakers. In *Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*;	*IPCC*	**https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf**
2019	Wainwright +	Eastern African Paradox' rainfall decline due to shorter not less intense Long Rains.	*Clim Atmos Sci.*	https://doi.org/10.1038/s41612-019-0091-7
2018	Muhati +	Past and Projected Rainfall and Temperature Trends in a Sub-Humid Montane Forest in Northern Kenya Based on the CMIP5 Model Ensemble.	*Glob. Ecol. Cons.*	https://doi.org/10.1016/j.gecco.2018.e00469.
2017	Lyon, Vigaud,	Unraveling East Africa's climate paradox. *Climate extremes: Patterns and mechanisms*.	*Climate extremes.*	https://doi.org/10.1002/9781119068020.ch16
2015	Rowell +	Reconciling past and future rainfall trends over East Africa.	*J. Clim.*	https://www.researchgate.net/publication/349226633_