Major drivers of East African Monsoon variability and improved prediction for Onset dates

Indrani Roy[1, 2] (Indrani.roy@wemcouncil.org), Meshack Mliwa[1] and Alberto Troccoli[1]
[1]World Energy and Meteorology Council (WEMC), The Enterprise Centre University Drive University of East, Norwich NR4 7TJ; [2] University College London, UK

1. Background

Monsoon rainfall plays a crucial part in Africa's socio-economic structure. Its year-to-year variability has profound implications for agricultural, energy, and other societal sectors. Identification of any large-scale climate drivers – those that contribute to the year-to-year fluctuations of monsoon seasonal rainfall in regions of Africa – which can be used to improve the quality of onset and rainfall amount predictions a few months ahead would have enormous implications for the livelihood of millions of Africans.

East African countries are much prone to floods and droughts. The main focus is on October-November-December (OND), because it is the season that has the common onset for rainy seasons in large parts of East Africa. Moreover, in this particular season various monsoon-related features in East African countries show a much larger degree of interannual variability compared to any other season (Nicholson, S. E. 2017, Hastenrath et al. 1993).

2. Data and Methods

In this study, data of two large scale climate drivers, El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are analysed, in relation to precipitation. For ENSO, Nino3.4 index is used; while the intensity of the IOD is represented by a Dipole Mode Index (DMI), which is anomalous Sea Surface Temperature gradient between the western equatorial and the south eastern equatorial Indian Ocean. For precipitation, Global Precipitation Climatology Project (GPCP) data, Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data and ECMWF Reanalyses Version 5 (ERA5) data are used. In the initial part of analyses, we used three independent datasets, though our results are similar using other data sources too. The limitations of one particular dataset are compensated while presented together results with other data sources. Onset of the rainy season is however dependent on datasets and for simplicity only CHIRPS data is presented for onset. The period of the analyses cover at least 30 years period, namely 1993 to present, but also from 1979 when available.

Various commonly used statistical techniques/relationships are applied to identify robust signatures of large-scale drivers of east African OND monsoon. The Correlation, Regression analyses and Compositing method are among the methods used in this study. For significance testing, student's t test is applied. For Compositing, the method of mean difference is applied to identify significant regions. [See at the end sources for major data used]

3.1 Results: Correlation Analyses

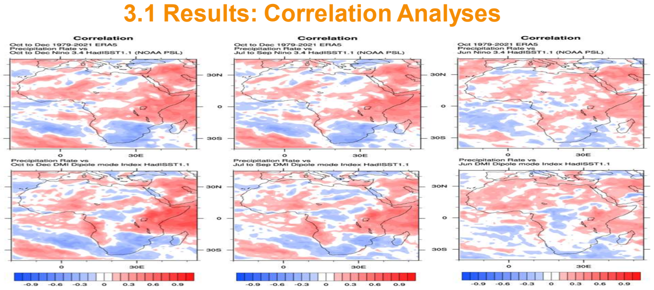

Figure 1: *Correlation of Precipitation with Nino3.4 (top) and IOD (bottom). Data for ERA5 is shown for 1979-2021. Correlation with various lead times used: left) Without any lead, middle) lead of one season, and c) lead of a season and a month (June is used). Correlations higher of .23 are significant at 95% level.*

Strong Positive correlation for precipitation (OND) with both ENSO and IOD is seen not only in simultaneous relation (left), but also with a lead time of a season [Jul-Aug-Sep (JAS), middle]. Signal is also present in June too, right (Fig. 1). Results are similar if used either only earlier years of data or later years of data. Regression study also indicates similarly (not shown here).

3.2. Results: Method of Compositing

To eliminate effects of confounding factors of ENSO and IOD, when those are in the opposite phase, the Compositing technique is applied. Figure 2 suggests a deficit (excess) of more than 100mm of rain from normal in SE African countries when IOD and ENSO both are negative (positive) in JAS, for Case 1 (Case 3). Results are similar if Case 2 is used instead of Case 1 and Case 4 is used instead of Case 3. On the other hand, no signal is detected when IOD and ENSO are in the opposite phase at JAS (Case 5). Similar results using other data too

Case 1: ENSO, IOD negative in JAS and OND; **Case 2:** ENSO, IOD negative in JAS
Case 3: ENSO, IOD positive in JAS and OND ; **Case 4:** ENSO, IOD positive in JAS
Case 5: ENSO, IOD opposite in JAS ; **Case 6:** All years (1993-2021) together

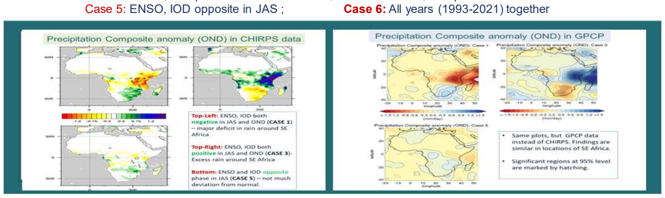

Figure 2: *Precipitation composite anomaly (OND) for 1993-2021, using CHIRPS data (left) and GPCP (right): Results are shown for Case 1, Case 3 and Case 5.*

3.3. Mechanisms involving Walker Circulation

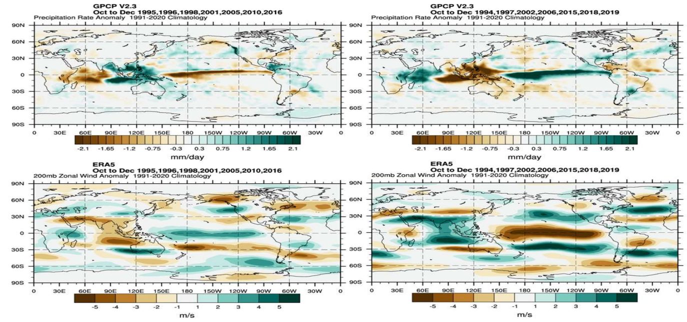

Figure 3: *Composites for Precipitation (top) and Zonal wind at 200mb (bottom) in OND. Cases when IOD and ENSO are both negative in JAS (Case 1, left) and when both are positive (Case 3, right)*

The Walker circulation plays an important role in modulating precipitation (Fig 3). Less (excess) precipitation in Case 1 (Case 3) in SE Africa, associated with consistent 200mb wind anomaly.

3.4. Onset Techniques and Importance of Alternate Method

The OND Onset day using the Standard Technique (ST) based on the definition from Tanzania Meteorological Authority (TMA) depends on thresholds: a) the first occasion in the season when 20 mm or more rain is received in four consecutive days, b) with at least two wet days and c) no dry spell of 10 days or more within the following 30 days. A technique (Fig. 4) that mainly considers cumulative amounts of anomalous seasonal rainfall (Macleod et al. 2018; Zampieri et al. 2022) can overcome many limitations of the ST and is adopted here (referred to as Alternate Technique 1, AT1).

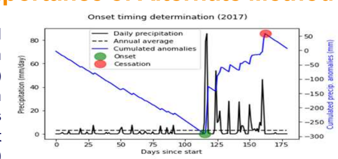

Figure 4: *Onset, Cessation and duration of monsoon (OND) in a location Kibaha, Tanzania in 2017 using CHIRPS data with AT1. Onset 23rd Oct, cessation on 9th Dec and duration of the seasonal monsoon 47 days. AT1: a change in cumulative rainfall from annual average (Y axis, right), shown in blue, plotted over time (days since 1st July in X axis). The time of long-term daily change in phase from decrease to increase is defined as Onset date, while reverse behaviour is the Cessation date.*

3.5. Cumulative Rain and Onset: Various Cases

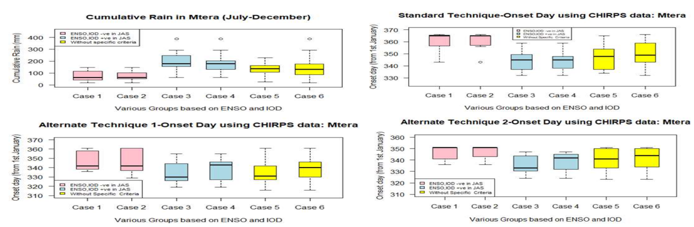

Figure 5: *Cumulative rain in mm (top left) and Onset in three different techniques (ST, AT1 and AT2) in Mtera*

Figure 5 shows rainfall deficit in Case 1 and 2, while excess for Case 3 and 4 (top left). As Cumulative rain plays important role, another new technique or Alternate Technique 2 (AT2) is applied based on Cumulative rain (bottom right). Late Onset for pink and early Onset for blue is clearly noticed for all techniques. Also, uncertainty is reduced in Case 1, 2 (pink) and Case 3, 4 (blue) than Case 6. Similar observation is noticed for other neighbouring stations too.

3.6. Onset in Various Techniques with Drivers

Onset using ST, AT1, AT2 is also included with Agricultural Onset (Agr) in Fig. 6. All results are comparable. Usually, late Onset for Case 1, 2 are seen, while early Onset for Case 3, 4 in all techniques. Uncertainty is reduced, if focus is either on Case 1,2 or Case 3,4 (max for Case 3).

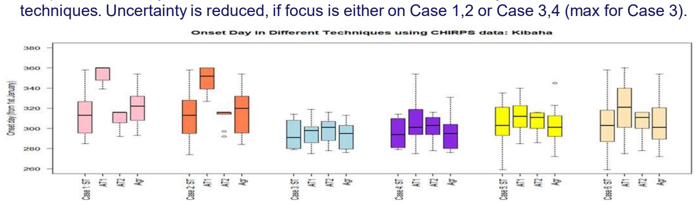

Figure 6: *Onset of Monsoon (OND) in Kibaha, Tanzania using CHIRPS data for 1993 to 2021 as a function of various ENSO and IOD phases. Results are shown for four Techniques ST, AT1, AT2 and Agr.*

4. Conclusions

- Two important drivers of Monsoon (OND) in SE Africa viz., ENSO and IOD are discussed and affected regions are identified. Positive significant correlations are noticed for rain (OND) with both ENSO or IOD, a season ahead. Results are similar using various data, covering either earlier or later years, and detrending data beforehand.
- Compositing separates confounding influence and detects strong signals also from JAS. A significant deficit in the rain when both drivers ENSO and IOD are negative and vice versa when positive. Walker circulation plays an important role and the future outlook of rains possible a season ahead.
- An Alternate Technique (AT1) for 'Onset' (Zamperi et al, 2022, MacLeod, 2018.), that can eliminate many biases of the official Standard Technique (ST) is tested. It is based on cumulative rainfall anomaly and offers fair results which are comparable to ST as used by Tanzanian Meteorological Authority (TMA).
- IOD and ENSO phases in JAS are not only good indicators for cumulative rain (OND), but also indicate about Onset. Late (Early) Onset in OND is observed when both drivers are negative (positive); true even using different techniques. Another new technique (termed here as AT2), based on cumulative rainfall is also tested (Dunning et al. 2016). Agricultural onset technique (Agr) is also examined.
- Uncertainty range on OND monsoon-related parameters is shown to improve based on IOD and ENSO phase in JAS. Individual stations are tested (shown here e.g., Kibaha and Mtera). Results suggested similar patterns even though four different techniques (ST, AT1, AT2, Agr) are applied.

Data
ENSO: https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/nino34.long.anom.data
IOD: https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.had.long.data
GPCP: https://climatedataguide.ucar.edu/climate-data/gpcp-monthly-global-precipitation-climatology-project
CHIRPS: https://www.chc.ucsb.edu/data/chirps
ERA5: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

References
Dunning, et al. (2016), J. Geoph. Res. Atmos., 121, 11, 405–11,424.
Hastenrath S,et al. (1993) J Geophys Res Oceans (1978–2012) 98(C11):20219–20235
MacLeod, D., 2018. Weather Clim. Extrem. 21, 27–35.
Nicholson, S. E. (2017). Reviews of Geophysics, 55, 3
Zampieri et al., (2022). Under revision in Climate Services.

Acknowledgement:
This work was funded by the EU H2020 FOCUS-Africa project GA869575 (https://focus-africaproject.eu/)