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Diagnosis of DJF Rainfall Climatology and Associated Circulation Mechanisms over Zambia

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Abstract: In order for a developing country like Zambia to be able to positively respond to and withstand the social-economic impacts of droughts and floods, scientific analysis of historical rainfall patterns and associated circulation anomalies is significant. In this paper, we describe the rainfall climatology and trends from 1960 – 2010. Monthly rainfall data for 38 meteorological stations archived by the Zambia Meteorological Department (ZMD), monthly precipitation datasets from the Global Precipitation Climatology Centre (GPCC) and reanalysis datasets are used. Composite analysis was deployed to understand the circulation anomalies during the time of study. Analysis of wind, velocity potential and divergence/convergence over the study area showed that wet years were characterized by convergence in the lower troposphere implying rising motion and divergence at the upper level. On the other hand, dry years were characterized by divergence in the lower troposphere implying sinking motion and convergence at the upper level. A relationship between variations in rainfall patterns over Zambia and El Niño Southern Oscillation was explored and found. The study found that El Niño conditions (warm phase) bring drier than average conditions in the wet summer months (DJF) in the southern half of the country, whilst the north of the country simultaneously experiences significantly wetter than average conditions. The reverse pattern occurs with La Niña (cold phase) episodes, with dry conditions in the north and wet conditions in the south.

Index Terms : Climate, Rainfall, Interannual Variability, ENSO, Anomalies, DJF, Zambia.

1 Introduction

Much of the economic, cultural and social life of Zambia is dominated by the onset and offset of the rain season, and the amount of rain it brings. Failure of the rains causes hunger from time to time [1]. Excess of the rains also causes damage to crops and property. Precipitation is thus, one of the most important parameters for the Southern African developing country. With Zambia's high vulnerability to climate change [2], the study and analysis of factors influencing precipitation have become imperative. It is therefore of great importance to have a good understanding of previous climate events and their impacts so as to make reliable and accurate forecasts to minimize the impact of these extreme occurrences of climate [3]. To improve long range forecasting further, better understanding of the climate variability of the region and assessing rainy season characteristics and the possible relationships between large-scale climate modes or identifiable regional circulation anomalies and dry and wet spell characteristics need to be investigated. [4].

Zambia experiences a sub-tropical climate with three distinct seasons; a dry and hot season from mid-August to November with temperatures in the range between about 26 and 38 °C, a dry and cool season from May to mid-August with temperatures in the range between about 13 and 26 °C and a rainy season from October/November to March/April [5]. During the rainy season the temperatures range between about 27 and 34 °C [6]. Over Zambia, annual rainfall totals fall within the range of 500mm and 1400mm. The highest rainfall is in the north, especially the north-west and the north-east, decreasing towards the south; the driest areas are in the far south west and the Luangwa River and middle Zambezi River valleys, parts of which are considered semi-arid. None of the country is considered arid or to be desert.

On a mesoscale, topography, temperature, atmospheric pressure and evapotranspiration are some of the factors that influence precipitation [7]. The relationship between the El Niño Southern Oscillation (ENSO) and widespread precipitation patterns is one of the most significant factors [8]. ENSO is a major contributor to inter-annual climate variations in Africa and beyond [9]. The Southern African inter-annual rainfall variability is known to be linked to the ENSO. During El Niño, warm episode, Zambia has a high risk of severe drought while during the cold episode, La Niña, most parts of Zambia experience above average rainfall [10, 11, 12, 13, 14).

2 Data and Methods

2.1 Data

Rainfall data from 38 Meteorological Stations spread across

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Zambia has been used to compare and validate Global Precipitation Climatology Centre (GPCC) data. Figure 1 presents the distribution of the stations used in the study to validate the Climatic Research Unit (CRU) precipitation data. For further analysis, we continued to use the monthly precipitation dataset from the Global Precipitation Climatology Centre (GPCC). It is calculated from the global station data [15]. GPCC Precipitation data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA. This data is used because the African rain-gauge data has many spatial and temporal discontinuities over large sections of Africa [16, 17]. We also used reanalysis fields from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) , including zonal and meridional wind and velocity potential, with a horizontal resolution of 2.50 X 2.50.

2.2 Omega

Pressure is often a convenient vertical coordinate to use in place of altitude [18]. In pressure coordinates the vertical velocity is defined as:

$$\omega \equiv \frac{Dp}{Dt}, \qquad (1)$$

and is commonly called simply omega. Therefore, Omega is defined as a partial differential equation for the vertical velocity which is defined as a Lagrangian rate of change of pressure with time. The equation reads:

$$\sigma\nabla^2 H^{\omega} + f^{2\frac{\partial^2\omega}{\partial P^2}} = f\frac{\partial}{\partial p}\left[V_g \,.\, \nabla_H(\varsigma_g + f)\right] - \nabla_H^2 \left(V_g \,.\, \nabla_H \frac{\partial\phi}{\partial p}\right) \qquad (2)$$

where *f* is the Coriolis parameter is the static stability, is the geostrophic velocity vector, is the geostrophic relative vorticity, is the geopotential, is the horizontal Laplacian operator and is the horizontal del operator [19]. The units of w are Pa/s (often microbars per second, μb/s, is also used).

2.3 Composite Analysis

Composite analysis is used in this study. It involves identifying and averaging one or more categories of fields of a variable selected according to their association with key conditions. Results of the composites are then used to generate hypotheses for patterns which may be associated with the individual scenarios [20, 21]. In this study, the key conditions for the composite analysis are wet/flood year and dry/drought year, where the composites for wet and dry years were separately done, especially for wind vector, This is mainly to detect the circulation anomalies associated with wet/dry events over the region. A number of authors, including [22] and [23] have used composite methods in their analyses over the African continent.

2.4 Simple Correlation

Correlation analysis reveals simple relationship between pairs of variables. In this study, correlation analysis is aimed at establishing whether the areal average DJF rainfall (DJF index) is representative of the different stations used in the study. DJF index is correlated with individual station DJF rainfall over the study area. [24].

3 Results

In this chapter the results obtained from the various methods that were used to address the objectives of the present study are presented and discussed in their respective sub-sections.

3.1 Statistical Characteristics of December to February (DJF) Rainfall

The annual cycle of rainfall over Zambia was examined based on both station rainfall and the Climate Research Unit (CRU) in an attempt to validate the CRU dataset, which was used in subsequent analyses. Results (Figure 2) shows that the two datasets are in agreement, with higher rainfall amount noted between November and March, whereas the least amount is recorded between May and September.

The stations used in the study and their locations are shown in Figure 1(a). Figure 1(b) displays the average seasonal rainfall over the study area. From the figure, it can be seen that the north and northwestern regions such as Samfya, Msekera, Mwinilunga and Mansa, tend to receive more rainfall compared to other regions of the country.

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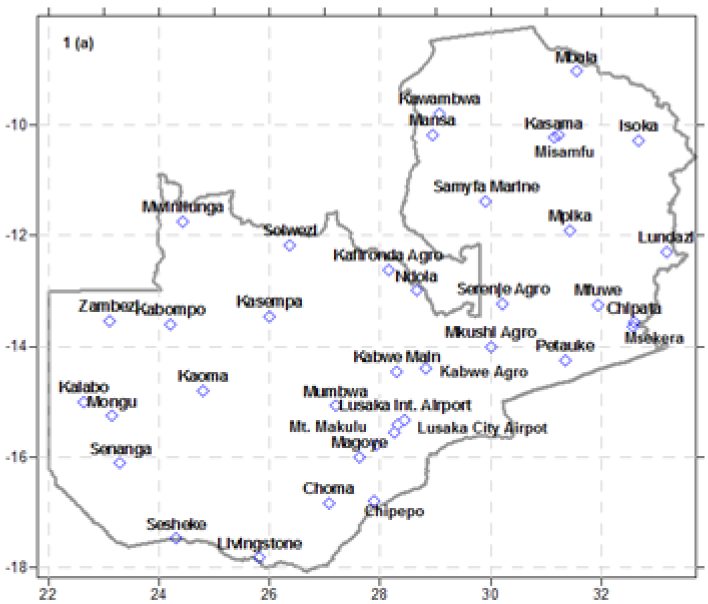
Figure 1:(a)Distribution of the rainfall stations used in the study area (b) Mean seasonal rainfall distribution over Zambia



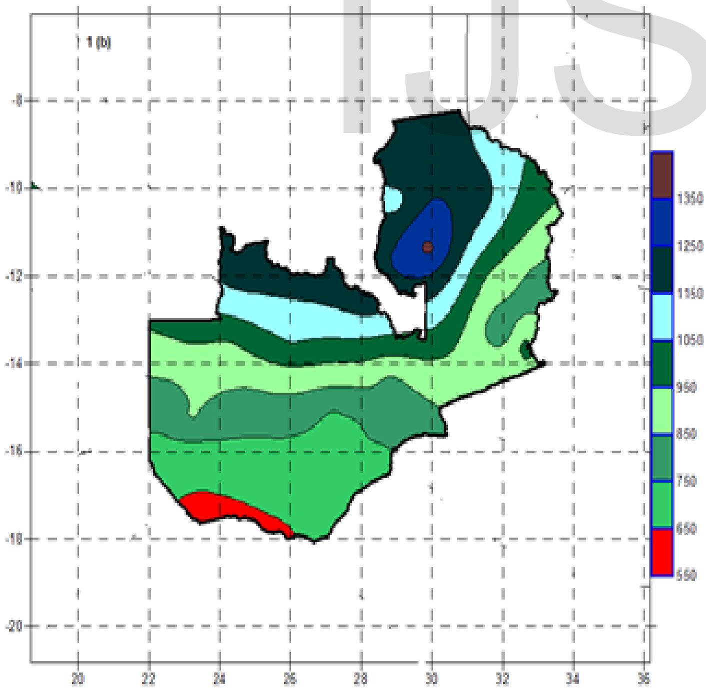
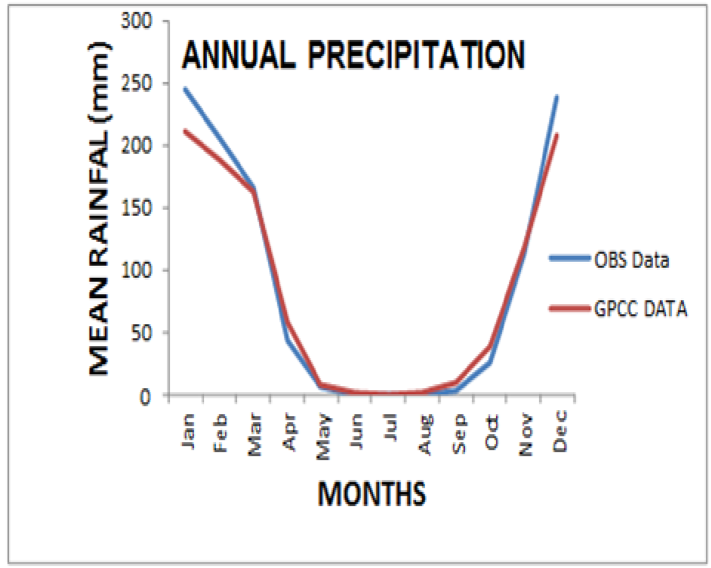
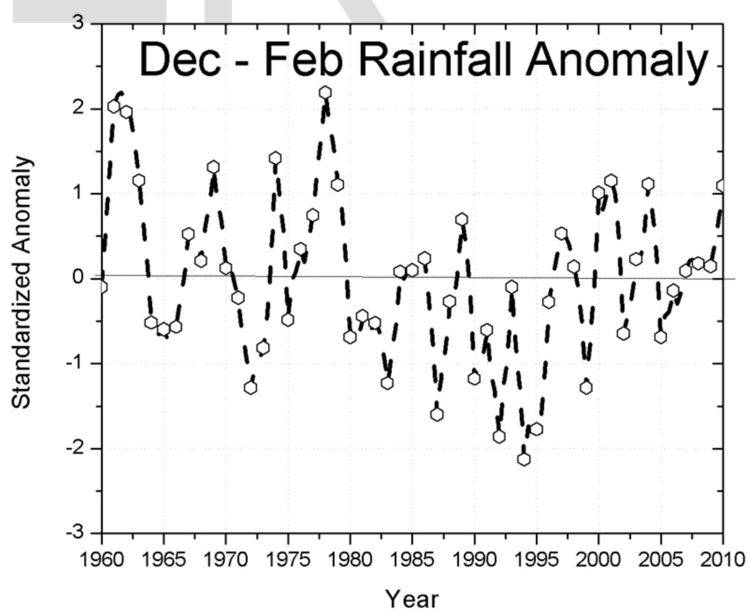


Figure 2: The mean annual cycle of rainfall (mm) over Zambia for station data (in red) and 3 CRU data (in black), averaged over longitudes 21°E - 34°E and latitudes 19°S - 7.5°S for the 4 period 1960 -2010



The standardized anomaly of December - February rainfall for the study period is shown in Figure 3.

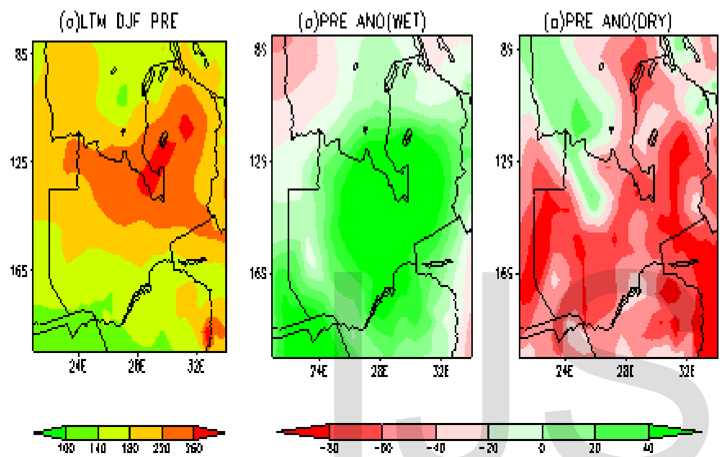
Figure 3: Interannual variability of December - February rainfall (standardized anomaly) for the Period 1960 – 2010



Analysis of the interannual variability of the mean DJF rainfall (Figure 3) shows that 2004 was a wet year during the period 1960-2010. This year (2004) is further examined in this study alongside the drought year (1982) in order to understand the prevailing circulation anomalies in the region during flood and drought events.

In general, the northeastern and northwestern parts of the country and Copperbelt provinces receive more rainfall compared to the rest of the country (Figure 4). The least amount of rainfall is observed in the south eastern and southwestern parts of the country. Further analysis of the spatial distribution of rainfall during wet and dry years shows that the wet year was dominated by positive rainfall anomalies (Figure 4b), as opposed to the dry year which had negative rainfall anomalies in most regions of Zambia (Figure 4c).

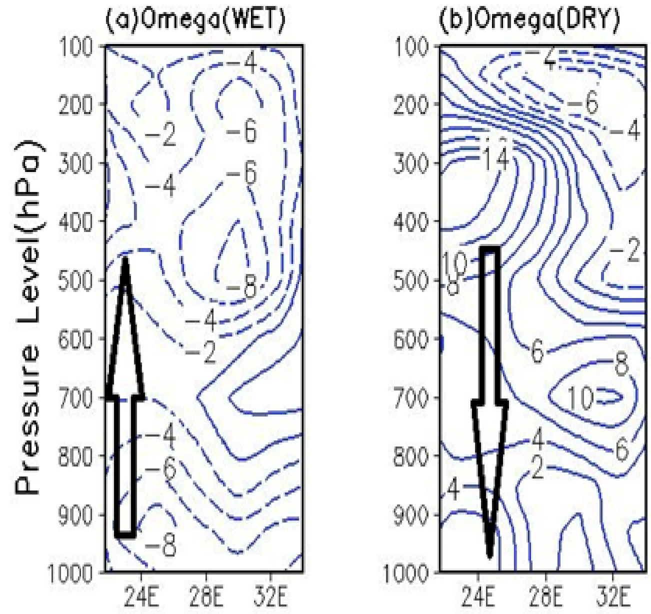
Figure 4: (a) Climatology of the mean DJF rainfall (mm) based on the period 1981-2010 (b) Mean rainfall anomaly during wet year (2004) (c) Mean rainfall anomaly during dry year (1982)



3.2 Circulation Anomaly Patterns Associated With Wet and Dry Events of December - February

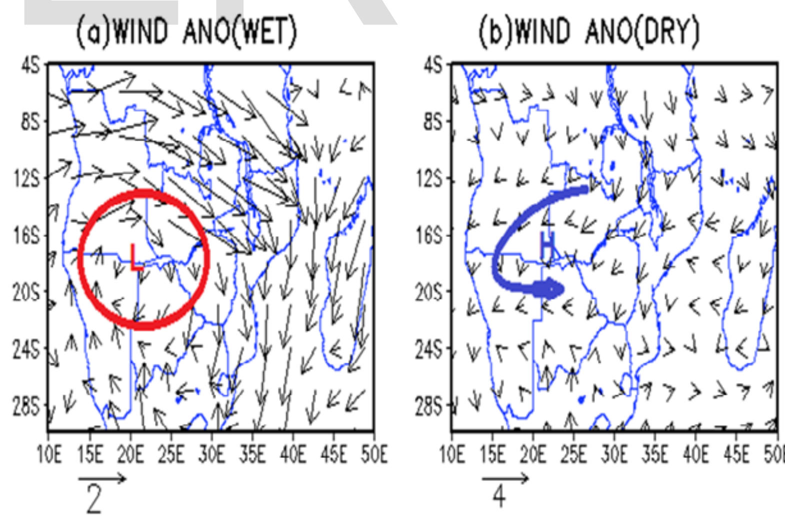
In order to understand the vertical motion associated with wet and dry events over the region, we investigate the pressure vertical velocity (Omega). Results show that the wet year was dominated by negative anomalies, which depict rising motion (Figure 5a). Rising motion is associated with convergence at low level and divergence at upper level. Dry year on the other hand was characterized by positive anomalies (Figure 5b), which exhibits sinking motion. Sinking motion may be associated with convergence at upper level and divergence at low level. Convergence at low level leads to vertical stretching, whereas divergence leads to vertical shrinking which suppresses convection due to subsidence [25].

Figure 5: The mean meridional cross-section of DJF pressure vertical velocity (omega) anomaly ($x10^{-3}Pa\ s^{-1}$) for wet year (2010) and dry year (1992) at 15°S, over longitudinal section 21°E - 34°E. For NCEP/NCAR data (a) wet year (b) dry year



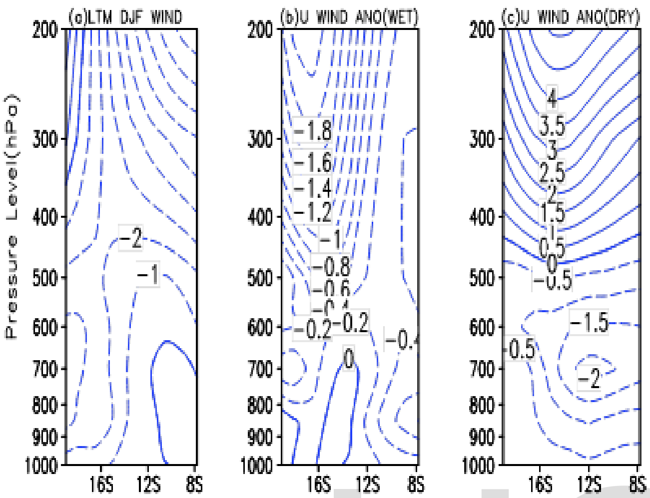
When we analyzed the anomalous horizontal wind vectors associated with wet and dry events over the region of study, the results showed that at 850 hpa level, there exists an anomalous convergence zone (marked L) over the region in the wet year (Figure 6a). Convergence at low level (850hpa) leads to ascending motion which favors rainfall, hence wet year; 2004. The dry year (Figure 6b) exhibits anomalous high pressure system (H) over the study area, depicting divergence at this level, which suppressed rainfall, hence dry year; 1982.

Figure 6: The mean DJF wind anomaly vectors (ms^{-1}) at 850 hpa (a) Wet year (2004), and (b) Dry year (1982), based on ERA interim reanalysis data.



The zonal wind is further investigated to understand its behavior during wet and dry events. Results (Fig.7) show that the climatology of zonal wind is characterized by easterly flow (Fig. 7a), except at low level. During wet year, this flow is reversed with westerlies dominating at the lower level and easterlies on high level as observed in the anomalous vertical cross section of the zonal wind (Fig. 7b). This flow is reversed during dry year (Fig. 7c), with easterlies dominating below 500 hpa, as westerlies dominate above this level.

Figure 7: The vertical cross section of the mean DJF zonal wind , averaged over longitudes 21°E - 34°E for (a) Long term mean (LTM) based on 1981-2010 period (b) Anomaly for wet year , and (c) Anomaly for dry year , based on NCEP/NCAR reanalysis data.



4. Conclusions

Results reveal that from 1960 to 2010, Zambia experienced an equal number of wet and dry years. However, the intensity of the wet events was more than that of the dry events. Analysis of the drought and flood years with respect to the different variables including wind, velocity potential and divergence/convergence vectors revealed that the drought (flood) years were characterized by divergence (convergence) in the lower troposphere and convergence (divergence) at the upper level, implying sinking (rising) motion, especially over the western Indian Ocean and the study area. The anomaly convergence zone was identified within (outside) the region of study during flood (drought) years.

The study also showed that the observed atmospheric circulation associations with wet and dry events can be monitored in future to avert the losses associated with wet and/or dry events.

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Conflicts of Interest

The author declares no conflict of interest.

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