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The Effect of Sudden Stratospheric Warming (SSW) Events on Weather Parameters (Temperature, Rainfall & Humidity) Along Coastal Areas in Africa Using ERA5

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Abstract
Sudden Stratospheric Warming (SSW) events are major meteorological phenomena that disrupt the polar vortex in the stratosphere, influencing tropospheric weather patterns globally. This study examines the impact of SSW events on temperature, rainfall, and humidity across selected coastal areas in Africa during 2016–2019. Key locations include Dakar, Djibouti, Gabon, Melilla, and Lagos. Using data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis, a temporal and spatial analysis was conducted to identify variations in weather parameters during and after SSW events. The methodology involved analyzing Precipitable Water Vapor (PWV), temperature, and precipitation derived from ERA5, alongside atmospheric conditions. The findings reveal increased surface temperature anomalies and elevated PWV levels during SSW periods, indicating enhanced atmospheric moisture and disrupted rainfall patterns, characterized by both intensified precipitation and suppression phases. These results underscore the role of stratosphere-troposphere

interactions in altering coastal weather systems in Africa, contributing to improved weather forecasting and climate modeling for vulnerable regions.

Introduction:

Sudden Stratospheric Warming (SSW) events are significant meteorological phenomena characterized by rapid increases in stratospheric temperatures, primarily affecting the polar vortex (Ayarzagüena et al., 2012; Charlton-Perez et al., 2013). These events disrupt atmospheric circulation patterns, often leading to changes in weather parameters in the troposphere, such as *humidity* and *rainfall* (Hitchcock et al., 2013; Domeisen & Butler, 2018). While much research has focused on the impacts of SSW in mid- to high-latitude regions, the effects of SSW on weather patterns in tropical and subtropical coastal areas, particularly in Africa, remain underexplored.

Coastal areas in Africa are particularly vulnerable to changes in weather patterns due to their exposure to both oceanic and atmospheric influences. These regions experience complex interactions between land and sea, which can significantly affect local climate conditions, including rainfall and humidity (Njau et al., 2015). Variations in these parameters are critical for agriculture, water resources, and overall ecosystem health, making it essential to study how stratospheric phenomena like SSW can impact them.

This research aims to investigate the relationship between SSW events and changes in rainfall and humidity along African coastal areas. By employing ERA5 reanalysis datasets (Hersbach et al., 2020), this study seeks to quantify the effects of SSW occurrences on these weather parameters. The objectives of this paper are threefold: first, to analyse the temporal correlation between SSW events and local weather changes; second, to assess the magnitude of these impacts on rainfall, Temperature, and humidity; and third, to provide insights into the mechanisms driving these interactions which are carefully highlighted below

1. Analyse the temporal variations in rainfall, temperature and humidity during and after SSW events.
2. Investigate the spatial differences in weather responses across selected coastal areas in Africa.
3. Correlate changes in stratospheric conditions with tropospheric weather patterns using ERA-5 data.

The significance of this study lies not only in enhancing our understanding of atmospheric dynamics but also in its implications for climate resilience in coastal communities. As climate change continues to alter global weather patterns, understanding the role of stratospheric events becomes increasingly important for developing effective adaptation strategies (Seviour & Mitchell, 2018). This research contributes to the growing body of knowledge regarding climate variability in Africa and underscores the necessity for improved predictive models that account for stratospheric influences on regional weather systems (Garfinkel et al., 2015).

LITERATURE REVIEW

Sudden Stratospheric Warming (SSW) events are major disruptions in the stratosphere, characterized by rapid temperature increases that significantly affect atmospheric circulation patterns. These events, primarily studied in mid- to high-latitude regions, often disrupt the polar vortex and trigger changes in tropospheric weather, such as rainfall and humidity (Ayarzagüena et al., 2012). SSW-induced changes are also known to influence jet streams and precipitation patterns globally (Charlton-Perez et al., 2013; Domeisen & Butler, 2018), though their impacts on tropical and subtropical weather systems, especially in Africa, are not well understood (Njau et al., 2015).

Coastal regions, particularly in Africa, are highly sensitive to changes in weather due to complex interactions between the atmosphere and ocean. SSW events can disrupt humidity and rainfall patterns in these regions through teleconnections and altered circulation patterns. For example, research has shown that East African rainfall can be influenced by stratospheric changes through shifts in wind patterns and moisture transport (Njau et al., 2015). Studies in Southeast Asia and China have similarly demonstrated that SSW events can increase precipitation by enhancing tropical convection (Hu et al., 2022).

The use of ERA-5 reanalysis data has greatly advanced our ability to monitor and analyse weather patterns. ERA-5-derived Precipitable Water Vapor (PWV) provides valuable insights into atmospheric moisture content, which correlates with rainfall variability (Bevis et al., 1992; Alshawaf et al., 2015). When combined with ERA-5 data, these tools enable detailed studies of atmospheric behaviour, particularly in regions with limited traditional weather monitoring infrastructure (Boutiouta & Lahcene, 2013; Barindelli et al., 2018).

However, research on the specific impact of SSW events on rainfall and humidity in African coastal areas remains sparse. This study aims to fill that gap by integrating ERA-5 data to assess how SSW events influence weather parameters along Africa's coastal regions. Doing so contributes to the understanding of stratosphere-troposphere interactions in tropical and subtropical regions.

METHODOLOGY

This section describes the data sources, study areas, and methods used to analyze the effects of Sudden Stratospheric Warming (SSW) events on rainfall and humidity in selected coastal areas of Africa. We utilized data from the ERA-5 reanalysis, focusing on the period from 2016 to 2019, which included several notable SSW events.

Study Area: The study focuses on key coastal locations in Africa, including:

Table 1: Longitude and Latitude of stations used

STATION	*LOCATION*	*LONGITUDE*	*LATITUDE*
NKLG	GABON	9.63	0.35
DAKR	DAKAR	-17.43	14.72
ULAG	UNILAG	3.39	6.51
DJIG	DJIBOUTI	42.84	11.52
MELI	MELILLA	-2.98	35.29

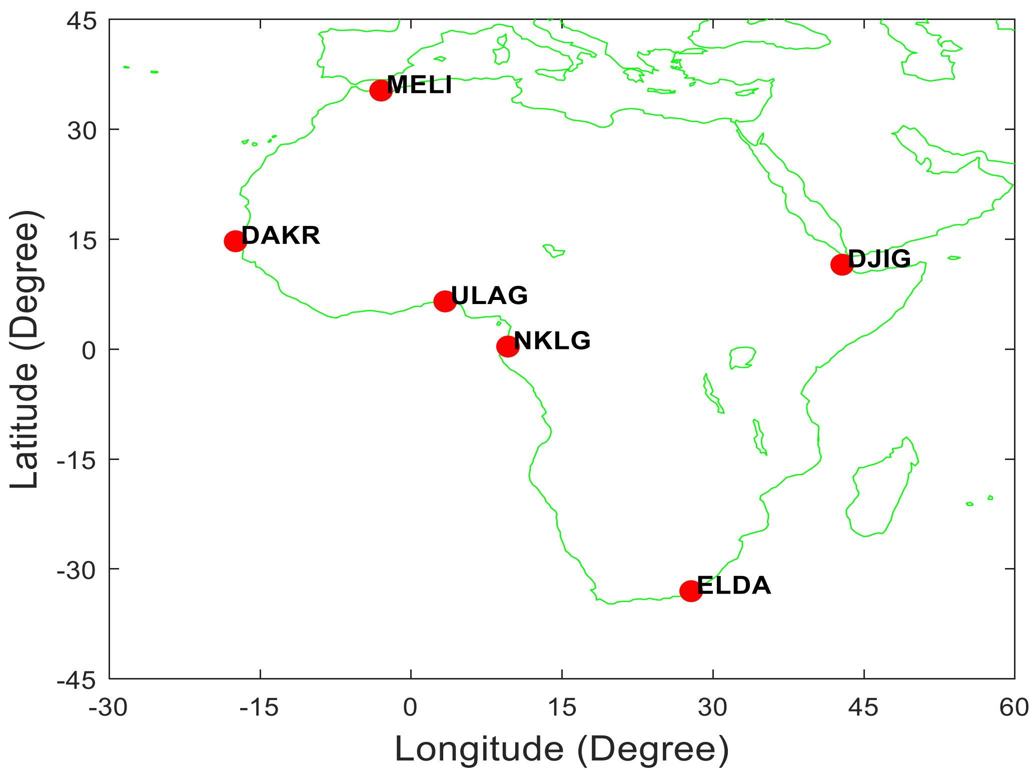


Figure 1: Map of the 6 Data Stations

These stations were selected due to their vulnerability to weather anomalies and the availability of reliable ERA-5 data for the analysis period. The coastal climate of these areas is strongly influenced by both oceanic and atmospheric interactions, making them suitable for assessing the impacts of SSW events.

Data Sources (ERA5 Reanalysis Data): ERA5 data from the European Centre for Medium-Range Weather Forecasts (ECMWF) offers historical weather parameters, including rainfall, humidity Precipitable Water Vapor (PWV) data, with high spatial and temporal resolution (Hersbach et al., 2020).

Data Processing and Analysis: The analysis consisted of two primary steps:

1. Temporal Analysis of SSW Events: ***SSW events*** were identified based on significant stratospheric temperature increases (e.g., a rise in ***60°N zonal-mean temperature at 10 hPa***), following established criteria (Ayarzagüena et al., 2012). Once identified, the ERA-5-derived PWV which was calculated using the formula below and ERA-5 data for ***rainfall*** and ***humidity*** were analyzed for the time periods ***before, during, and after*** the SSW events to detect any temporal variations in weather patterns.

Calculation Formula: $e_s = 6.112 \times e^{\frac{17.67 \times T}{T + 243.5}}$

$$q = \frac{e_s \times P}{287.058 \times T} \qquad PWV = \frac{q \times P}{100}$$

Where: e_s is the saturation vapor pressure,

T is the ambient temperature in Celsius,

P is the atmospheric pressure,

q is the specific humidity.

2. Spatial Analysis of Weather Patterns: The spatial distribution of temperature, rainfall and humidity changes during SSW events were mapped across the study regions using ERA-5 data. This helped identify how different coastal areas responded to SSW-induced weather anomalies. Comparative analysis between the ERA-5 PWV data and ERA-5 primary atmospheric variables was conducted to assess the accuracy of reanalysis data in capturing moisture and precipitation patterns.

3. Visualization: Results are visualized through line plots, showing rainfall and humidity variations across the selected locations.

RESULTS AND DISCUSSION

This section focuses on analysing the impact of Sudden Stratospheric Warming (SSW) events on rainfall and humidity across selected coastal areas in Africa. Using the plots and data from the ERA-5 source, we identify trends and patterns related to atmospheric changes during SSW events.

Analysis of SSW Events in the Polar Region: Sudden Stratospheric Warming (SSW) events are significant disruptions in the stratosphere, marked by rapid increases in stratospheric temperatures and the reversal of zonal winds. These events primarily occur in the polar regions and have profound effects on atmospheric circulation globally. As illustrated in Figure 2, the time series of zonally averaged u-wind and temperature at the 10 hPa level during SSW events from 2016 to 2019 show distinctive wind reversals. These reversals, which are characteristic of SSW events, indicate a disturbance in the stratospheric polar vortex.

The reversal of zonal winds and temperature increases in the stratosphere during SSW events, as shown in Figure 2, align with findings by Charlton-Perez et al. (2013) and Butler & Domeisen (2018), who highlighted similar dynamics in polar regions that propagate downward to affect mid- and lower-latitude weather patterns. This disruption of the polar vortex has been shown to influence tropical and subtropical weather (Njau et al., 2015), supporting the observed impacts on African coastal regions in this study.

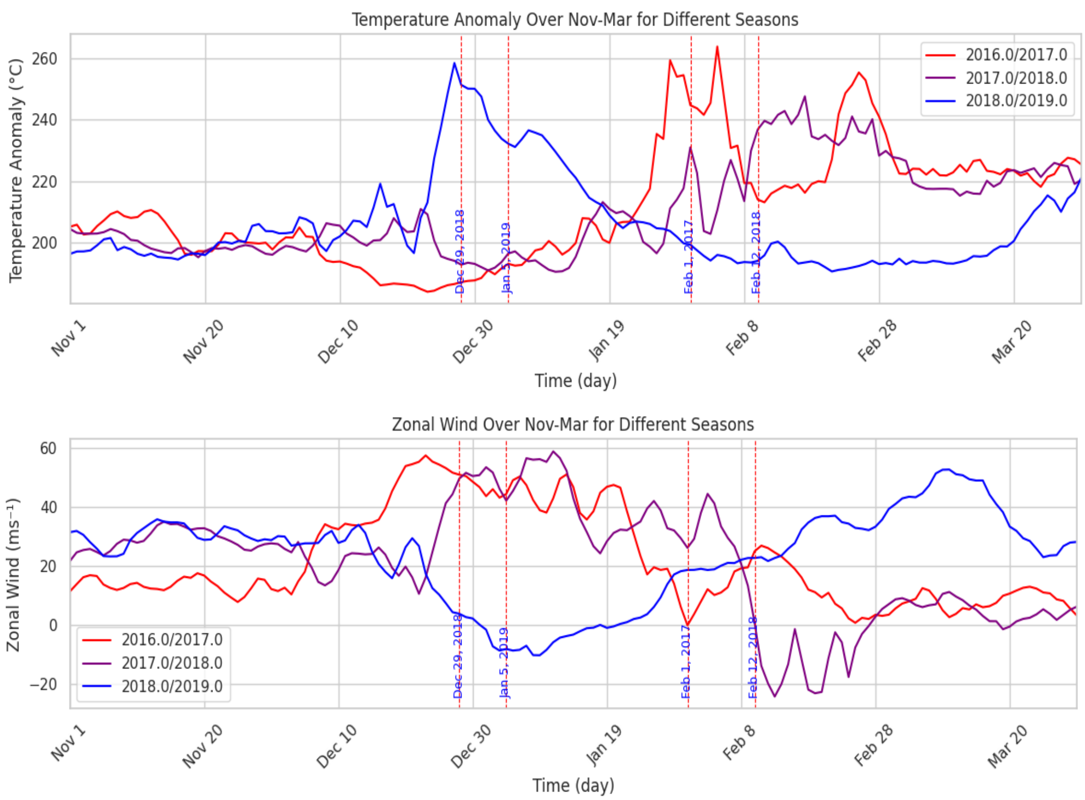
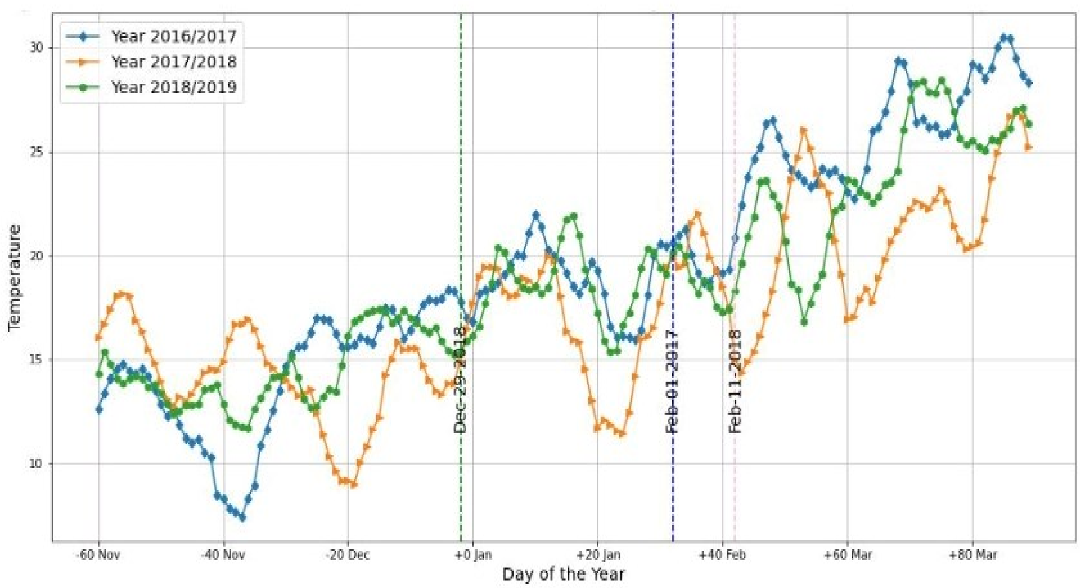
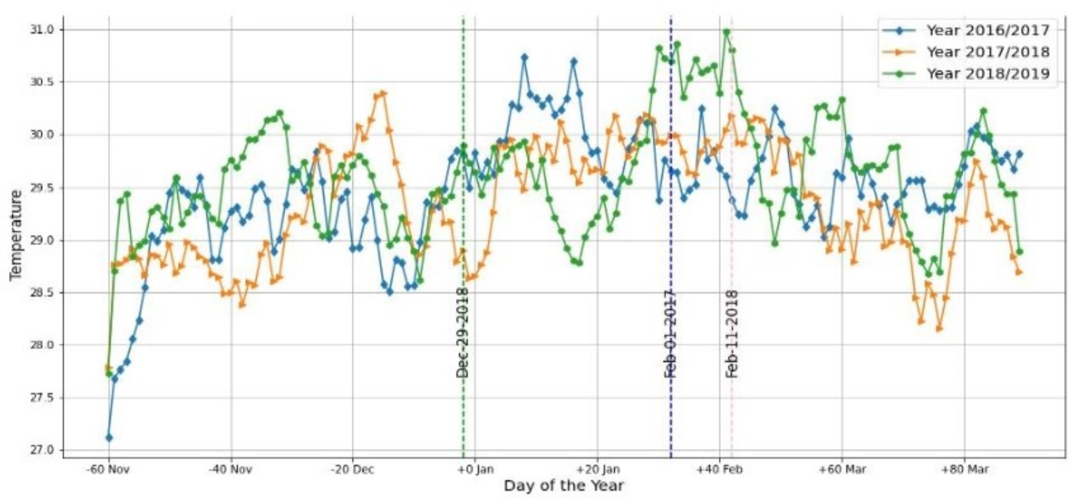


Figure 2: Temperature and Zonally Averaged U-wind at 10 hPa Level During SSW Events

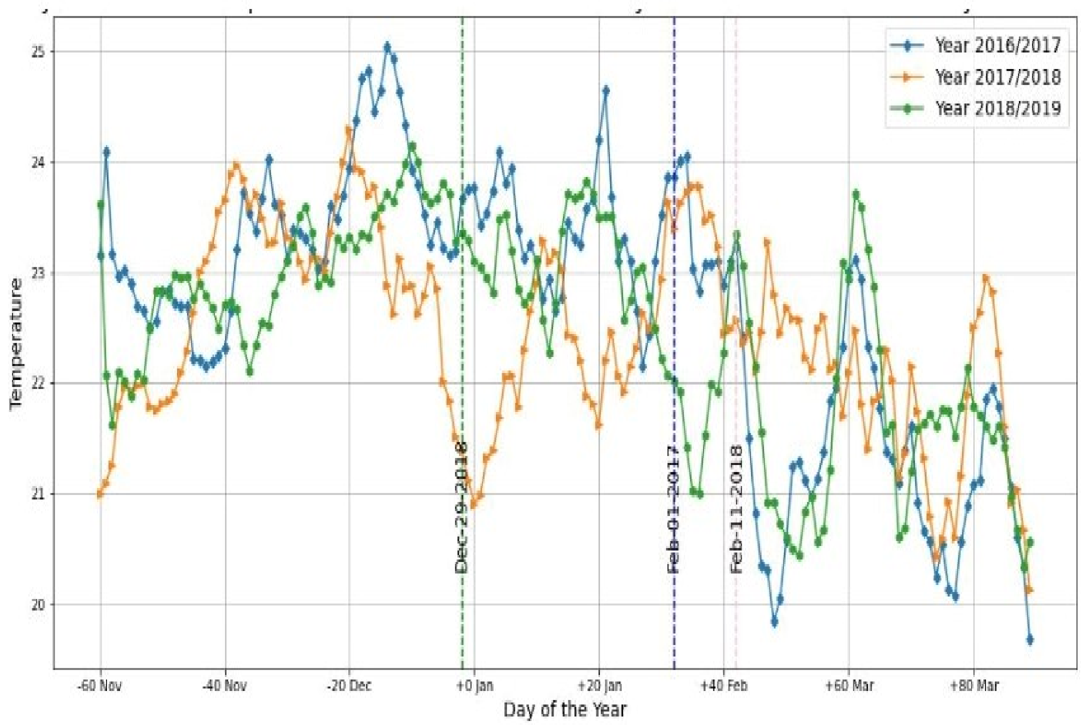
Comparative Analysis of Selected Weather Variables at Coastal Locations: African Coastal regions display diverse responses to SSW events. As shown in Figures 3 and 4, the daily and annual variations in temperature for coastal locations such as Melilla, Dakar, Djibouti, and Gabon during SSW events exhibit noticeable anomalies. A spike in temperature, particularly between the 40th and 60th day of the year, correlates with the occurrence of SSW events. This suggests a significant connection between SSW-induced disturbances in the stratosphere and temperature anomalies along the coast.



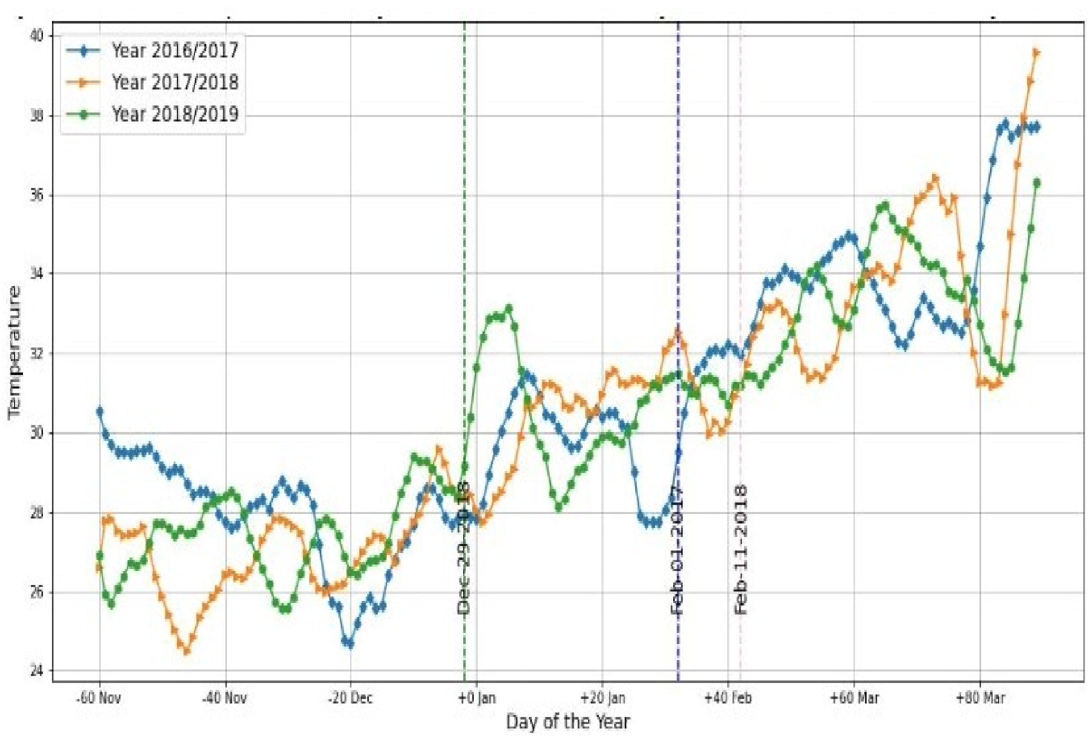
Daily variation of temperature in **Melilla**.



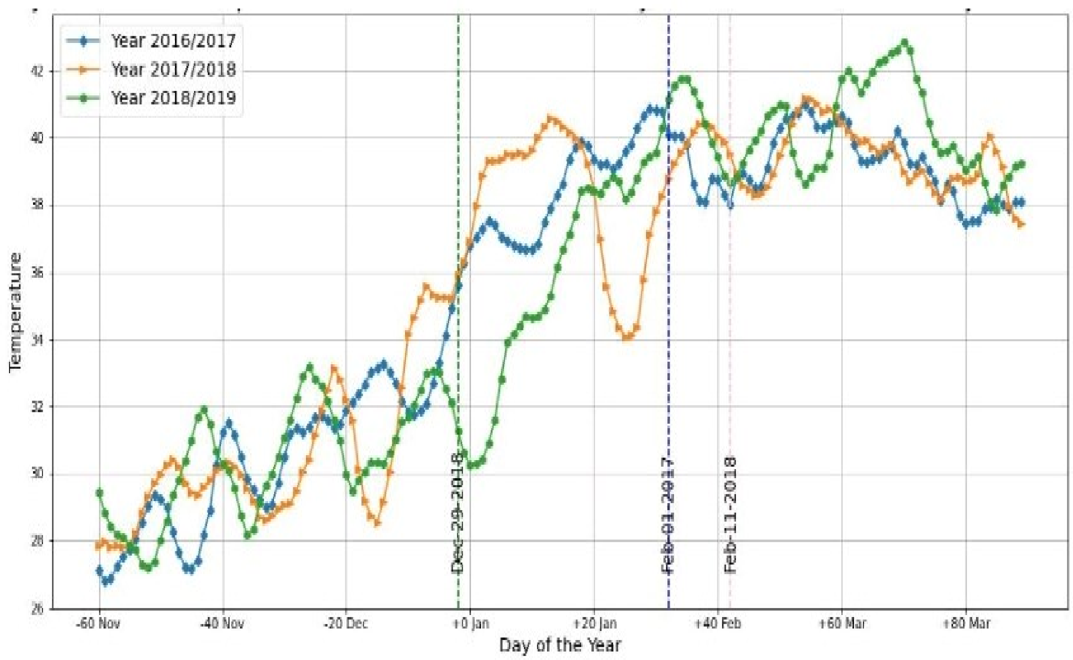
Daily variation of temperature in **Gabon**



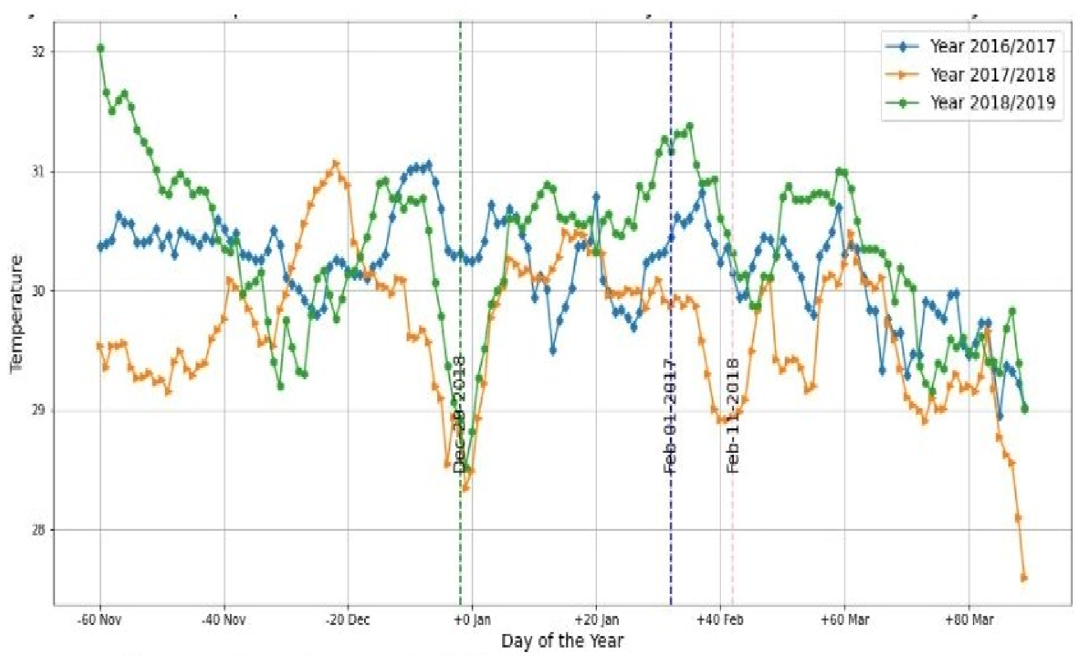
Daily variation of temperature in **ELDA**



Daily variation of temp. in **Djibouti**



Daily variation of temperature of **Dakar**



Daily variation of temp. in **UNILAG**

Figure 3: Daily Variation of Temperature in the selected Coastal Area of Africa around SSW events in the year 2016/2017, 2017/2018, 2018/2019

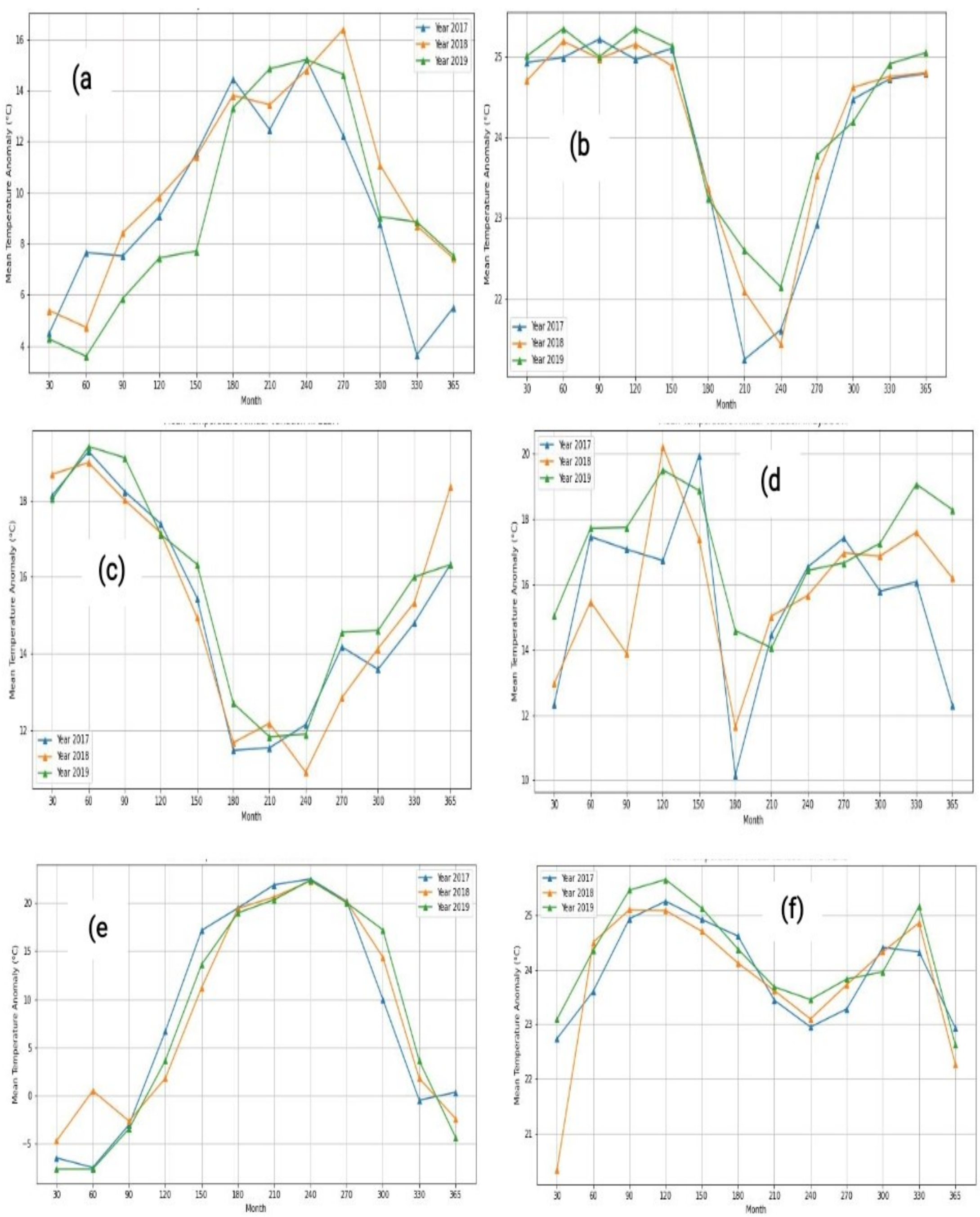
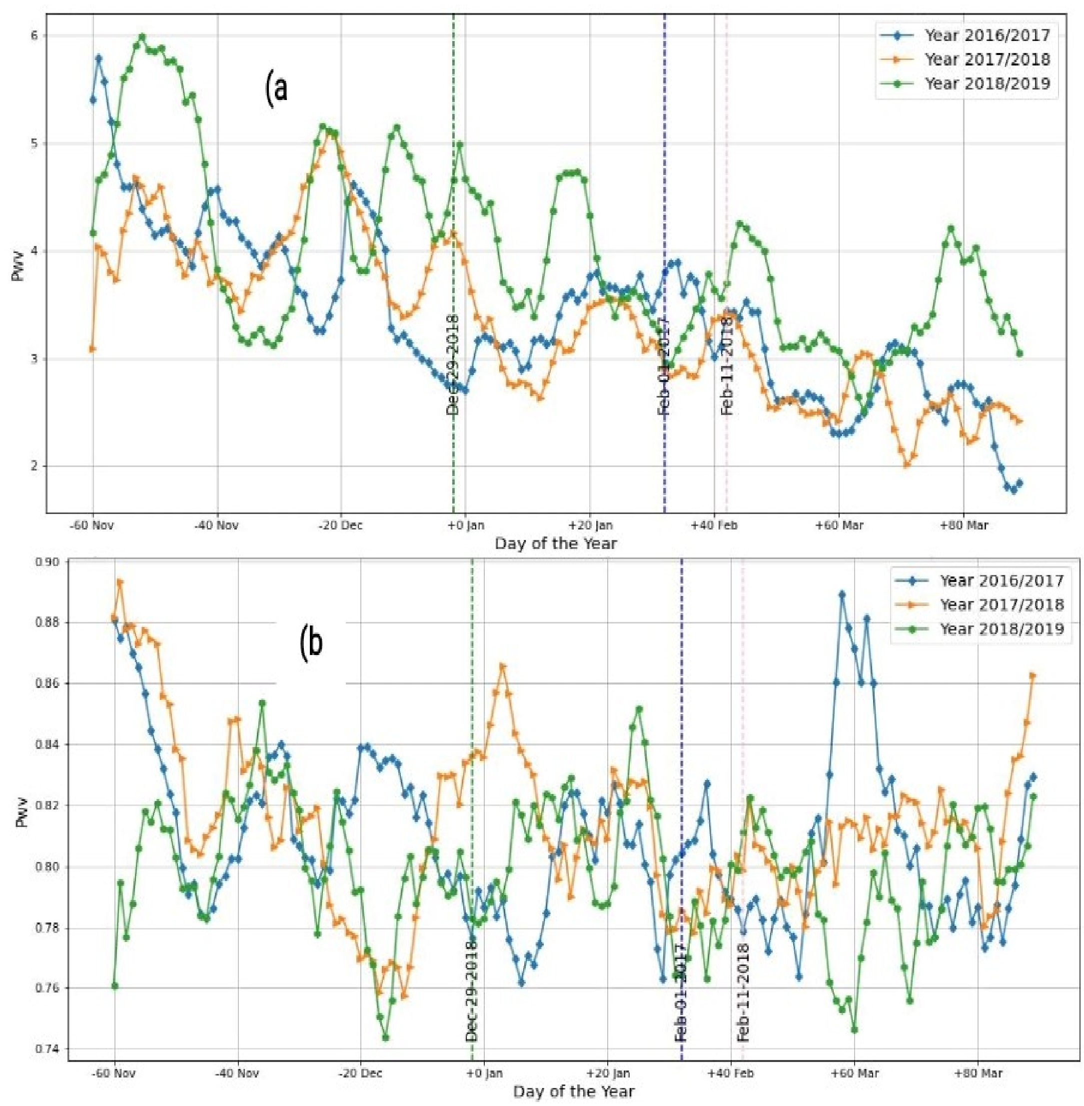
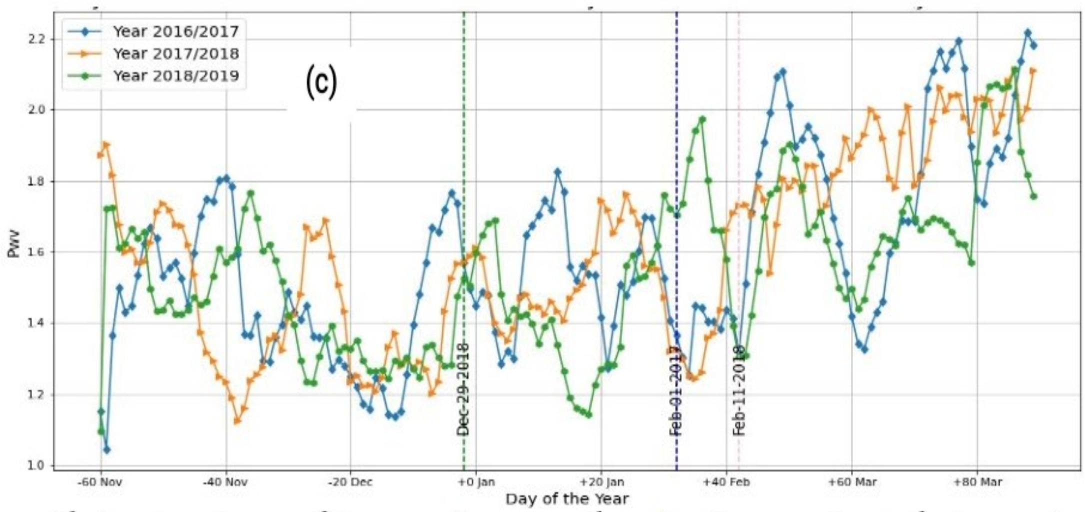


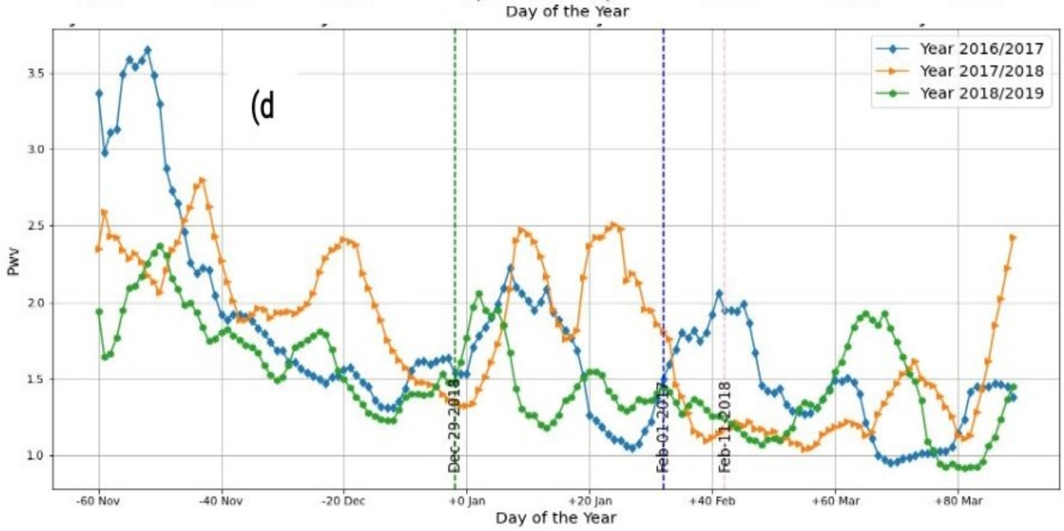
Figure 4: Annual Variation of Temerature along (a) GABON, (b) MELILIA, (c) DJIBOUTI, (d) ELDA, (e) DAKAR, and (f) UNILAG in the coastal regions of Africa

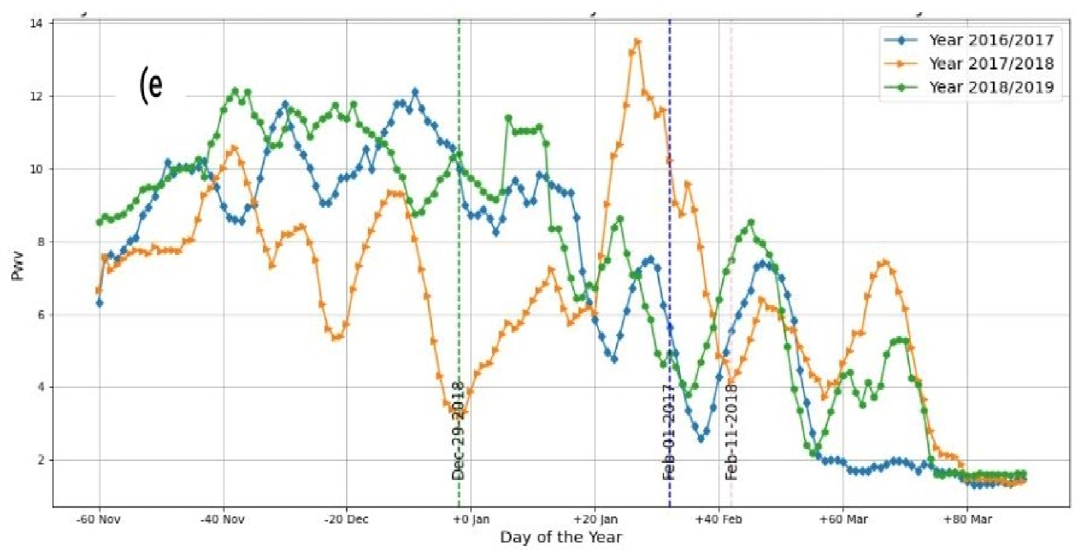
The observed temperature anomalies in coastal areas, with spikes occurring around SSW peaks (Figures 3 and 4), are consistent with the temperature responses to SSW events documented by Hu et al. (2022) in Southeast Asia. Similar patterns of elevated temperatures, particularly around the 40th to 60th day of the year, suggest a strong influence of stratospheric changes on local temperatures, as seen in studies on stratosphere-troposphere interactions (Hitchcock et al., 2013).

Moreover, ***Figure 5*** presents the daily variations in ***Precipitable Water Vapor (PWV)*** for locations like ***Djibouti, Dakar, and Gabon***. These plots show consistent increases in PWV during the peak of SSW events. The observed rise in ***atmospheric moisture*** content could be attributed to disruptions in wind patterns and enhanced moisture transport from the stratosphere to the troposphere during SSW events. This finding aligns with existing research on how stratospheric disruptions can influence moisture levels in tropical and subtropical regions (Remya & Venkat Ratnam, 2020).




(c)
Year 2016/2017
Year 2017/2018
Year 2018/2019
Pwv
Day of the Year
Dec-29-2018
Feb-01-2017
Feb-11-2018


(d
Year 2016/2017
Year 2017/2018
Year 2018/2019
Pwv
Day of the Year
Dec-29-2018
Feb-01-2017
Feb-11-2018


(e
Year 2016/2017
Year 2017/2018
Year 2018/2019
Pwv
Day of the Year
Dec-29-2018
Feb-01-2017
Feb-11-2018

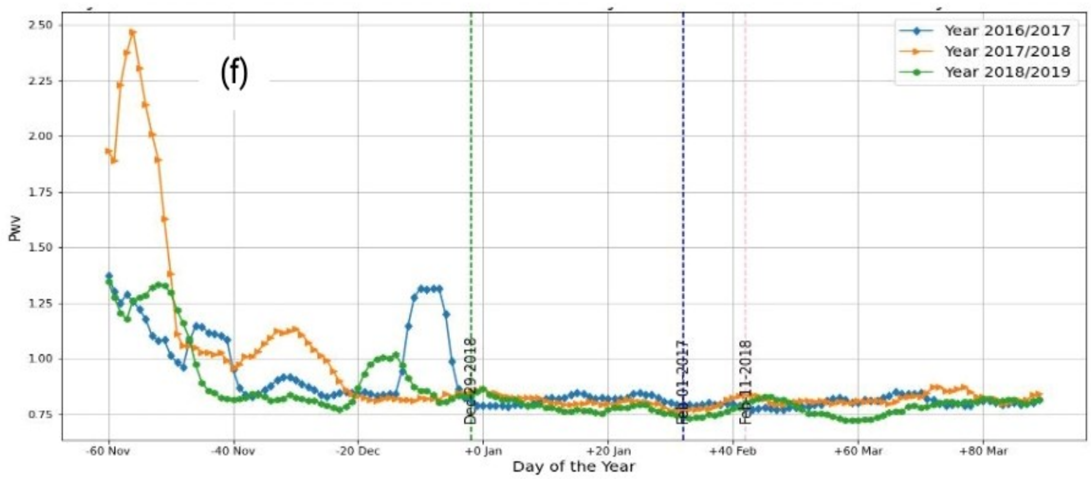
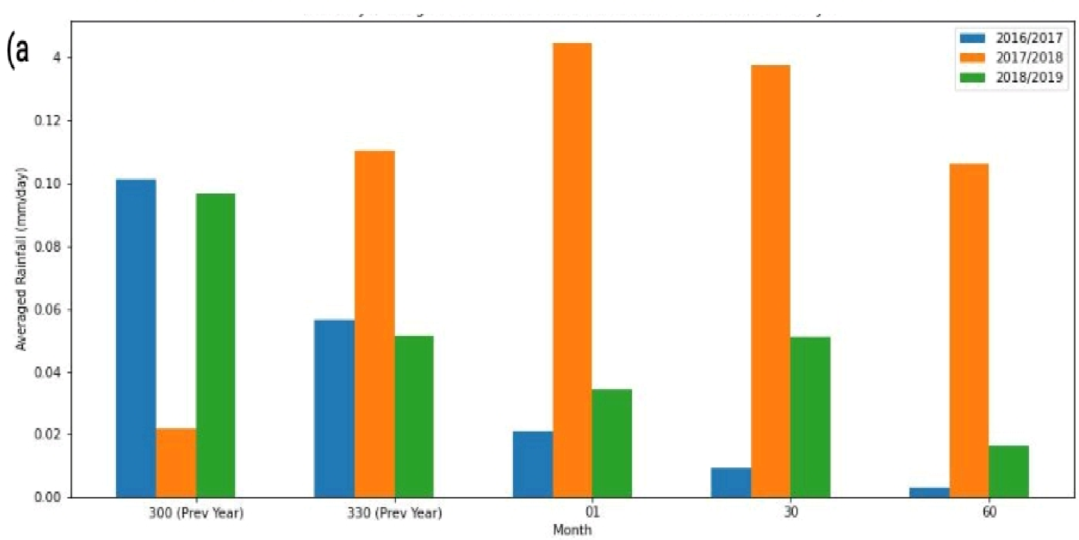
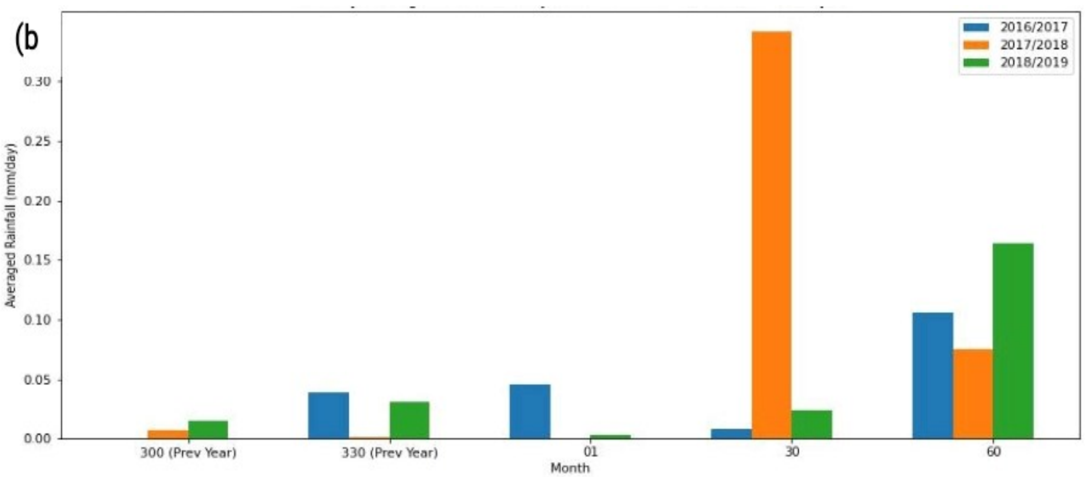


Figure 5: Variation of Precipitable Water Vapour in the selected coastal areas (a) GABON, (b) MELILA, (c) ELDA, (d) DJIBOUTI, (e) DAKAR, and (f) UNILAG

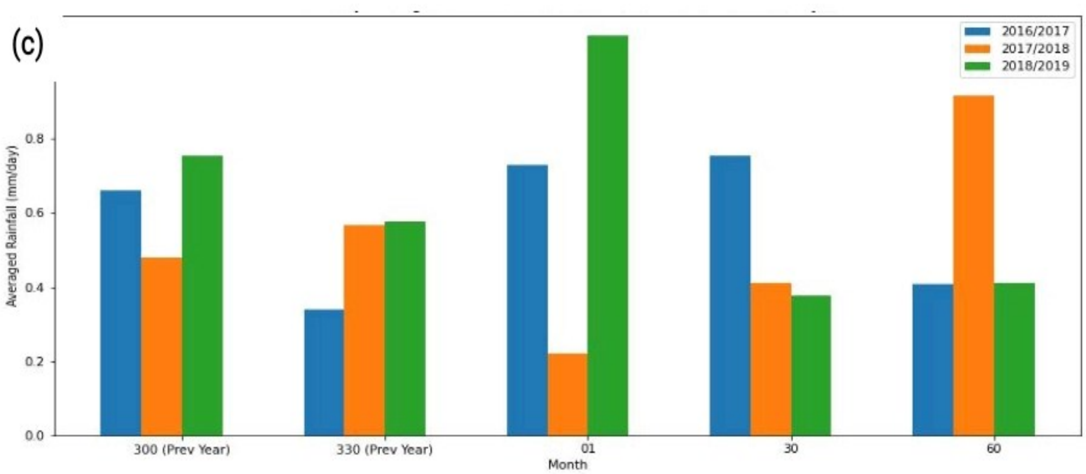
Rainfall Patterns and SSW Impact on Coastal Precipitation: The effect of SSW events on rainfall in coastal regions is evident, particularly during the peak winter months. Figures 6 and 7 present the time series of monthly rainfall for coastal locations such as Melilla, Gabon, and Djibouti, highlighting significant increases in rainfall from January to March, which coincides with the peak of SSW events. The rainfall patterns in these locations show a marked increase, likely resulting from enhanced convection and moisture transport triggered by stratospheric disturbances during SSW events.



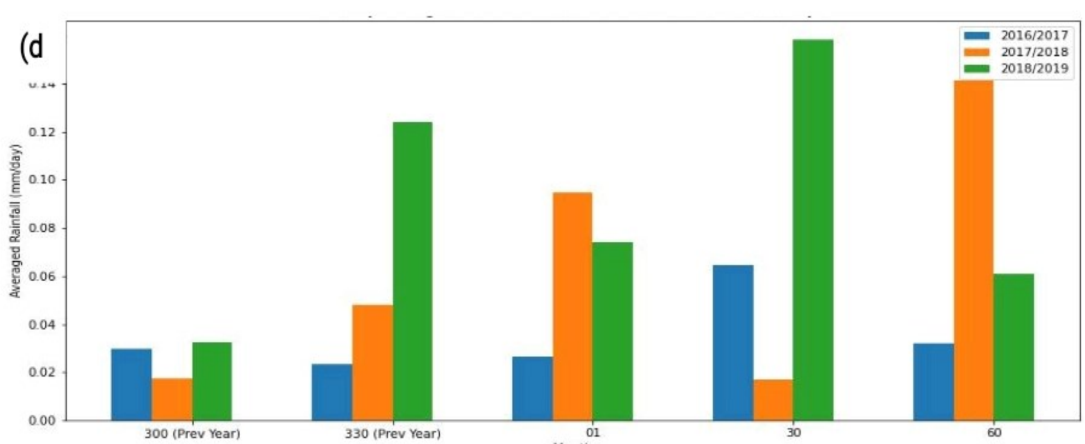
Monthly Average Rainfall for MELILLA over the years (First 150 Days)



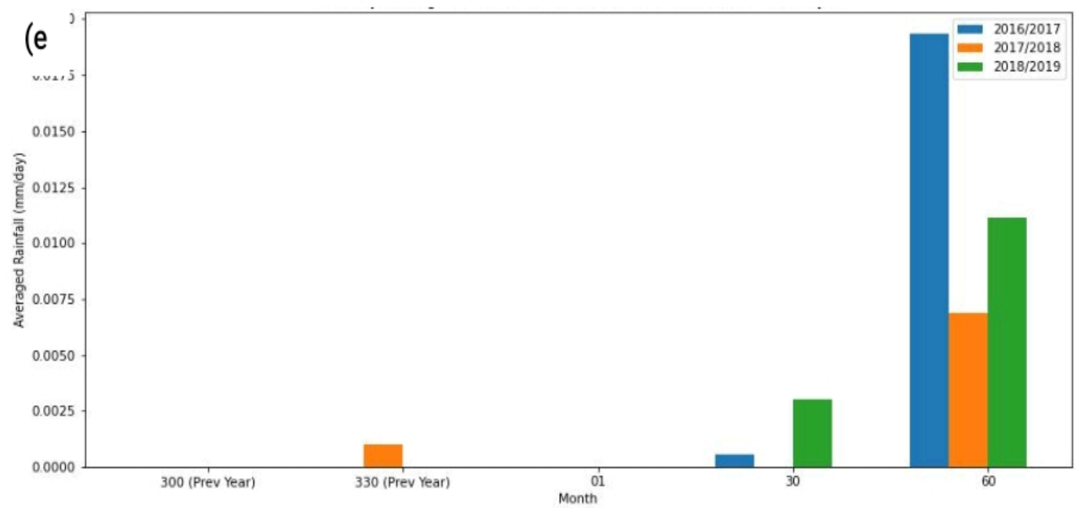
Monthly Average Rainfall for GABON over the years (First 150 Days)



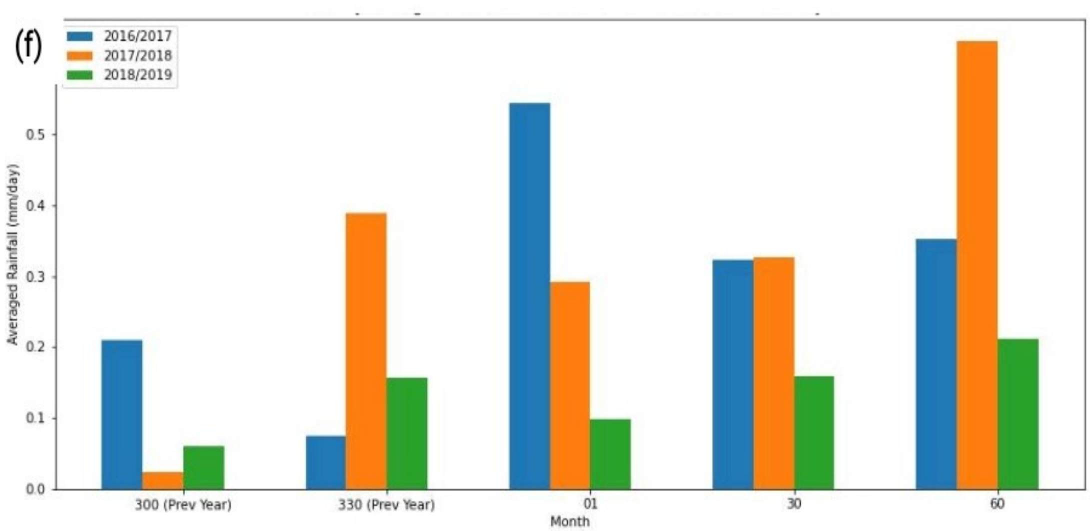
Monthly Average Rainfall for ELDA over the years (First 150 Days)



Monthly Average Rainfall for DJIBOUTI over the years (First 150 Days)



Monthly Average Rainfall for DJIBOUTI over the years (First 150 Days)

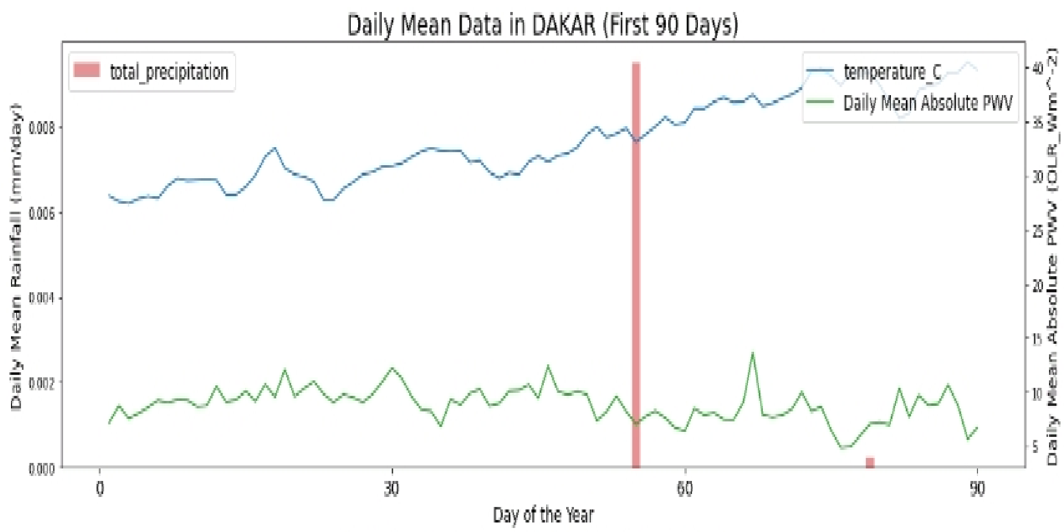


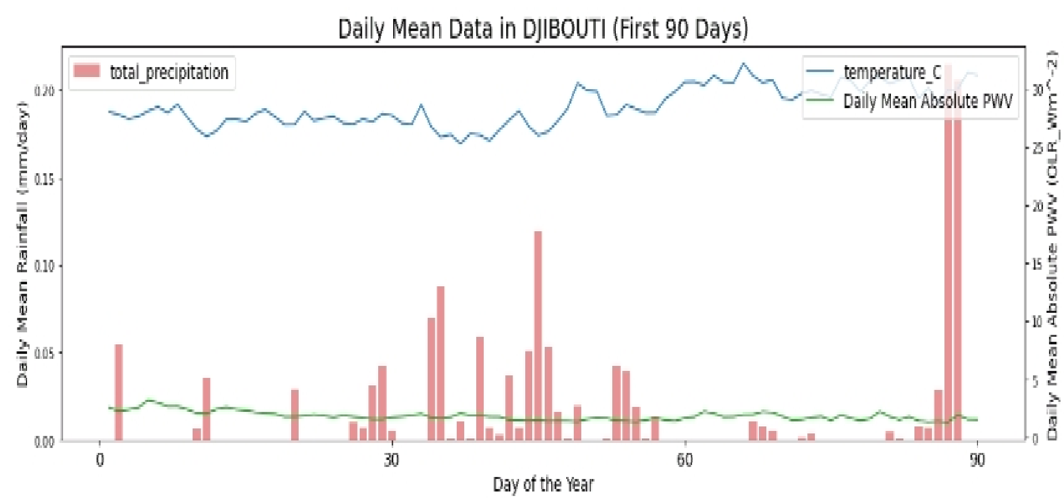
Monthly Average Rainfall for UNILAG over the years (First 150 Days)

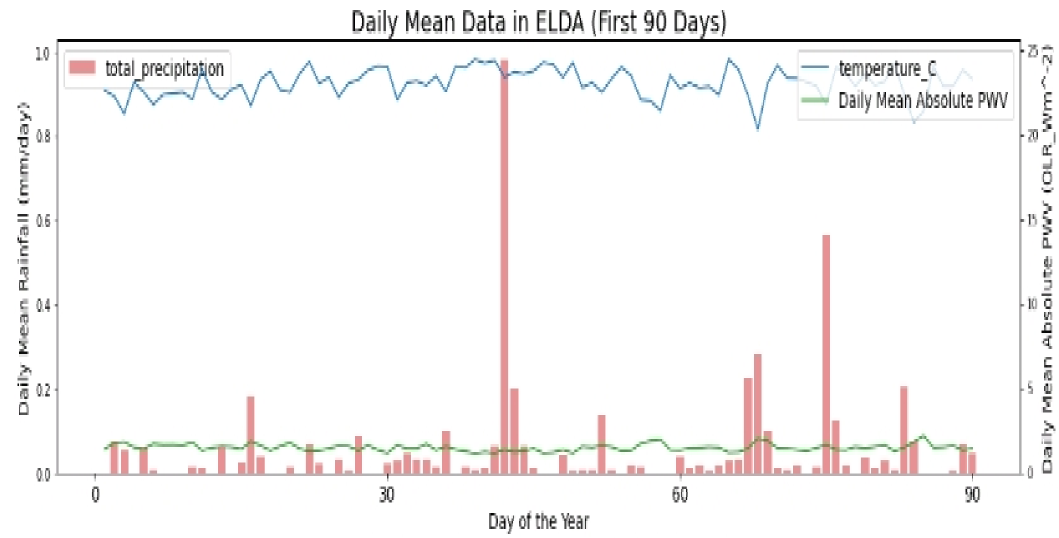
Figure 6: Time series of Montly rainfall (mm) (a-f) for each study area, 5 months around the central date of 2016/17, 2018/19, and 2018/19stratospheric major warming.

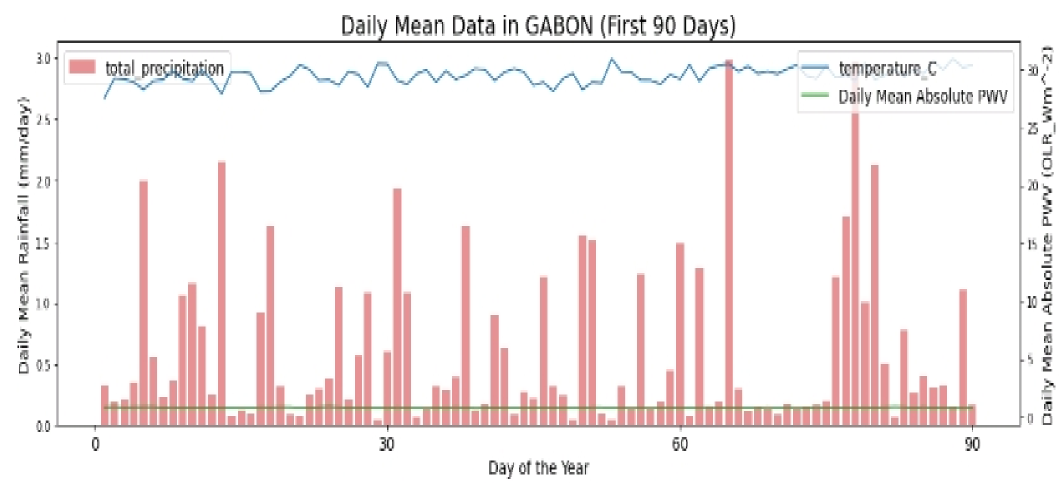
This finding is consistent with studies in other regions, such as *Southeast Asia*, where increased rainfall has been linked to SSW events due to the destabilization of atmospheric circulation and the enhancement of *tropical convection* (Hu et al., 2022). The results suggest that *SSW-induced changes* in the stratosphere could lead to more frequent and intense precipitation events along African coastal regions.

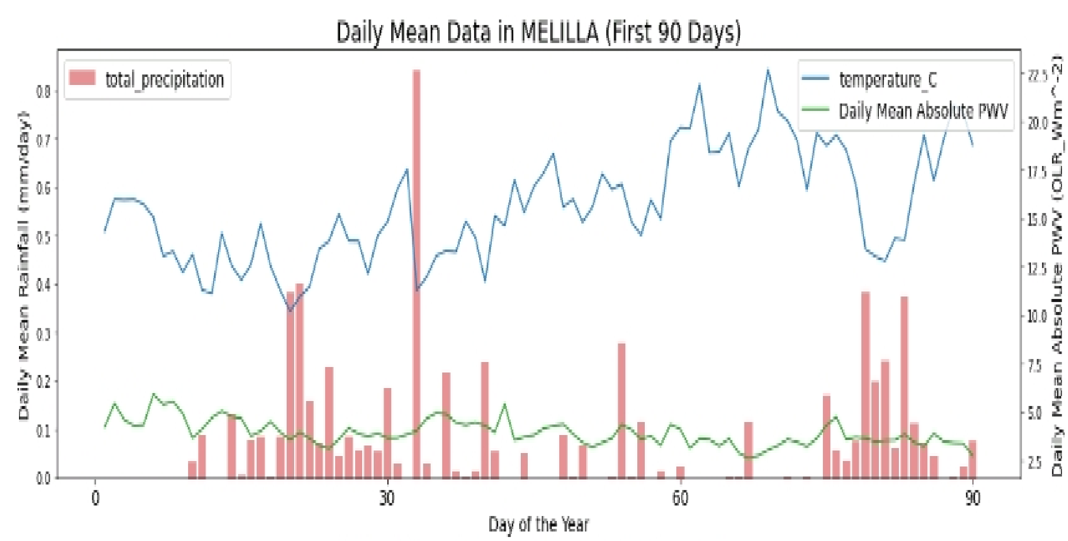
Precipitable Water Vapor (PWV) and Temperature Interactions: The interactions between *Precipitable Water Vapor (PWV)* and *surface temperature* are crucial in understanding how *SSW events* influence *precipitation*. *Figure 7* presents the composite time series of *PWV, surface temperature (Tmax), and rainfall* during SSW events across the studied regions. The data shows that as *PWV* and *Tmax* rise during the peak of SSW events, a corresponding increase in *rainfall* is observed.
The correlation between PWV, temperature (T_{max}), and rainfall (Figure 7) reflects the role of atmospheric moisture in driving rainfall during SSW events. This finding is consistent with Bevis et al. (1992), who demonstrated that PWV is a critical factor in rainfall variability. The observed rise in PWV during SSW periods aligns with studies such as Alshawaf et al. (2015), which identified PWV increases as a precursor to precipitation, influenced by atmospheric instability from stratospheric changes.






Daily Mean Data in ELDA (First 90 Days)
total_precipitation
temperature_C
Daily Mean Absolute PWV
Daily Mean Rainfall (mm/day)
Daily Mean Absolute PWV (OLR_Wm^-2)
Day of the Year


Daily Mean Data in GABON (First 90 Days)
total_precipitation
temperature_C
Daily Mean Absolute PWV
Daily Mean Rainfall (mm/day)
Daily Mean Absolute PWV (OLR_Wm^-2)
Day of the Year


Daily Mean Data in MELILLA (First 90 Days)
total_precipitation
temperature_C
Daily Mean Absolute PWV
Daily Mean Rainfall (mm/day)
Daily Mean Absolute PWV (OLR_Wm^-2)
Day of the Year

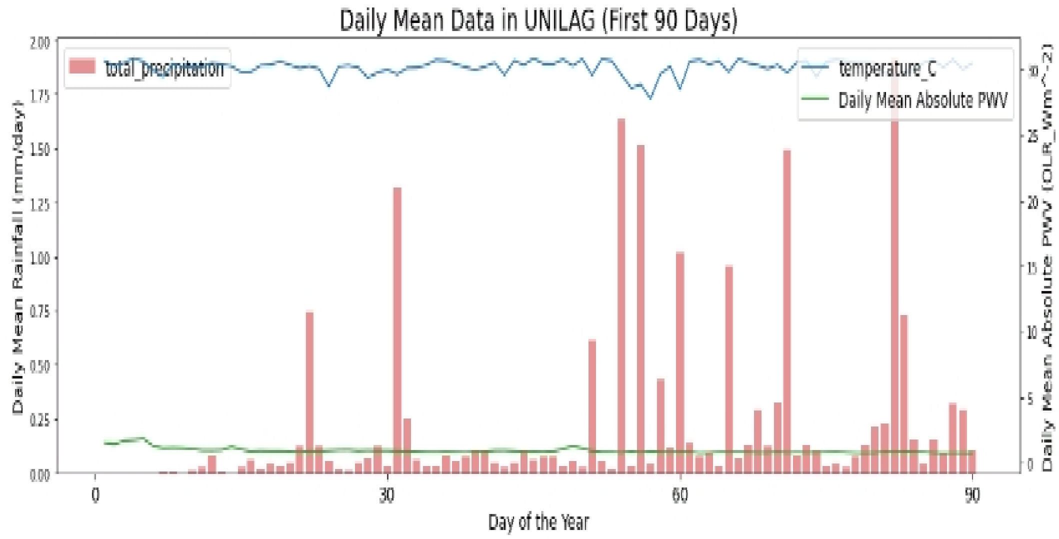
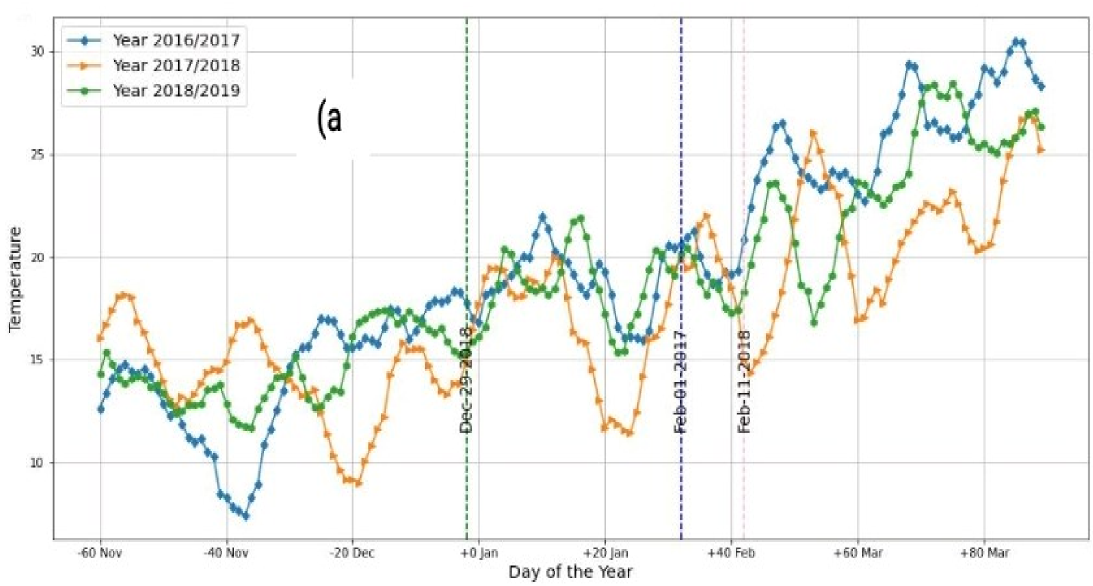
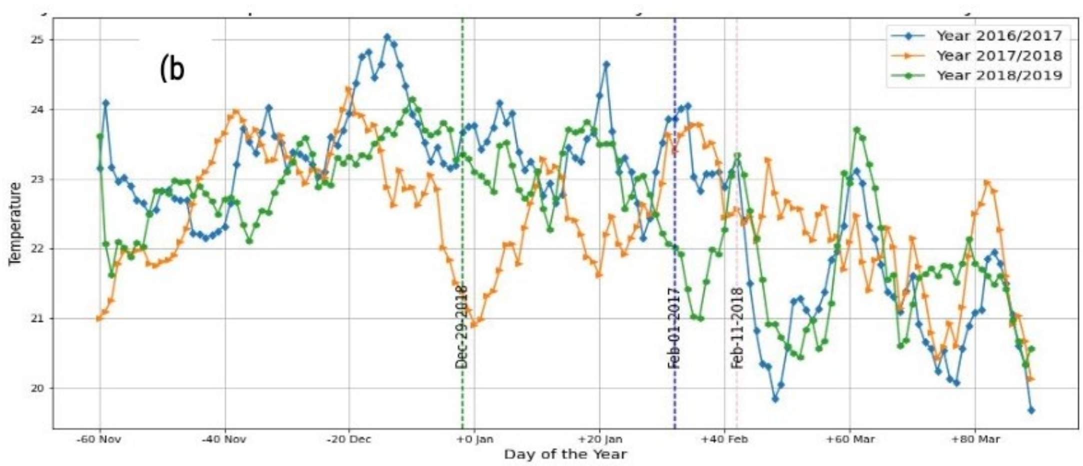


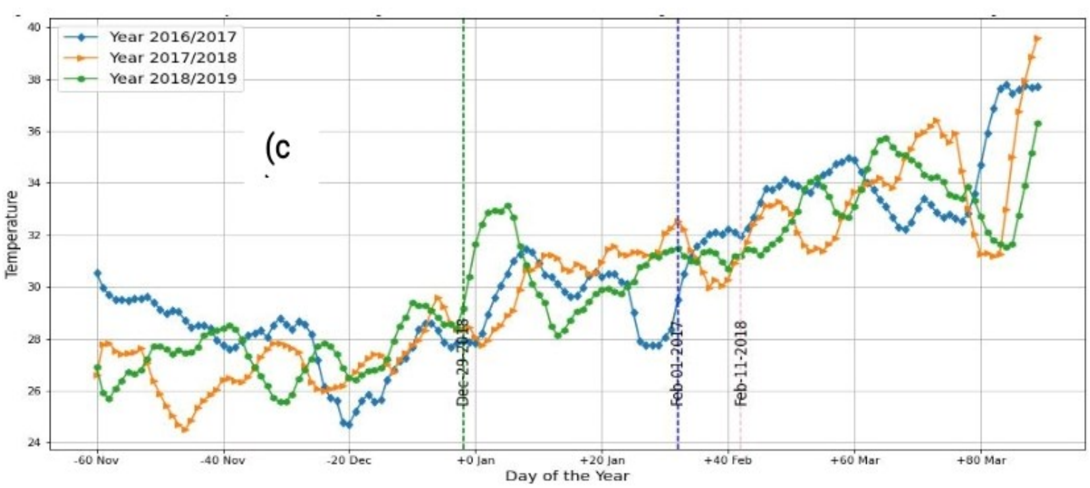
Figure 7: Composite time series of daily values of PWV and surface T_{max} (°C), superposed on the daily rainfall (mm)

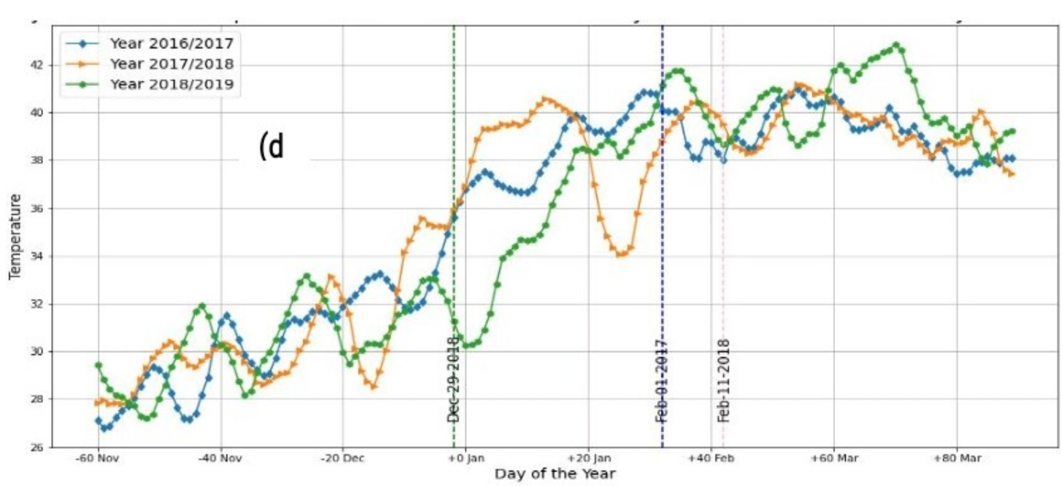
Temperature Dynamics in Coastal Regions During SSW Events

The impact of Sudden Stratospheric Warming (SSW) events on temperature in African coastal regions is highlighted through distinct seasonal and daily variations, particularly around the time of SSW peaks. Figures 4 and 8 illustrate daily and annual temperature trends across selected coastal sites, including Dakar, Gabon, and Djibouti, showing a pattern of temperature anomalies that align closely with SSW event periods.




(b
Year 2016/2017
Year 2017/2018
Year 2018/2019
Temperature
Dec-29-2018
Feb-01-2017
Feb-11-2018
-60 Nov
-40 Nov
-20 Dec
+0 Jan
+20 Jan
+40 Feb
+60 Mar
+80 Mar
Day of the Year


Year 2016/2017
Year 2017/2018
Year 2018/2019
(c
Temperature
Dec-29-2018
Feb-01-2017
Feb-11-2018
-60 Nov
-40 Nov
-20 Dec
+0 Jan
+20 Jan
+40 Feb
+60 Mar
+80 Mar
Day of the Year


Year 2016/2017
Year 2017/2018
Year 2018/2019
(d
Temperature
Dec-29-2018
Feb-01-2017
Feb-11-2018
-60 Nov
-40 Nov
-20 Dec
+0 Jan
+20 Jan
+40 Feb
+60 Mar
+80 Mar
Day of the Year

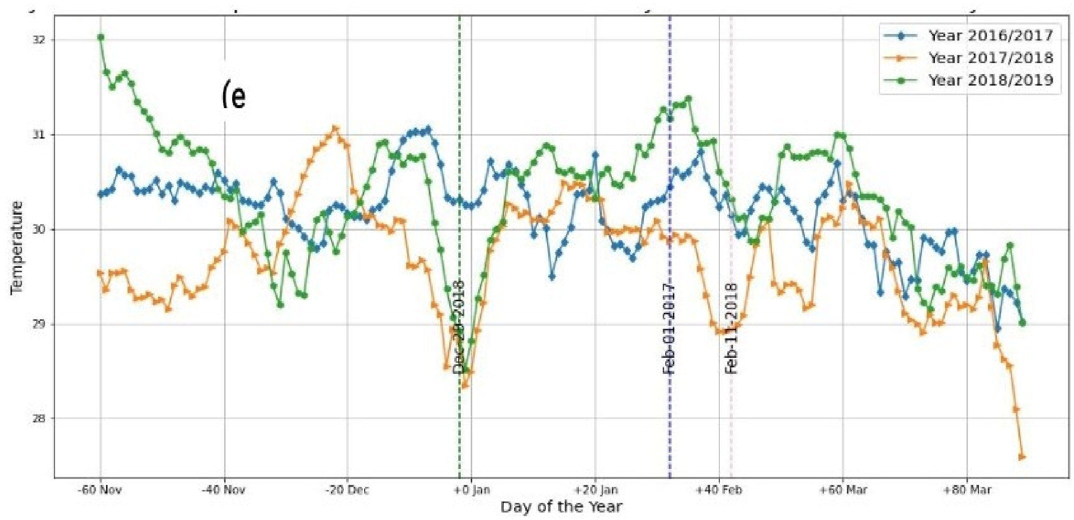


Figure 8: Daily variation of temperature of (a) **MELILLA,** (b) **GABON,** (c) **ELDA,** (d) **DAKAR** and (e) **UNILAG** from last 60 days of last year to first 90 days of Next Year

During the peak phases of SSW events; especially between the 40th and 60th day of the year, coastal regions experience notable temperature increases. These spikes are consistent with stratospheric warming dynamics observed in the Northern Hemisphere (Figure 2), where zonal wind reversals and temperature increases disrupt typical atmospheric circulation patterns. The observed temperature anomalies in coastal areas suggest a downstream impact of these stratospheric changes on tropical and subtropical climates.

Location-specific responses to SSW events further underscore the local sensitivity of coastal regions to atmospheric disturbances. For instance, **Dakar and Gabon** exhibit pronounced temperature increases during SSW peaks, suggesting that the proximity to oceanic influences may amplify these temperature responses. The annual temperature pattern shown in figure 4, reveal that the influence of SSW events extends beyond the immediate period, occasionally causing shifts in seasonal transitions, as seen around the 270th day of the year (late August), where temperature reversals occur following the summer period.

The distinct temperature increases in African coastal areas (Figure 8), particularly between the 40th and 60th day of the year, align with global patterns observed by Ayarzagüena et al. (2012) and Hu et al. (2022). These studies noted that SSW events can disrupt typical seasonal temperature progression, leading to anomalies that resonate with the observed temperature spikes in Dakar and Gabon. This observed linkage between stratospheric warming and coastal temperature changes underscores the importance of considering SSW events in understanding local weather patterns. By affecting both temperature and atmospheric stability, SSW events may drive broader regional climate impacts, particularly in regions like Africa's coastline, which are susceptible to both oceanic and atmospheric influences.

CONCLUSION AND RECOMMENDATIONS

Conclusion: This study examined the effects of Sudden Stratospheric Warming (SSW) events on rainfall, humidity, and temperature across coastal regions in Africa using GNSS and ERA-5 data. The findings reveal that SSW events significantly influence tropical weather patterns, with notable spikes in surface temperature anomalies occurring around SSW peaks. These temperature increases align with stratospheric disturbances, suggesting that stratospheric warming can drive downstream effects on coastal weather. ERA5-derived *Precipitable Water Vapor (PWV)* consistently rose during SSW events, indicating enhanced atmospheric moisture content, which, in turn, contributes to increased atmospheric instability. Precipitation levels also showed significant increases, particularly from *January to March*, which aligns with the peak of *SSW events* and reflects shifts in moisture transport and convection patterns. These results underscore the critical role of SSW events in modifying temperature, humidity, and rainfall patterns in Africa's coastal regions, highlighting the need for further research on the mechanisms driving these interactions to improve climate adaptation and forecasting efforts in vulnerable areas.

Recommendations: To improve understanding and forecasting of SSW impacts, we recommend the following;

1. **Enhanced Monitoring**: Establish a more reliable and extensive network of GNSS stations along African coastal regions to improve the accuracy and resolution of atmospheric data collection. This will facilitate real-time monitoring of humidity and other critical weather parameters.
2. **Regional Climate Models**: Develop regional climate models that integrate stratospheric data with local meteorological information. Such models should account for the unique climatic characteristics of different coastal areas to provide more accurate predictions.
3. **Climate Adaptation Strategies**: Implement targeted climate adaptation strategies for coastal communities based on the insights gained from this study. This may include developing water resource management plans that consider potential increases in rainfall variability linked to SSW events.

By using ERA-5 data, this study enhances the understanding of stratosphere-troposphere interactions, providing valuable insights for both scientific research and climate resilience efforts in vulnerable coastal areas.

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