OPEN ACCESS
J Extreme Events, Vol. 9, No. 4 (2022) 2450002 (16 pages)

DOI: 10.1142/S2345737624500027

Klerksdorp Tornado on March 4, 2007, in South Africa: A Synoptic Overview

Offoro N. Kimambo

Department of Geography and Environmental Studies,
College of Natural and Applied Sciences,
Sokoine University of Agriculture,
Morogoro, Tanzania
offoro@sua.ac.za

Received 15 July 2022
Accepted 14 March 2024
Published 29 June 2024

This research delves into the factors contributing to tornado formation in South Africa, with a specific focus on the Klerksdorp tornado that occurred on March 4, 2007, in Northwest Province. Despite their recurrent occurrence and significant potential for damage, tornadoes have received relatively little attention. Between 1990 and 2014, these weather phenomena incurred estimated costs exceeding half a billion American dollars in addition to other weather-related disasters. In this study, data from multiple observation systems, including the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) in Germany, and the South African Weather Service (SAWS), were thoroughly analyzed. The findings reveal that the Klerksdorp tornado was linked to a cold front and a cut-off low, which were the dominant weather systems on the day of the tornado. This case study enhances our comprehension of tornado dynamics in South Africa, aiding in improving short-term forecasts and potentially early warning systems. Future research should concentrate on the recurring nature of tornadoes in association with tropical weather systems and locally-driven factors.

Keywords: Klerksdorp tornado; synoptic overview; convective available potential energy; cold front; cut-off low.

1. Introduction

A tornado is a swiftly rotating column of air that comes into contact with the Earth's surface (Leitão and Pinto 2020; Bluestein 2013). The term "tornado" has also been employed to describe magnetic structures within the solar atmosphere (Mghebrishvili *et al.* 2018). Tornadoes possess varying degrees of strength (Kantamaneni *et al.* 2017), capable of causing destruction to infrastructure and, in some instances, resulting in casualties (Wang *et al.* 2017). In the United States of America, particularly in Texas, the highest number of fatalities is linked to floods and tornadoes (Paul *et al.* 2018). In India, tornadoes have been associated with land degradation (Bhattacharyya *et al.* 2015). It is globally recognized that tornado events typically occur between 20° and 60° latitudes in both the southern and northern hemispheres (Figure 1), however, a comprehensive data on tornado occurrences worldwide, please refer to the World Meteorological Organization's Global Weather and Climate Extremes Archive at https://wmo.asu.edu/content/world-meteorological-organization-global-weather-climate-extremes-archive. This calls for further research on tornado occurrences, dynamics, and forecasting in South Africa, given the substantial damages they have inflicted. To further demonstrate the complexity involved in understanding tornadoes, for instance, recently there was an amendment in the definition of tornadoes by the American Meteorological Society (AMS) (http://glossary.ametsoc.org/wiki/Tornado) which led to the amendment of its taxonomy (Agee 2014).

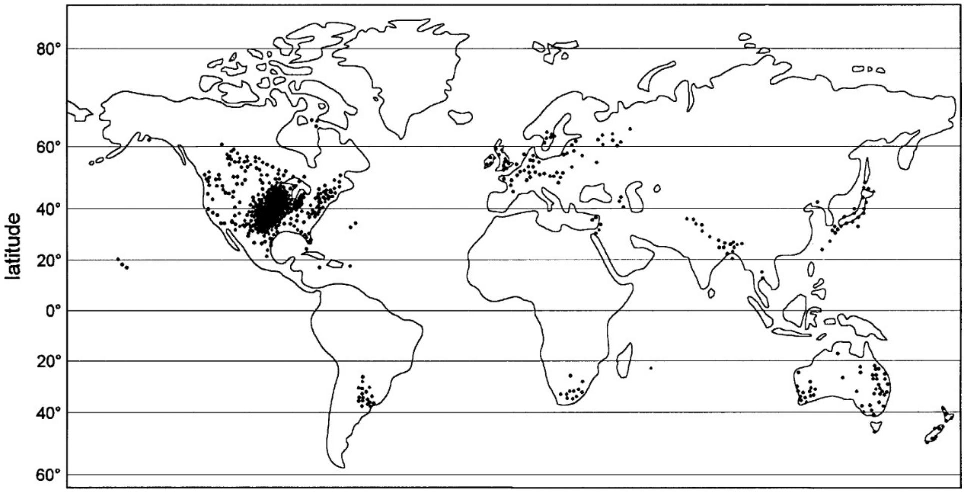


Figure 1. Occurrence or Concentration of Tornadoes Around the World, Adopted from Goliger and Milford (1998) and Fujita (1973)

Principally, there are several ingredients for tornadoes, such as a deep layer of mid-atmospheric dry air above a moist surface, steep moisture, temperature gradients, high surface temperatures, vertical wind shear, and atmospheric instability (Dean and Schneider n.d.). Apart from that, for a tornado to occur, the first thing required is a thunderstorm. Others include moisture, a mass of unstable air (warm air mass below a cold air mass), and the external force that mixes the air, causing updrafts (upper air divergence, vertical wind shear), high surface temperature, and mid-level dry air instruction (De Coning and Adam 2000). In the process of thunderstorm development, there are upward and downward motions (updrafts and downdrafts) that cause lighting and thundery activities. In that process, thunderstorms are classified into four types, including a single-cell, multicell cluster, multicell line, and supercell storm (Blamey *et al.* 2017). The multicell line is stronger than the first two in that series and can lead to hail as well as small tornadoes. The most violent is the supercell which is most likely to produce tornadoes. Several parameters can be used to measure thunderstorm development, including Convective Available Potential Energy (CAPE), wind shear, above-normal surface, and dew point temperatures (Simpson and Dyson 2018).

In South Africa, tornadoes are a recurring phenomenon (Blamey *et al.* 2017; Fauchereau *et al.* 2003; Goliger and Milford 1998; Kantamaneni *et al.* 2017) with an average of three tornadoes per year (Goliger and Milford 1998). Most tornadoes occur in eastern South Africa and can cause severe damage and even the loss of lives (Reason 2017). The available history (Dotzek *et al.* 2003) indicates that most tornadoes range from light to severe on the international intensity scale (Sioutas *et al.* 2006). Their coverage can be as wide as 70 km (Fauchereau *et al.* 2003). A study by Goliger and Retief (2002) assessed zones of extreme wind events in South Africa that match areas suspected of tornadoes in South Africa (accessed at https://www.weather.gov/oun/tornadodata-okc-appendix). An analysis of tornado climatology in South Africa (Figure 2) was made by investigating tornadoes from 1905 to 2002. It was estimated that the damages from storms (i.e., cut-off lows, fronts, tropical cyclones, and tornadoes) amount to 800 million American dollars from 1990 to 2014 (DEA 2016), apart from those related to floods, wildfires, and drought. Besides, in South Africa, it is argued that tornadoes are given less attention by the media because of the localities (rural areas) but also because of the nature of the losses mainly for crops and occasionally buildings (Grobler 2001). The reason might be valid because they are observed more frequently (D'Abreton 1991) than generally realized (Perry 1995). Therefore, this scenario raises more questions about the public weather service and prompts more scientific discussions for improving the understanding of the emergence of phenomena or for practical processes such as weather predictions or warnings.

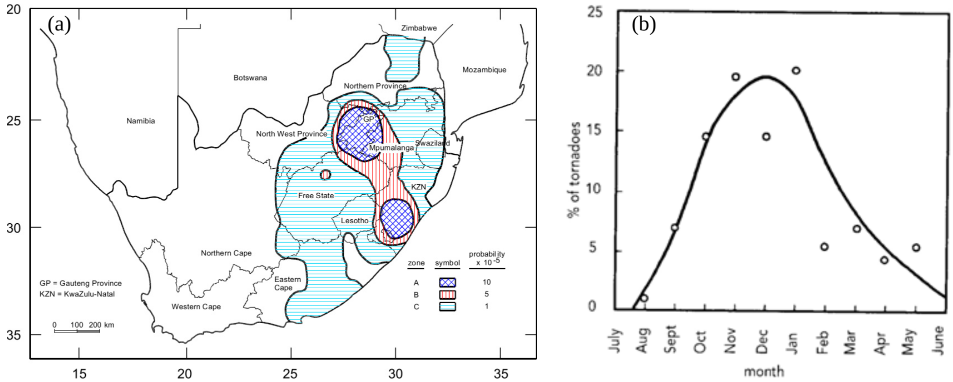


Figure 2. (a) Mean Annual Rate of Occurrence of Tornadoes (Goliger and Milford 1998; Goliger and Retief 2007) and (b) Timing for the Occurrence of Tornadoes in South Africa (Source: http://www.weathersa.co.za/learning/weather-questions/75-when-and-where-do-tornadoes-occur-in-south-africa)

Tornadoes are associated with thunderstorms and lightning (Blamey *et al.* 2017). Lightning occurs over the interior and late in the afternoon in the northern interior of South Africa, and the risk involved is extreme (Gijben 2012). According to Gijben (2012), before 2006, the South African Weather Service (SAWS) could not measure lighting activities over South Africa, despite some recent advancements for instance, having a model for the identification of weather systems over South Africa (Dyson and Van Heerden 2002). In the development process, one would wonder why the work of Gijben (2012) did not recognize some previous studies (Goliger and Milford 1998) that produced a map indicating areas with high chances of tornadoes, which are directly associated with lighting and thunderstorms. A gap noted from this particular study (Goliger and Milford 1998) is that there is a general count of lightning occurrences without specifying the type of thunderstorm clouds (e.g., single-cells, a squall line, a cluster of cells and/or supercells).

In its 2016/2017 annual report (SAWS 2017), within the context of public weather forecasting, SAWS issued a media release in response to the Tembisa tornado that struck on July 27, 2016, causing damage to Phumulani Mall and a tertiary hospital in Tembisa, South Africa. In recognition of the impact of tornadoes, SAWS has been actively exploring the integration of a Lightning Detection Network (LDN) with tornado data to create an advanced nowcasting tool (Fensham *et al.* 2018). This particular study shows flash and stoke detection efficiencies of 88.3% and 72.1%, respectively.

The present study aimed to examine a synoptic overview of the tornado dynamics associated with the extratropical systems using a Klerksdorp tornado case, which occurred on March 4, 2007, in Northwest Province, South Africa. Similar approaches have been used in other parts of the world, such as in Spain (Homar *et al.* 2003). The study aimed to address the subsequent inquiries: What are the properties of tornadic events in South Africa in terms of their nature with respect to the Klerksdorp tornado, which occurred on March 4, 2007, and how was it linked to the dominant weather systems of the day. This will contribute to understanding the dynamics of tornadoes, the articulation of essential skills for improving forecasts, disaster management, and raising awareness among the highly vulnerable community.

2. Materials and Methods

Meteosat Second Generation (MSG) satellite data were sourced from European Organization for the Exploitation of Meteorological Satellite (EUMETSAT) and processed using the Software for the Utilization of Meteosat Outlook (SUMO), as documented in the previous work (Simpson and Dyson 2018). The processing primarily aimed to obtain various imagery, including water vapor images (WV6.2 μm), convective red, green, and blue (RGB) images, and natural daylight color imagery (NIR1.6, VIS0.8, and VIS0.6). The use of MSG satellites has shown significant potential for investigating thunderstorm activities and gaining insights into tornado development (Reason 2017).

Additionally, radar imagery, generously provided by the SAWS, was incorporated into the analysis. Geopotential height (in meters) and vertical velocity (omega in Pascal/s) data for the event on March 4, 2007, at 1200 Z were examined to visualize and assess the dominant weather systems. For the study of CAPE on the event day, data and images from the National Oceanic and Atmospheric Administration (NOAA) ESRL Physical Sciences Division in Boulder, Colorado, USA, available at http://www.esrl.noaa.gov/psd/ were utilized. The visualization of CAPE data was facilitated by Panoply Software version 4.10.4 (https://www.giss.nasa.gov/tools/panoply/). Furthermore, upper air sounding data for the Irene station in Pretoria, South Africa, was obtained from the University of Wyoming Website (http://weather.uwyo.edu/upperair/sounding.html). Surface analysis charts and real-time observations for Klerksdorp were kindly provided by the SAWS. The daily weather patterns were carried out using Microsoft Excel.

3. Results and Discussion

3.1. *Upper-air observations*

The diagnostic assessment of the event involved the utilization of a range of image combinations, including images in the day natural color RGB, the water vapor channel, convective RGB, and radar image (as depicted in Figures 3(a)–3(d), respectively). Notably, the upper-level tropospheric water vapor channel at 6.2 μm (Figure 3b) clearly reveals the presence of a jet stream originating from Namibia and extending over southeastern Botswana into the western interior of South Africa. The phenomenon is in line with some other previous study (De Coning and Adam 2000), which indicated that primary conditions responsible for tornadoes to occur include high surface air temperature, steep moisture, middle-level instability, strong vertical wind shear, mid-level dry air (intrusion of dry air), low-level convergence, and upper-level divergence.

Primarily, the factors contributing to the occurrence of tornadoes involve the intrusion of mid-level dry air, a pronounced moisture gradient, and elevated surface temperatures, as evident in Figures 3(b), 8(a), and 8(b). Figure 3(b) displays a notable presence of dry air aloft, particularly over the western interior, which is further corroborated by the surface dewpoint analysis in Figure 8(a). The delineation of the activity's boundary is also evident in Figure 3(a) and the convective

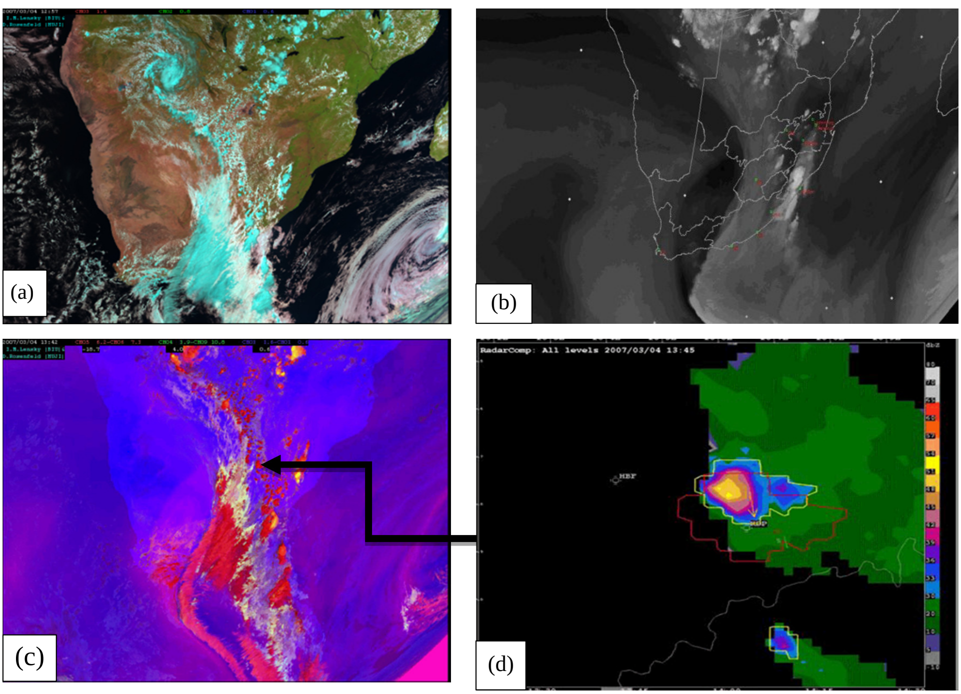
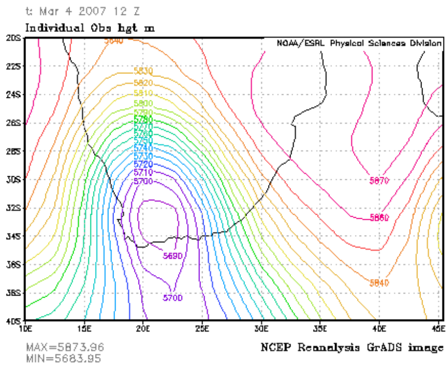
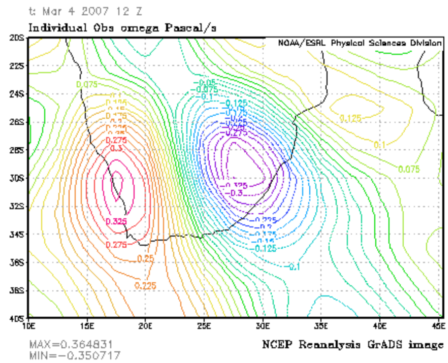


Figure 3. (Color Online) Daytime Natural Color Representation in RGB Format (a), the Upper-level Tropospheric Water Vapor Band (Water Vapor Channel at 6.2 μm) (b), Convective RGB (c), and a Radar Image Dated March 4, 2007, Highlighting the Presence of an Echo Region (ER) Over Klerksdorp, South Africa (d)



(a)



(b)

Figure 4. Geopotential Heights (in Meters) Depicted in (a) and Vertical Velocity (Omega) in Pascal per Second (Pascal/s) Shown in (b), Both Pertain to the 500 hPa Level

RGB representation in Figure 3(c). This pattern aligns with the existence of updrafts, as observed in the radar imagery's ER shown in Figure 3(d).

The geopotential height (hgt) at 500 hPa clearly illustrates the presence of a distinct cut-off low, as depicted in Figures 4(a) and 4(b). East of the trough, as shown in Figure 4(b), there is an evident upward vertical motion in Pascal per second (Pascal/s), indicated by omega/vertical velocity, which plays a significant role in the initiation of thunderstorms. Thunderstorm development, as depicted in Figure 3(c), is occurring on the eastern side of the trough. This relationship is further supported by the observations in Figure 3(a), which represent the day's natural color, and the water vapor channel (as represented in Figure 3(b), with dark shades corresponding to the 6.2 μm water vapor channel), highlighting the presence of the jet stream in that region.

Conversely, the convective activities displayed in Figure 5 imply that there is a distinct separation between tropical weather systems and extratropical weather systems, as evidenced by a noticeable boundary. This observation is grounded in the CAPE index, which serves as a reliable indicator of severe weather systems (Tuluri *et al.* 2010). Additionally, the water vapor channel, also known as the upper-level tropospheric water vapor band at 6.2 μm, is commonly employed for several purposes. It helps in tracking upper-tropospheric winds, pinpointing jet streams, predicting mid-latitude storms, monitoring the potential for severe weather, and estimating moisture levels in the upper and mid-levels of the atmosphere, including the vertical moisture profile (Santurette and Georgiev 2007). Moreover, the sounding observations (as depicted in Figure 8(b)) reveal the presence of robust upper-level winds and instability, providing favorable conditions for the initiation of tornadoes.

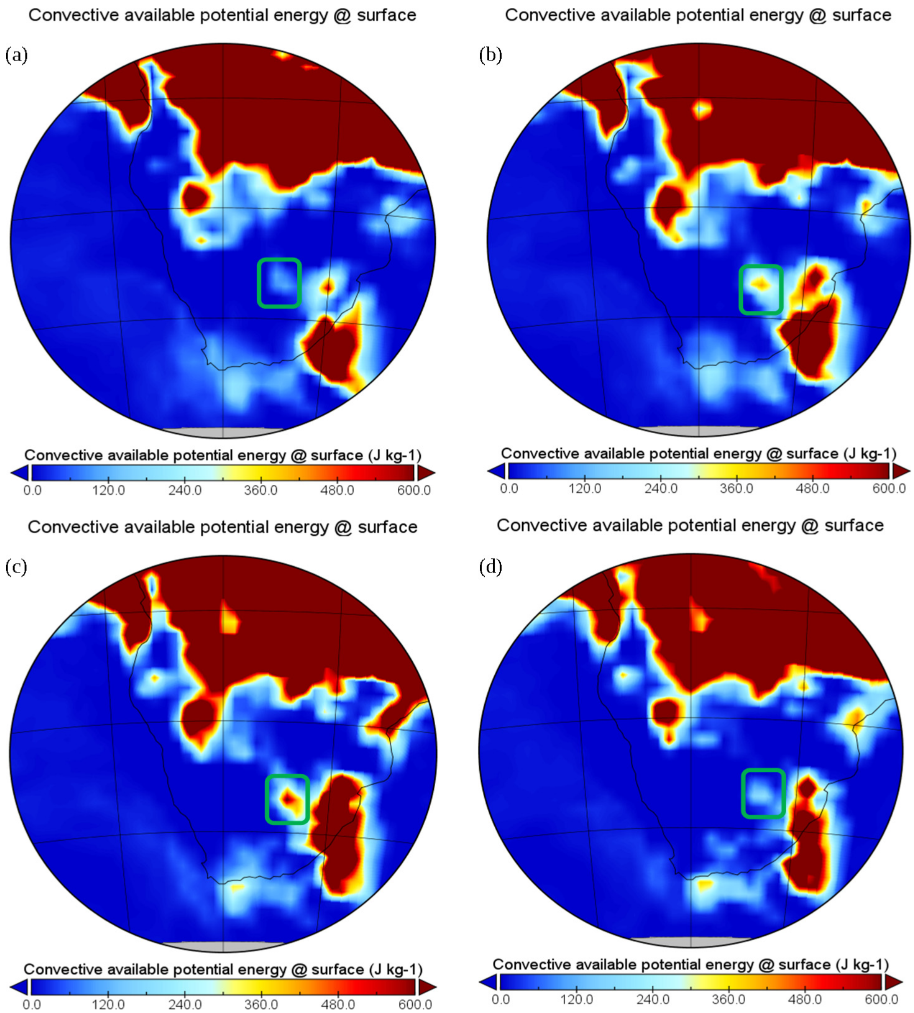


Figure 5. CAPE on March 4, 2007 for Different Forecast Hours Starting from 0900 Z (a), Followed by 1200 Z (b), Intensifying at 1500 Z (c) and Clearing or Weakening at 1800 Z (d)

At the upper air sounding station (Pretoria Irene, 1200 Z, as shown in Figure 8(b)), the CAPE measured at 142 J/kg, indicating a marginal level of instability. Applying the logarithmic relationship described by Equation (1), which relates CAPE to wind shear for distinguishing between non-severe and severe thunderstorm activities (Brooks *et al.* 2003), the tornado event can be categorized as a severe occurrence.

$$\mathrm{Log}(S6) = \frac{(8.36 - 1.79\log(\mathrm{CAPE}))}{2.86} \tag{1}$$

where S6 equals to the 0–6 km shear (m/s) and above, phenomena are likely to be associated with severe thunderstorms. In this context, using the CAPE value from the sounding data (142 J/Kg), we calculate S6 to be 37.67 m/s. According to the criteria established by Brooks *et al.* (2003), this indicates a severe tornado event. To discern the interaction between the tropical system and the southern weather systems, Figure 6 illustrates a time-series of latitudinal convective activities from the year 2000 to the present.

Figure 6 illustrates the relationship between tropical and extratropical convective phenomena. Notably, in the northern hemisphere, the boundary is distinctly defined, which differs from the situation in the southern hemisphere. It agrees with the previous studies that weather patterns in South Africa are predominantly influenced by extratropical systems, characterized by features like cut-off lows, fronts, and the influence of ridges from the Atlantic high. However, during late summer, there is a notable influx of convective tropical weather systems (Dyson and Van Heerden 2002). Notably, the expansion of CAPE values from the equator southward is more prominent than in the northern regions, particularly around the latitude of approximately 26.7°. This phenomenon can be attributed to the characteristic interaction between tropical and extratropical weather systems, facilitated by the presence of tropical-temperate troughs (TTTs) (Dyson and Van Heerden 2002). Similar work on the annual variations of CAPE has also

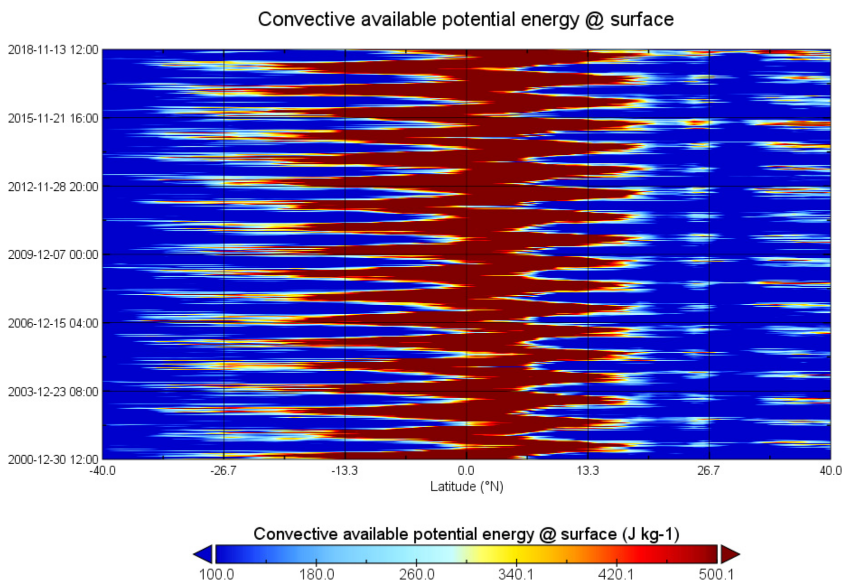


Figure 6. The Graph Presents CAPE Data Spanning from the Year 2000 to the Present, Encompassing Regions Both North and South of the Equator Across Africa

demonstrated, for instance, the climatology of potentially severe convective environments in Southern Africa (Blamey *et al.* 2017).

Gaining insight into the fundamental principles and components required for the development of tornadoes, such as the presence of sufficient moisture, instability, and external forces driving warm and moist air, is crucial (Goliger and Retief 2007). The analysis enables the differentiation of the connection between tropical and extratropical atmospheric circulations. It's worth noting that previous studies have already proposed and examined the idea that the interplay between extratropical systems and tropical systems, particularly through the TTT, serves as a catalyst for the development of severe weather phenomena like tornadoes (Reason 2017). The findings suggest that TTTs can lead to the formation of deep mesoscale convective complexes (see Figure 7).

3.2. *Surface observation and analysis*

Generally, both charts indicate that the western interior was dry and cold, otherwise moist and warm toward the northeastern part of the country. The hand analysis of

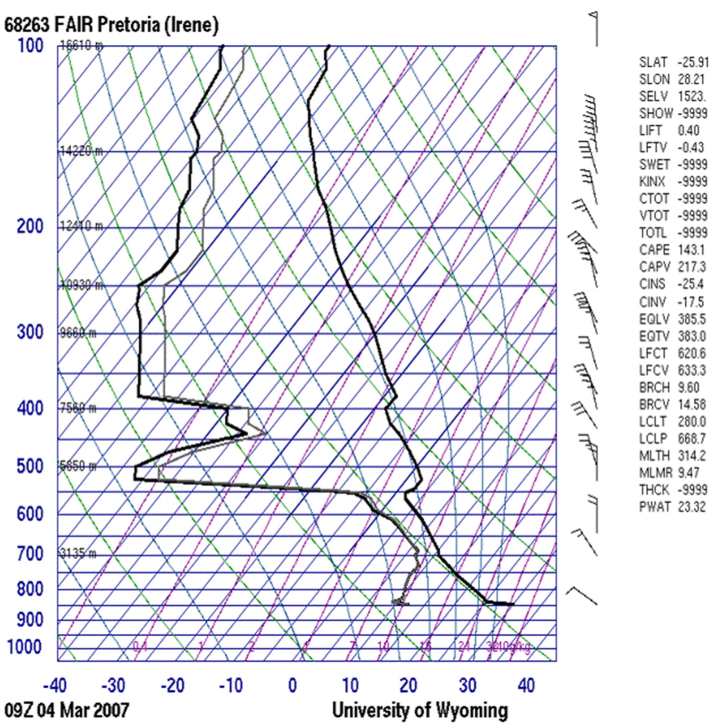
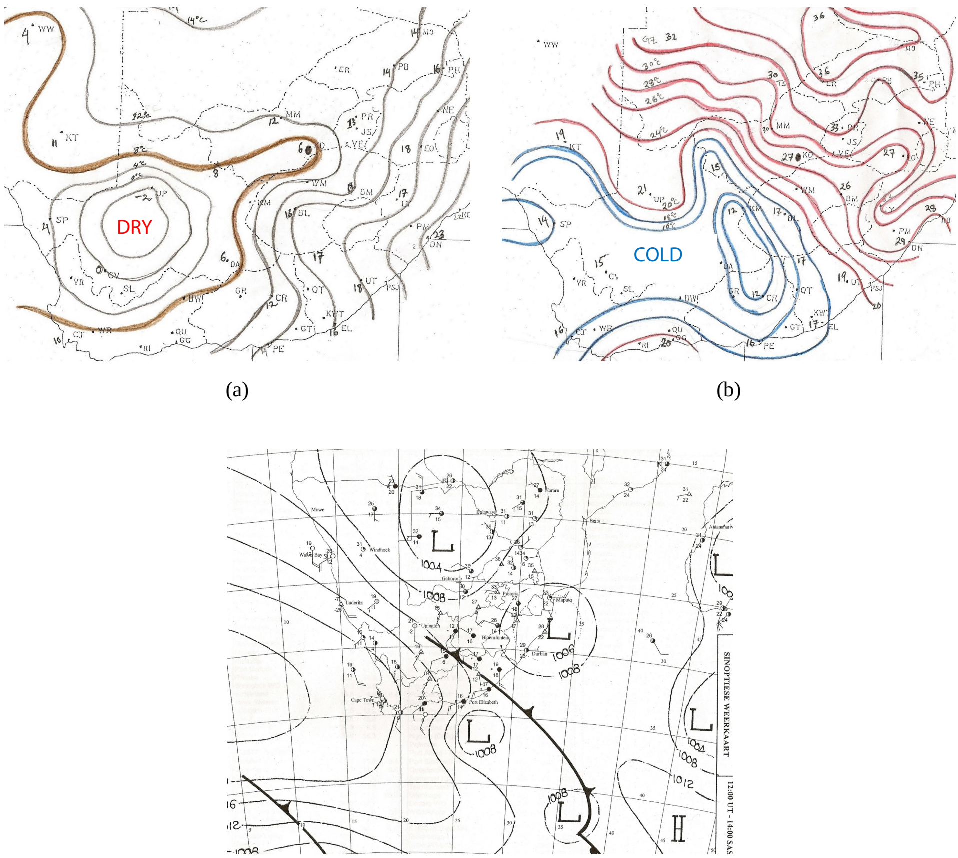


Figure 7. Upper-air Sounding for Pretoria, Irene Station, Indicates the Middle-level Instability in the Atmosphere with a CAPE of 143.1

surface dew point temperatures and air temperatures across South Africa reveals dry and chilly conditions in the western interior, with temperatures falling below 17°C. Conversely, in the area of interest, the air is warm, ranging between 27°C and 30°C, and moisture levels are relatively high which is an ideal condition for the development of thunderstorms (refer to Figure 8). In essence, a cold front is typically associated with temperature drops, increased wind speeds, and the likelihood of rain showers. In the Southern Hemisphere, the wind patterns shift southwesterly behind the cold front and northwesterly ahead of it, as depicted in synoptic weather charts (Figure 8a). This transition is also evident in



(a) (b)

(c)

Figure 8. Author's Hand Analysis of Both Surface Dewpoint (*Demarcating Dry and Moist Areas*) (a), Air Temperatures (°C) (*Demarcating Cold and Warm Areas*) (b) and the Synoptic Surface Chart on March 4, 2007 (c) (the Source of Graphs without Drawings is Courtesy of the SAWS, https://www.weathersa.co.za/home/synopticcharts)

Figures 9 and 10, which display shifts in wind speed and direction from southerly (S) to northwesterly (NW) and a simultaneous increase in pressure. Therefore, these findings lend support to the idea that a cold front passed over the station. Since cold fronts often trigger thunderstorms, it is reasonable to conclude that the Klerksdorp tornado on March 4, 2007, occurred within the broader atmospheric context of a passing cold front. The argument hold water since there have been similar claims (Byers *et al.* 1951).

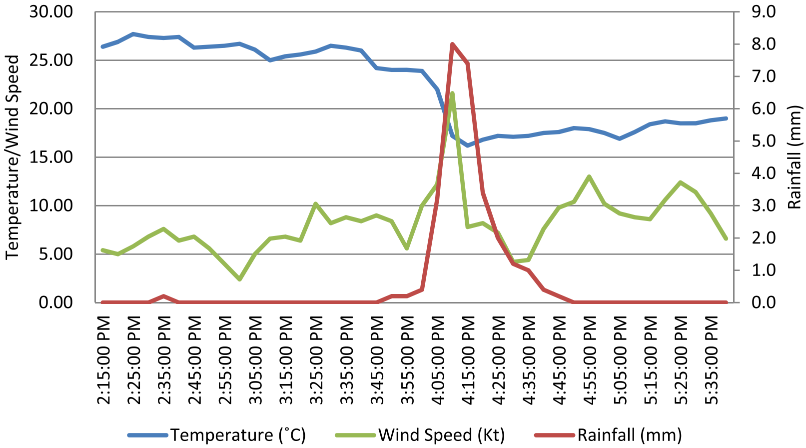


Figure 9. The Graph for Temperatures (°C), Wind Speed (Knots) (Concurrently), and Rainfall (mm) Changes During the Klerksdorp Tornado on March 4, 2007 (Data Courtesy of SAWS)

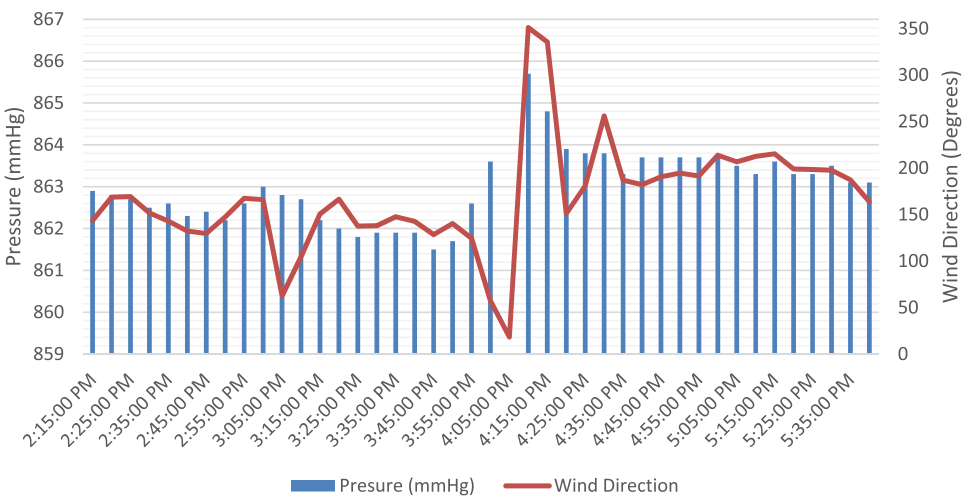


Figure 10. The Graph for Pressure (mmHg) and Wind Direction at Klerksdorp on March 4, 2007 (Data in the Courtesy of SAWS). During the Klerksdorp Tornado on March 4, 2007

As observed in Figure 9, a significant drop in temperature, a noticeable increase in wind speed (reaching 5 knots with gusts of up to 22 knots), and the onset of rainfall occurred roughly between 15:55-h and 16:25-h GMT (3:55 PM and 4:25 PM, local South African time), on March 4, 2007. Concurrently, Figure 10 illustrates a shift in wind direction, transitioning from the southerly (S) component to the northwesterly (NW) direction, later maintaining a southwesterly (SW) flow. These wind changes coincided with variations in atmospheric pressure, a characteristic feature of cold fronts. A time-series analysis of CAPE and deep-layer shear reveals that the development of severe storms in South Africa typically occurs during the early summer (Reason 2017). The study further emphasizes that during late summer, the atmospheric circulation takes on a predominantly tropical character. An outstanding question that requires further investigation is, specifically, the differentiation between tornadoes associated with extratropical weather systems and those connected to tropical weather systems in South Africa.

4. Conclusion

Research findings indicate that the Klerksdorp tornado was linked to the prevailing cold front and the cut-off low, which are characteristic features of extratropical circulations. There was no evident connection with tropical weather systems. This insight underscores the potential benefit of comprehending the interaction between extratropical weather systems, aiding in the issuance of short-term (now-casting) weather forecasts for natural disaster risk reduction. Future research endeavors should focus on monitoring the recurrence of tornadoes in this vulnerable region of the Northern Provinces, particularly those that interact with transvaal troughs (TTTs), cold fronts, and local topography. The integration of lightning detection systems and real-time data from various sources, such as weather observations, satellites, radar, and numerical modeling (forecasting), could enhance the diagnostic capabilities related to tornadoes in the region. It is important to acknowledge that while this study provides valuable insights into tornado dynamics in South Africa through a case study analysis, it may have limitations. For instance, a single case study may not fully represent the climatology of the studied phenomenon. Nevertheless, the study highlights the potential for future research, emphasizing the need for a more comprehensive investigation into tornadoes in the region, their interactions with both extratropical and tropical circulation, and the broader weather systems that influence South African weather patterns.

Acknowledgments

The author acknowledges the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Predictions (NCEP), EUMETSAT in Germany, and the South African Weather Service (SAWS) for data access. Additionally, sincere appreciation goes to L. Simpson and R. Coleen for their invaluable support and guidance, and the anonymous reviewers.

ORCID

Offoro N. Kimambo https://orcid.org/0000-0003-1194-7139

References

Agee, EM (2014). A revised tornado definition and changes in tornado taxonomy. *Weather and Forecasting*, 29: 1256–1258. https://doi.org/10.1175/WAF-D-14-00058.1.

Bhattacharyya, R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, Das K, Anil KS, Lalitha M, Hati KM and Franzluebbers AJ (2015). Soil degradation in India: Challenges and potential solutions. *Sustainability (Switzerland)*, 7(4): 3528–3570. https://doi.org/10.3390/su7043528.

Blamey RC, Middleton C, Lennard C and Reason CJC (2017). A climatology of potential severe convective environments across South Africa. *Climate Dynamics*, 49:2161–2178. https://doi.org/10.1007/s00382-016-3434-7.

Bluestein, HB (2013). *Severe Convective Storms and Tornadoes: Observation and Dynamics*. Springer. https://doi.org/10.1007/978-3-642-05381-8.

Brooks, HE, Lee JW and Craven JP (2003). The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmospheric Research*, 67(68): 73–94. https://doi.org/10.1016/S0169-8095(03)00045-0.

Byers, HR, Landsberg HE, Wexler H, Haurwitz B, Spilhaus AF, Willett HC, Houghton HG and Brooks EM (1951). Tornadoes and Related Phenomena. In *Compendium of Meteorology*. American Meteorological Society, pp. 673–680. https://doi.org/10.1007/978-1-940033-70-9_55.

D'Abreton, P (1991). A synoptic characterization of some South African tornadoes. *South African Journal of Science*, 87(1–2): 56–61.

De Coning, E and Adam, BF (2000). The tornadic thunderstorm events during the 1998–1999 South African summer. *Water SA*, 26(3): 361–376.

DEA (2016). Climate information and early warning systems for supporting the disaster risk reduction and management sector in South Africa under future climates.

Dean, AR and Schneider RS (n.d.). An examination of tornado environments, events, and impacts from 2003–2012 (P06; DOC/NOAA/NWS/Storm).

Dotzek, N, Grieser J and Brooks HE (2003). Statistical modeling of tornado intensity distributions. *Atmospheric Research*, 67(68). https://doi.org/10.1016/S0169-8095(03)00050-4.

Dyson, LL and Van Heerden J (2002). A model for the identification of tropical weather systems over South Africa. *Water SA*, 28(3): 249–258. https://doi.org/10.4314/WSA.V28I3.4892.

Fauchereau, N, Trzaska S, Rouault M and Richard Y (2003). Rainfall variability and changes in Southern Africa during the 20th century in the global warming context. *Natural Hazards*, 29: 139–154.

Fensham, HG, Schumann C, Hunt HGP, Tasman JD, Nixon KJ, Warner TA and Gijben M (2018). Performance evaluation of the SALDN using highspeed camera footage of ground truth lightning events over Johannesburg, South Africa. *2018 34th International Conference on Lightning Protection (ICLP)*. pp. 1–5. https://doi.org/10.1109/ICLP.2018.8503415.

Fujita, TT (1973). Tornadoes around the world. *Weatherwise*, 26(2): 56–83. https://doi.org/10.1080/00431672.1973.9931633.

Gijben, M (2012). The lightning climatology of South Africa. *South African Journal of Science*, 108(3/4): 10.

Goliger, AM and Milford RV (1998). A review of worldwide occurrence of tornadoes. *Journal of Wind Engineering and Industrial Aerodynamics*, 74(76): 111–121.

Goliger, AM and Retief JV (2007). Severe wind phenomena in Southern Africa and the related damage. *Journal of Wind Engineering and Industrial Aerodynamics*, 95(9–11): 1065–1078. https://doi.org/10.1016/J.JWEIA.2007.01.029.

Goliger, A and Retief J (2002). Identification of zones of strong wind events in South Africa. *Journal of Wind Engineering and Industrial Aerodynamics*, 90: 1227–1235.

Grobler, R (n.d.). A framework for modelling losses arising from natural catastrophes in South Africa.

Homar, V, Gayà M, Romero R, Ramis C and Alonso S (2003). Tornadoes over complex terrain: An analysis of the 28th August 1999 tornadic event in eastern Spain. *Atmospheric Research*, 67–68: 301–317. https://doi.org/10.1016/S0169-8095(03)00064-4.

Kantamaneni, K, Alrashed I and Phillips M (2017). Cost vs. safety: A novel design for tornado proof homes. *HBRC Journal*, 13(2): 223–232. https://doi.org/10.1016/J.HBRCJ.2015.05.004.

Leitão, P and Pinto P (2020). Tornadoes in Portugal: An overview, *Atmosphere*, 11(7): 679. https://doi.org/10.3390/ATMOS11070679.

Mghebrishvili, I, Zaqarashvili TV, Kukhianidze V, Kuridze D, Tsiklauri D, Shergelashvili BM and Poedts S (2018). Association between tornadoes and instability of hosting prominences. *The Astrophysical Journal*, 861(2): 112. https://doi.org/10.3847/1538-4357/aac823.

Paul, S, Sharif H and Crawford A (2018). Fatalities caused by hydrometeorological disasters in Texas. *Geosciences*, 8(5): 186. https://doi.org/10.3390/geosciences8050186.

Perry, A (1995). Severe hailstorm at Grahamstown in relation to convective weather hazards in South Africa. *Weather*, 50(6): 211–214. https://doi.org/10.1002/j.1477-8696.1995.tb06110.x.

Reason, CJC (2017). *Climate of Southern Africa*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190228620.013.513.

Santurette, P and Georgiev CG (n.d.). Water vapour imagery analysis in 7.3μ/6.2μ for diagnosing thermo-dynamic context of intense convection.

SAWS (2017). South Africa Weather Service — Annual report 2016/2017.

Simpson, L and Dyson LL (2018). Severe weather over the Highveld of South Africa during November 2016. *Water SA*, 44(1): 75. https://doi.org/10.4314/wsa.v44i1.09.
Sioutas, M, Doe R, Michaelides S, Christodoulou M and Robins R (2006). Meteorological conditions contributing to the development of severe tornadoes in Southern Cyprus. *Weather,* 61(1): 10–16. https://doi.org/10.1256/wea.268.04.
Tuluri, F, Suseela Reddy R, Anjaneyulu Y, Colonias J and Tchounwou P (2010). Environmental modeling, technology, and communication for land falling tropical cyclone/hurricane prediction. *International Journal of Environmental Research and Public Health*, 7(5): 1937–1952. https://doi.org/10.3390/ijerph7051937.
Wang, K, Zhong S, Wang X, Wang Z, Yang L, Wang Q, Wang S, Sheng R, Ma R, Lin S, Liu W, Zu R and Huang C (2017). Assessment of the public health risks and impact of a tornado in Funing, China, 23 June 2016: A retrospective analysis. *International Journal of Environmental Research and Public Health*, 14(10): 1–13. https://doi.org/10.3390/ijerph14101201.