University of Reading

Department of Meteorology

Using machine learning to predict the intensification and propagation of East African storms

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Declaration

I, Sean Kelley, of the Department of Meteorology, University of Reading, confirm that this is my own work and figures, tables, equations, code snippets, artworks, and illustrations in this report are original and have not been taken from any other person's work, except where the works of others have been explicitly acknowledged, quoted, and referenced. I understand that if failing to do so will be considered a case of plagiarism. Plagiarism is a form of academic misconduct and will be penalised accordingly.

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Sean Kelley
August 12, 2025

Abstract

Keywords: a maximum of five keywords/keyphrase separated by commas

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Report code: https://github.com/seangtkelley/uor-msc-dissertation-xai-african-storms

Acknowledgements

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Nomenclature

c Speed of light in a vacuum

h Planck constant

Glossary

El Niño-Southern Oscillation A shift in position of sea surface pressure anomalies between each side of the tropical Pacific Ocean with a period of 2-5 years. ix, 3

Indian Ocean Dipole An irregular oscillation of sea surface temperatures in the Indian Ocean. ix, 3

Intertropical Convergence Zone A belt near the equator where the northeasterly and southeasterly trade winds converge. ix, 2

Madden-Julian Oscillation Main component of tropical intraseasonal variability via a coupling of circulation and convection that travels slowly eastward over the Indian and Pacific Oceans. ix, 2

Mesoscale Convective System A group of thunderstorms organised into a single cloud system that lasts several hours, often resulting in extreme rainfall, flash flooding and hail. ix, 1, 2

Synoptic Scale Meteorological phenomena that occur at a horizontal scale of 200 kilometres and above, often associated with large-scale weather systems. 2

Teleconnection Climate patterns related to each other at large distances, typically thousands of kilometres apart, often influencing weather patterns across regions. 2

Acronyms

ENSO El Niño-Southern Oscillation. 3

IOD Indian Ocean Dipole. 3

ITCZ Intertropical Convergence Zone. 2

MCS Mesoscale Convective System. 1–3

MJO Madden-Julian Oscillation. 2

Chapter 1

Introduction

Gebrechorkos et al. (2019) Mesoscale Convective System (MCS)

1.1 Research Objectives

This section outlines the primary objectives of the research, which include:

- To investigate the factors contributing to the intensification and propagation of East African storms.
- To develop a machine learning model capable of predicting storm behavior based on historical data.
- To evaluate the performance of the proposed model against existing forecasting methods.

Chapter 2

Background and Literature Review

2.1 Mesoscale Convective Systems (MCSs)

Due to significant size, duration, and impact, Mesoscale Convective Systems (MCSs) constitute a critical component of regional weather forecasting and climatology. Officially, MCSs are defined as a complex of thunderstorms which become organised on a scale larger than any of the individual thunderstorms (NWS, 2025). Consequently, these storm systems often last for several hours and cover areas of tens of thousands of square kilometres. In addition, they often produce severe weather phenomena, including flooding, strong winds, and hail (Houze, 2014). Unlike many Synoptic Scale systems, MCSs are not usually associated with a well-defined center of circulation and instead are characterized by their multi-scale organization, typically incorporating a variety of convective cells and larger-scale features such as squall lines or mesoscale convective complexes (NWS, 2025; AMS, 2024). These systems are prevalent throughout the world and thus are key to understanding regional climatology. For example, in the United States, MCSs are a primary driver of warm-season precipitation over the Great Plains (Haberlie and Ashley, 2019). The Sahel region of Africa produces some of the strongest MCSs globally due to it being a climatic transition zone with strong seasonal cycles (Zipser et al., 2006).

2.1.1 MCSs in the Horn of Africa

The Horn of Africa is a region with complex topography and large-scale climatic variability that affects MCS development. From the west, the Sahel fades into the Ethiopian Highlands and later the East African Rift Valley, characterized by high topographic relief and complex orography. In the east, the Ethiopian Highlands transition into the low-lying coastal plains of Somalia. Unlike most other countries at this latitude, most of Somalia is arid or semi-arid, with the exception of its border region with Kenya (Beck et al., 2023). This contrast in geography is reflected in storm development and precipitation patterns. The mountains of Ethiopia dominate local convective processes (Negash et al., 2024) while the low-lying areas on the southeastern coast of the region are not nearly as conducive to MCS development and thus are much more susceptible to storm patterns over the Indian Ocean and the Gulf of Aden (Camberlin et al., 2024). The combination of land surface temperature and soil moisture also impact the storm development and intensification. Notably, studies in the Sahel have demonstrated that dry soils downstream of moisture anomalies can intensify convection by strengthening low-to-mid-level wind shear (Klein and Taylor, 2020; Taylor et al., 2017). These processes are similarly relevant to the Horn of Africa, especially in transitional climates bridging arid and humid zones. Large-scale Teleconnections also play a major role in governing MCS activity in this region. The Madden-Julian Oscillation (MJO) is a dominant intraseasonal factor which modulates rainfall in the tropics and in East Africa, its active phases coincide with increased convection and extreme rainfall events (Pohl and Camberlin, 2006; Ochieng et al., 2023). Quite uniquely for the tropics, the Intertropical Convergence Zone (ITCZ) passes over the region twice per year leading to two distinct rainy seasons, one short and one long (Palmer et al., 2023; Tefera et al., 2025). The El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) have also been shown to modulate rainfall patterns in the region, with coupled regional climate models able to reproduce these patterns at various timescales (Vashisht et al., 2021; Dubache et al., 2019; Endris et al., 2019). Overall, despite this complex array of factors, MCSs have been shown to account for over 60% of extreme rainfall in Ethiopia and Somalia (Hill et al., 2023).

Chapter 3

Methodology

Chapter 4

Results

4.1 Summary

Chapter 5

Discussion and Analysis

5.1 Significance of the findings

In this chapter, you should also try to discuss the significance of the results and key findings, in order to enhance the reader's understanding of the investigated problem

5.2 Limitations

Discuss the key limitations and potential implications or improvements of the findings.

5.3 Summary

Chapter 6

Conclusion

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Appendix A

An Appendix Chapter