

AI Based Located Characterizing and Tracking of Rain Cells Embedded in Nanoscale Convective Systems

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Abstract: The exploration of mesoscale convective systems (MCS) is a vital aspect of meteorology, particularly in understanding and predicting severe weather events. The automated identification of rain cells within MCS can significantly enhance the precision of weather forecasts. Recent advancements have led to the development of algorithms like the Tracking Algorithm for Mesoscale Convective System (TAMS), which employs area-overlapping and projected-cloud-edge tracking techniques to identify and track MCS with greater accuracy. Additionally, the integration of deep learning models, such as the deep Convolutional Neural Network for the Identification of Mesoscale Convective System (MesCoSNet), has shown promise in identifying mMCS from satellite data. These innovative approaches, utilizing infrared imagery and meteorological data, are crucial for early warning systems, which can save lives and reduce economic losses by providing timely alerts for severe weather conditions. The ongoing research in this field aims to unravel the complex interplay between various atmospheric parameters and the dynamics of rain cell formation, ultimately contributing to a more comprehensive understanding of weather patterns and MCS behavior.

Keywords: Machine Learning, Mesoscale Convective Systems, Rain Cells.

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I. INTRODUCTION

Mesoscale Convective Systems (MCSs) are indeed fascinating meteorological phenomena with far-reaching impacts on weather and climate. Their ability to form extensive clusters of thunderstorms makes them a critical element in the study of meteorology. The intricate interplay between their convective and stratiform regions, coupled with dynamic features like anvil clouds and overshooting tops, underscores the complexity of these systems. MCSs not only contribute to severe weather events but also play a vital role in the atmospheric redistribution of heat and moisture, which affects large-scale circulation patterns. The study of MCSs is crucial for enhancing our understanding of atmospheric processes and improving weather prediction models. By analyzing the development and behavior of MCSs, meteorologists can better forecast their significance in the

atmospheric system and highlight the need for continued research and observation to unravel the mysteries of these powerful storm clusters.

II. LITERATURE SURVEY

Hayden et al.[1] Mesoscale convective systems (MCSs) are significant atmospheric marvels, especially current in the tropics and mid-latitudes, where they greatly impact original rush and broader climatic patterns. The study you are pertaining to published in the journal of Geophysical Research Atmospheres, delves into the intricate parcels of MCSs throughout their life cycles. Exercising tools like IMERG, GPM, WWLLN, and a simplified shadowing algorithm, the exploration provides a comprehensive analysis of these systems. Similar studies are pivotal for enhancing our understanding of MCSs' impact on rainfall and climate

systems, potentially perfecting soothsaying delicacy and informing climate change models.

The study by Klein et al.[2] presents a significant advancement in meteorological exploration, particularly in the analysis of mesoscale convective systems(MCSs) and their relationship with extreme downfall events. Exercising Meteosat satellite data, the exploration demonstrates that all top temperatures can serve as a dependable index for prognosticating downfall intensity. This is particularly apparent in MCSs exceeding 15,000 km², where a temperature threshold of 40 degree celsius correlates with 91% of extreme downfall circumstances. Also, the study introduces a new system employing a two- dimensional nonstop sea transfigure, which enhances the discovery of deep convection from infrared imagery. This system not only improves upon traditional temperature threshold ways but also provides a more detailed spatiotemporal understanding of hosts characteristics. Similar perceptivity are pivotal for perfecting rainfall soothsaying and preparing for climate-related challenges.

The study by Z.Feng et al.[3] explores the complications of mesoscale convective systems(hosts) and their perceptivity to pall microphysics in convection-permitting simulations over the United States. The exploration, published in the journal of advances in Modeling Earth Systems, highlights the effectiveness of the Thompson simulation in landing the hosts' rush patterns, including the quantum, quotidian cycle, and distribution of hourly rush intensity. The Thompson simulation specially aligns better with compliances in terms of the hosts upper-position pall guard, rush area, and the confines of convective features. It also provides a more accurate partitioning between convective and stratiform rush. These findings emphasize the significance of microphysics parameterization in climate simulation and their profound impact on prognosticating extreme rainfall events and understanding the hydrologic cycle.

The study published in the international journal of climatology[4] provides a significance of assaying the characteristics of the cold convective core within mesoscale convective systems(MCSs), as these are more nearly identified with the rush generated. The exploration suggests that fastening on these characteristics can serve as a deputy for estimating the maximum violent rush through two-dimensional nonlinear regression models. This approach cloud enhances the delicacy of rush vaticinations, which is pivotal for the semi-arid regions of the sahel, where MCSs are a primary source of downfall.

RobertA.Houze Jr et al[5] A middle position subcaste of flux enters the stratiform region of the hosts from a direction determined by the large-scale inflow and descends in response to diabatic cooling at middle-to-low situations. A middle position mesoscale convective whirlpool develops in

the stratiform region, prolonging the host and may contribute to tropical cyclone development. A middle position subcaste of flux enters the stratiform region of the hosts from a direction determined by the large scale and descends in response to diabatic cooling at middle to low situations.

III. PROPOSED SYSTEM

In the proposed methodology the enhancement of the CCS algorithm through the integration of wavelet features and feature selection methods marks a significant advancement in meteorological technology. By focusing on the texture and temperature variations of the cloud patches the algorithm gains a more nuanced understanding of MCSs, allowing for more accurate grouping and classification of rain cells. The median merging technique further refines the temperature-rainfall relationship for each cluster, leading to improved precipitation estimation. With the incorporation of temperature data, the algorithm adapts to diverse meteorological conditions,ensuring robust performance. The rigorous validation against ground truth data underscores the reliability of this methodology. Ultimately, this innovative approach is poised to revolutionize forecasting and deepen our understanding of the dynamics of high-intensity rainfall within mesoscale convective systems.

➤ Data Acquisition

The integration of diverse data sources such as satellite imagery, radar data and ground based measurements provides a comprehensive view of the atmospheric conditions influencing MCS events. Satellite data from high resolution sources like the Sentinel-2 constellation, offers extensive spatial coverage and is instrumental in observing large-scale environmental patterns.

Radar imagery from the NEXRAD network is invaluable for its ability to track precipitation and provide detailed meteorological insights. Ground based measurements complement these datasets by offering localized and real time data on various weather parameters. Together these datasets form a robust foundation for analyzing MCS dynamics,aiding in the advancement of predictive models and contributing to our understanding of weather patterns and their impacts on the environment. Collaborative efforts with NASA and the National Weather Service have facilitated access to vital satellite and radar data, which combined with in house meteorological data and create a comprehensive dataset. This dataset's coverage of an entire year ensures that seasonal variations in MCS events are captured, providing a rich resource for analysis. The integration of multisensory data enhances the precision of predictive models while rigorous quality assurance protocols ensure the reliability of the findings. Such a detailed and systematic approach is crucial for advancing our understanding of meteorological phenomena and can significantly contribute to our proposed method for weather forecasting and climate science.

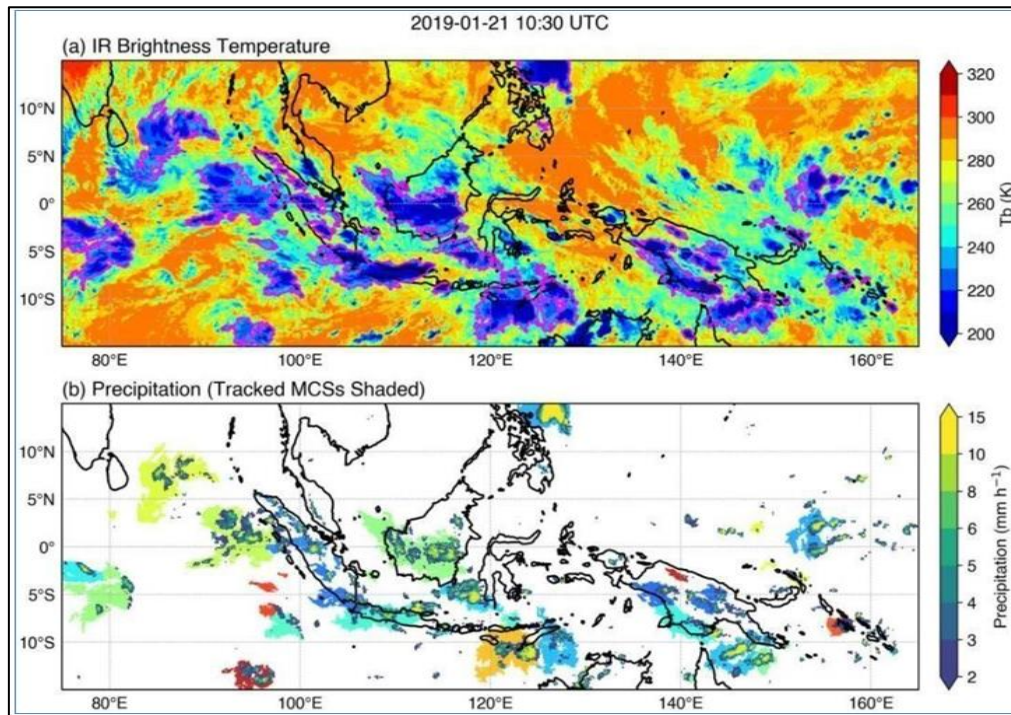


Fig 1 Sample Image from Dataset

➤ *Image Enhancement*

Enhancing the visibility of rain cells in MCSs through temperature calibration is a sophisticated approach that goes beyond traditional image enhancement techniques. By normalizing temperature data, correcting for atmospheric distortions, applying temperature thresholding and extracting key features, the proposed method systematically improves the accuracy of rain cell detection and tracking. Normalization ensures a uniform scale for analysis while atmospheric correction algorithms adjust for effects that could obscure rain cell indicators. Temperature thresholding then isolates potential rain cells area, enhancing contrast and aiding in their identification. Finally, feature extraction algorithms analyze the calibrated data to detail the characteristics of rain cells, providing valuable insights into their structure and behavior. This comprehensive process not only enhances the quality of the imagery but also significantly contributes to the reliability of weather forecasting models and the study of atmospheric phenomena.

➤ *Model Development and Training*

Convolutional Neural Networks (CNN) are indeed pivotal in the advancement of meteorological studies, particularly in the detection and tracking of rain cells within MCS. By utilizing annotated data from radar and satellite imagery, these machine learning models can be trained to recognize patterns and predict weather phenomena with increasing precision. The fine-tuning of network architecture and model parameters is a meticulous process that directly influences the accuracy, precision and recall of the system. Furthermore, the application of data augmentation techniques not only enriches the training dataset but also enhances the model’s ability to generalize from its training and perform reliably in diverse conditions. This is crucial for the development of robust forecasting models that can withstand the unpredictable nature of weather patterns and provide reliable predictions to aid in disaster management and planning.

➤ *Model Evaluation and Training*

In the realm of meteorological analysis, the detection and accurate classification of rain cells within Mesoscale Convective Systems is a critical task. Machine learning models are trained on robust datasets and play a pivotal role in this process. The use of independence test datasets to validate these models is a standard practice, ensuring that these models perform well not just on the data they were trained on but also on new, unseen data. This validation process typically involves a suite of performance metrics such as confusion matrices, ROC curves and precision-recall curves, which provide a comprehensive view of a model’s predictive capabilities.

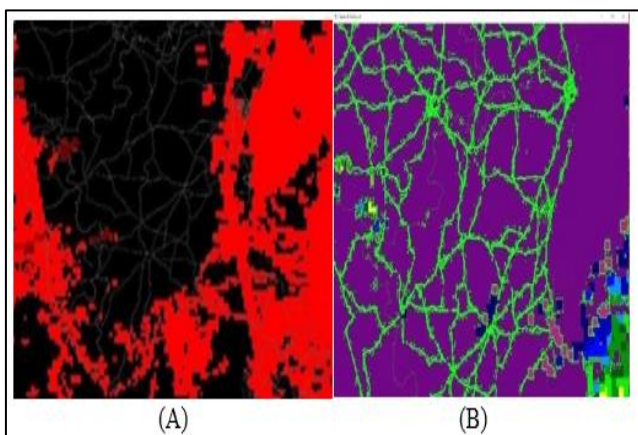


Fig 2 Calibrate Image (a) No Rainfall (b) Heavy Rainfall

V. RESULT AND DISCUSSION

The sophisticated integration of preprocessing techniques in meteorology, particularly for the analysis of Mesoscale Convective Systems (MCSs), is a testament to the advancements in atmospheric sciences. Image enhancement algorithms, which include noise reduction, histogram equalization, and contrast adjustment, play a crucial role in refining the quality of radar and satellite imagery. This leads to significant improvement in the clarity and contrast of images, thereby enabling more accurate detection of rain cells. The meticulous calibration of temperature data further enhances the reliability of these detections, which is essential for the accurate tracking of weather patterns and the issuance of timely weather warnings.

The synergy between data acquisition and image enhancement techniques lays a solid foundation for precise weather analysis and forecasting. Moreover, the application of wavelet transform for feature extraction allows for a more nuanced understanding of spatial variations within the imagery, which machine learning models can leverage to predict rainfall with greater accuracy. The color-coded temperature values serve as a visual guide, indicating the likelihood of rain and enriching the meteorological data for researchers and forecasters alike. This multi-faceted approach underscores the importance of precision and detail in the study of climatic behaviors and the prediction of weather phenomena.

K-means clustering and Support Vector Machines (SVM) are indeed central to image analysis in meteorology. K-means excels in segmenting complex radar and satellite data, enabling meteorologists to pinpoint and track rain cells with remarkable accuracy. This segmentation is vital for differentiating between various weather patterns, which directly informs forecasting and analysis. The iterative refinement of cluster centroids in K-means ensures that the segmentation becomes increasingly precise, a testament to its reliability in remote sensing.

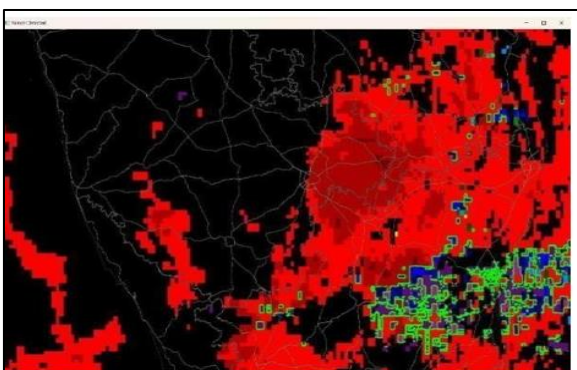


Fig 5 Rainfall Detection

Similarly, SVMs play a crucial role in classification tasks within machine learning. Their ability to construct an optimal hyperplane by leveraging labeled data sets allows for the effective separation of rain cells from other atmospheric entities. This maximizes the classification margin, leading to highly accurate identification of weather phenomena. The

efficiency of SVMs is greatly enhanced by their use of suitable feature representation and a comprehensive training data set, making them indispensable in the analysis of multiscale convective systems. Both techniques exemplify the synergy between machine learning and meteorology, driving advancements in accurate weather prediction and analysis.

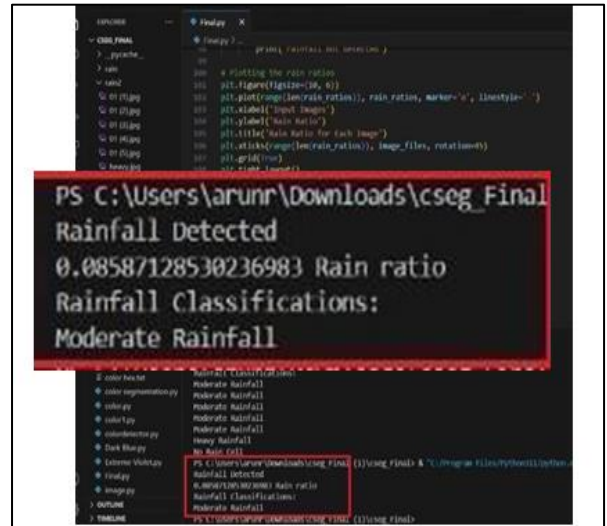


Fig 6 Rainfall Detection Code

The significance of advancing research in the field of rain cell analysis within Mesoscale Convective Systems (MCSs) cannot be overstated. The integration of enhanced data collection and image processing techniques is paramount for improving the accuracy and reliability of rain cell detection. Future research clouds focus on developing more advanced preprocessing methods, which, when combined with machine learning algorithms, have the potential to revolutionize rain cell detection systems. Additionally, incorporating real-time data streams and automated processing workflows could significantly boost the operational efficiency of monitoring and prediction systems. This would not only refine the precision of current methodologies but also pave the way for groundbreaking advancements in meteorological research and weather forecasting. The pursuit of these research avenues promises to yield substantial benefits for both the scientific community and society at large.

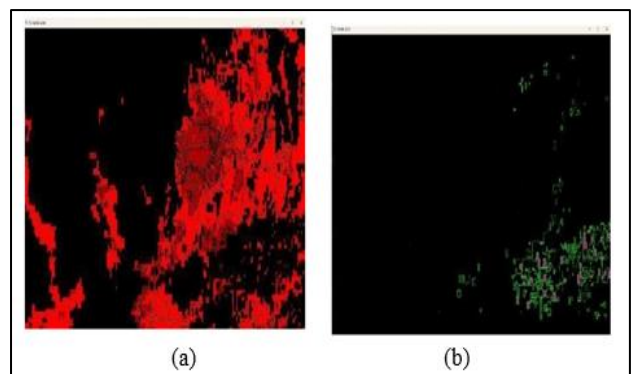


Fig 7 (a) No Rainfall Zone (b) Rainfall Zone

VI. CONCLUSION

The integration of advanced image processing and machine learning techniques in meteorological studies, particularly in the identification and tracking of rain cells within MCS, represents a significant advancement in the field. The projects' utilization of extensive data acquisition methods, including the analysis of satellite and radar imagery, coupled with meticulous preprocessing steps such as image enhancement and segmentation has enabled the extraction of meaningful features associated with rain cells.

The employment of machine learning algorithms, notably Support Vector Machines, has been instrumental in classifying rain cells within MCS with commendable accuracy. Achieving an 80% accuracy rate on a dataset comprising 365 samples is a testament to the projects' capability to detect rain cells, even during the nascent stage of MCS formation. This level of precision not only underscores the efficacy of the applied methodologies but also serves as a benchmark for future research endeavors in the domain.

The projects' success in accurately classifying rain cells has profound implications for meteorological forecasting and development of mitigation strategies. By facilitating early detection and detailed characterization of rain cells, the methodology enhances the ability to forecast weather with greater precision. This, in turn, enables the implementation of timely interventions aimed at mitigating the adverse effects of severe weather conditions.

Looking ahead, the exploration of sophisticated numerical modeling techniques in future research initiatives holds the promise of further augmenting our understanding of MCS behavior. The continuous refinement of predictive models through the incorporation of cutting edge methodologies is likely to yield improvements in the forecasting of severe weather events. Such advancements will play a crucial role in bolstering resilience and preparedness against the backdrop of evolving climate patterns.

REFERENCES

- [1]. Kattsov, V.M.; Akentieva, E.M.; Anisimov, O.A.; Bardin, M.Y.; Zhuravlev, S.A.; Kiselev, A.A.; Klyueva, M.V.; Konstantinov, P.I.
- [2]. Korotkov, V.N.; Kostyanoy, A.G.; et al. Third Assessment Report on Climate Change and Its Consequences on the Territory of the Russian Federation; General Summary; Roshydromet Science-Intensive Technologies: St. Petersburg, Russia, 2022.
- [3]. Diffenbaugh, N.S.; Scherer, M.; Trapp, R.J. Robust increases in severe thunderstorm environments in response to greenhouse forcing. *Proc. Natl. Acad. Sci. USA* 2013, 110, 16361–16366. [PubMed]
- [4]. Rädler, A.T.; Groenemeijer, P.H.; Faust, E.; Sausen, R.; Půcik, T. Frequency of severe thunderstorms across Europe expected to

increase in the 21st century due to rising instability. *npj Climate Atmos. Sci.* 2019, 2, 30.

- [5]. Chernokulsky, A.; Eliseev, A.; Kozlov, F.; Korshunova, N.; Kurgansky, M.; Mokhov, I.; Semenov, V.; Shvets', N.; Shikhov, A.; Yarinich, Y.I. Atmospheric severe convective events in Russia: Changes observed from different data. *Russ. Meteorol. Hydrol.* 2022, 47, 343–354.
- [6]. Meredith, E.P.; Semenov, V.A.; Maraun, D.; Park, W.; Chernokulsky, A.V. Crucial role of Black Sea warming in amplifying the 2012 Krymsk precipitation extreme. *Nat. Geosci.* 2015, 8, 615–619.
- [7]. Chernokulsky, A.; Kurgansky, M.; Mokhov, I.; Shikhov, A.; Azhigov, I.; Selezneva, E.; Zakharchenko, D.; Antonscu, B.; Kühne, T. Tornadoes in northern Eurasia: From the middle age to the information era. *Mon. Weather Rev.* 2020, 148, 3081–3110.
- [8]. Chernokulsky, A.; Shikhov, A.; Bykov, A.; Azhigov, I. Satellite-based study and numerical forecasting of two tornado outbreaks in the Ural Region in June 2017. *Atmosphere* 2020, 11, 1146.