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Next-Generation Weather Prediction

Ayush Chandel[1], Manjeet Kaur[2]

School of Computational Science, GNA University, Phagwara, Punjab[1,2]

Abstract: Accurate weather forecasting is essential for disaster management, agriculture, aviation, and environmental planning. Traditional weather prediction relies on numerical weather prediction (NWP) models that simulate atmospheric processes using complex physical equations. Although these models are scientifically reliable, they require significant computational resources and long processing times.

Modern AI models such as GraphCast and FourCastNet can analyze large atmospheric datasets and produce forecasts much faster than traditional models. Research shows that these systems can generate global weather predictions in less than one minute while maintaining competitive accuracy compared with conventional forecasting systems. AI techniques use deep neural networks, graph neural networks, and large climate datasets to detect patterns in temperature, pressure, humidity, and wind variables. These approaches have demonstrated promising results in predicting extreme weather events such as storms, cyclones, and heatwaves. However, challenges remain, including data dependency, model interpretability, and limitations in predicting rare climate events.

This study reviews recent advancements in AI-based weather prediction models and analyzes their advantages, limitations, and future potential in climate science. The findings suggest that AI does not replace traditional meteorological models but complements them, enabling faster and more efficient forecasting systems.

Keywords: AI, Weather Prediction, Climate Science, Machine Learning, Deep Learning, Extreme Weather, Climate Modeling, severe

I. INTRODUCTION

In the last few years, climate change has become one of the most important problems facing the world. It has an impact on the environment, the economy, and people's lives. There are more and more extreme weather events like floods, heatwaves, droughts, and cyclones, which has made people very worried about how well current weather prediction systems work. These events are happening more often and in ways that are harder to predict, which makes it harder for governments and organizations to get ready for and deal with them. So, accurate weather forecasting is very important for planning for disasters, farming, and keeping people safe. Numerical weather prediction (NWP) models are the basis for traditional weather forecasting. These models use math to model how the atmosphere works. These models use physical laws like thermodynamics and fluid dynamics to make predictions about the weather. They are scientifically reliable, but it takes a lot of time and computer power to process large amounts of data (Rasp et al., 2022). Because of this limitation, it is hard to make real-time forecasts, especially when the weather is changing quickly.

Artificial Intelligence (AI) has become a promising way to predict the weather for the next generation in the last few years. AI methods, especially deep learning and machine learning, can look at big datasets and find patterns that are hard to find with other methods (Camps-Valls et al., 2023). These models use historical weather data from satellites, sensors, and weather stations to learn and make predictions about future climate conditions.

AI systems can process data quickly and make predictions faster than traditional models, which is very important in emergencies. Data volume, gaps, limited resources, and limited collaboration slow down progress. These problems called for better high-performance computing power and better data.

This paper examines the role of Artificial Intelligence in next-generation weather forecasting and its implications for climate science. It seeks to examine how AI enhances forecasting precision and efficacy, while also recognizing its constraints and prospective advancements.

This study helps make weather prediction models more reliable and useful by looking at the pros and cons of AI-based systems.

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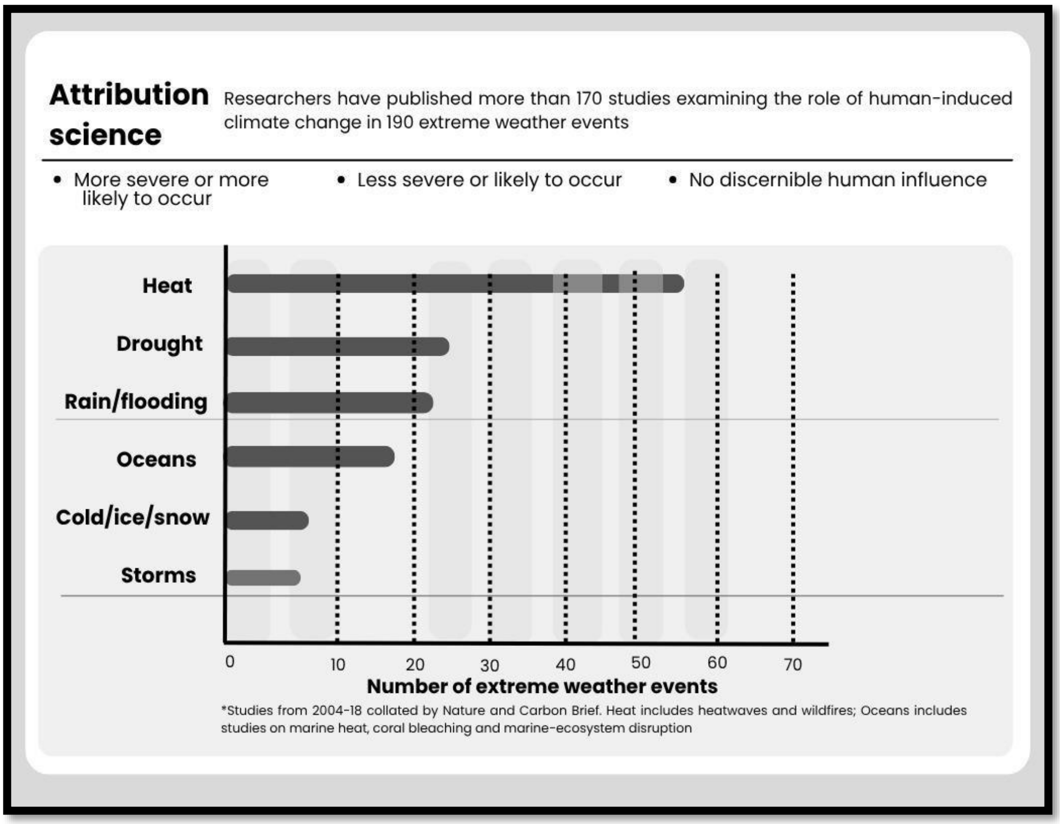

Main objective of this research:

- The primary aim of this research: The principal assertions of this paper are• To investigate the role of Artificial Intelligence in transforming cutting-edge rainfall prediction systems and enhancing climate analysis.
- To comprehend the utilization of machine literacy and deep literacy methodologies in the analysis of extensive climate data to discern intricate patterns (Camps-Valls et al., 2023).
- To analyze the functionality of AI in predicting extreme rainfall events such as cataracts, heatwaves, and cyclones, and its importance in disaster management (Nguyen et al., 2024).
- To evaluate AI-based rainfall prediction models against conventional numerical rainfall forecasting systems regarding speed, accuracy, and efficacy (Rasp et al., 2022).
- To examine the role of AI in creating faster and more real-time predictions for rain using satellite and sensor data (Bi et al., 2023).
- To recognize the key problems facing AI in climate prediction, such as dependence on data, absence of transparency, and ability to predict rare events.
- To understand the untapped potential of AI in next-generation rain prediction and its inherent implications for climate prediction.

II. LITERATURE REVIEW

AI technology has been attracting interest in climate science in the recent past because of its abilities to handle vast amounts of data and improve the prediction system. Scientists have been exploring different machine learning and deep learning approaches in order to boost forecasting efficiency and precision. As noted by Camps-Valls et al., deep learning models are highly efficient in handling complex climate-related information and capturing non-linear relations among various climate parameters. They concluded that AI could help to improve climatic models since they are capable of recognizing some complicated patterns.

According to Bi et al., an innovative AI-based weather forecasting system was developed and proved its capability of producing worldwide forecasts within shorter periods than traditional numerical weather models. The researchers found that AI is particularly efficient in producing weather predictions, taking into account that AI models operate fast and

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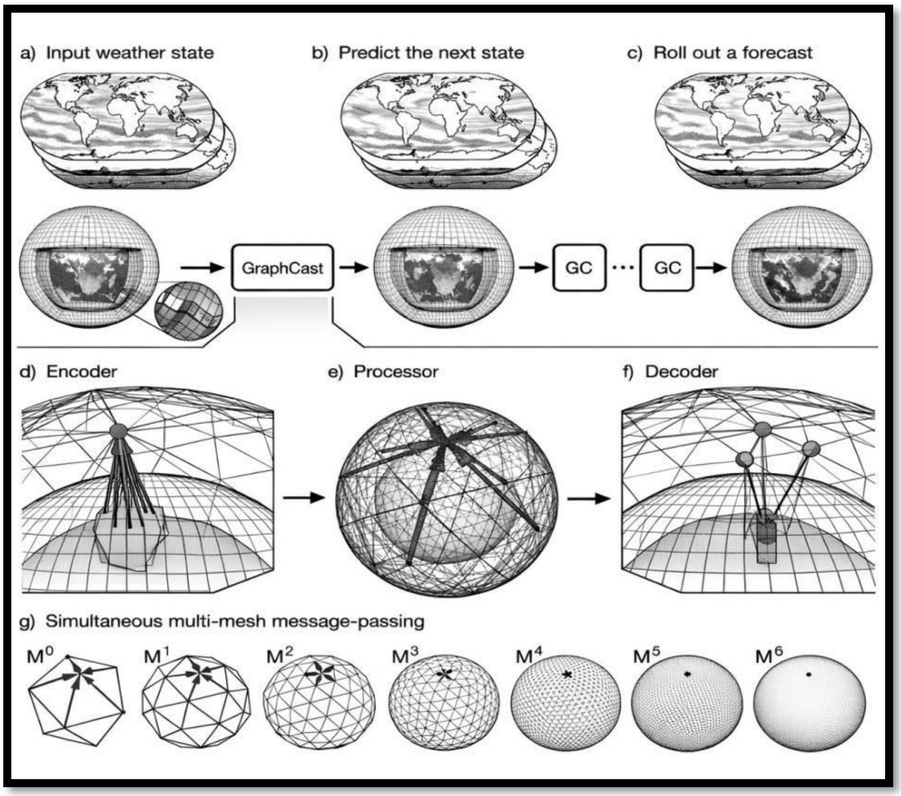
provide accurate forecasts simultaneously. Consequently, AI algorithms may prove helpful in real-time weather forecasting.

Additionally, Nguyen et al. have been studying AI-based deep learning approaches aimed at extreme weather event prediction. According to their findings, AI models are capable of providing early warning alerts through analysing historical data and recognizing extreme weather-related pattern Nevertheless, it is imperative to point out that these methods rely significantly on the quality of data, which may make their work difficult when trying to predict rare or unprecedented cases.
Rasp et al. (2022) stressed the significance of using benchmarks like the Weather Bench dataset when assessing the quality of AI models for weather predictions. This research showed that data quality, availability, and consistency are critical factors in AI accuracy. The authors further mentioned that although AI is fast and efficient, the integration of both AI models and physical models would improve its reliability.

Moreover, according to Kumar et al. (2023), machine learning can be utilised to analyse precipitation patterns and river flow in order to predict floods. This shows the applicability of AI in the case of disaster management and risk assessment In conclusion, the literature reviewed above presents evidence that AI can revolutionise weather prediction systems. Nonetheless, it still requires the improvement of data management and incorporation of other methods of prediction.



Discussion of former Studies

- Soothsaying of Extreme Weather via AI Research done by India's Ministry of Earth Sciences (2024) on AI-driven prediction of floods and storm tides reduces early warnings and disaster management issues. AI technology such as TeleViT predicts wildfires well before they happen, contributing towards threat management.
- Sensing CO_2 and NO_2 via AI Research done between 2023- 2025 on AI technology highlights its ability to monitor greenhouse gas emissions through satellite images.
- Models such as GeoViT allow for superior perception while using less energy. Integration of Hybrid Models
- The use of AI along with physical-based models for the weather enhances sensitivity and efficiency in computations.
- Scalability and Real-Time Processing AI-based models enable scalability for real-time monitoring of the weather, which is very essential for disaster response and warning.

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TABLE I
COMPARISON OF EXISTING STUDIES

Ref. No.	Author(s) & Year	Main Contribution	Limitation
[1] Rohm et al. (2025)	AI applications in engineering and environmental systems	Focused on broad AI applications	Not specific to weather forecasting
[2] Chang (2025)	AI in weather and climate prediction	Emphasized forecasting applications	Limited discussion on model comparison
[3] Rolnick et al. (2019)	Machine learning for climate change solutions	Broad climate-change perspective	Less focus on operational forecasting
[4] Karuppusamy (2024)	ML techniques for weather forecasting	Focused mainly on forecasting accuracy	Limited discussion of challenges
[5] Recent Review Study (2025)	Review of ML weather prediction methods	Summarized existing methods	Limited future scope analysis
[6] AI Research Community (2025)	Advances in AI weather models	Highlighted latest AI models	Limited comparison with traditional methods
[7] Thorpe (2025)	Physics-integrated trustworthy AI forecasting	Focused on model trustworthiness	Less emphasis on applications
[8] AI Climate Study (2025)	AI for heatwave prediction and climate adaptation	Focused on extreme heat events	Limited coverage of other weather events
[9] AI Atmospheric Model Research (2026)	Large AI weather models and future prospects	Focused on model architecture	Limited practical applications
[10] Wang et al. (2025)	XiChen fully AI-driven forecasting system	Focused on one forecasting model	Limited comparative analysis
[11] Guo et al. (2025)	FuXi-TC forecasting model	Specialized forecasting framework	Focused on a specific model
[12] Schultz et al. (2021)	Comparison of deep learning and NWP	Evaluated AI performance	Earlier-generation AI models
[13] Bi et al. (2023)	GraphCast medium-range forecasting	High forecasting accuracy	Limited discussion on interpretability
[14] Lam et al. (2023)	FourCastNet forecasting model	Fast global weather prediction	Model-specific study

III. PROBLEM STATEMENT

It is important to make accurate predictions in order to deal with disasters, plan agricultural activities, and take care of the environment. Even though there has been progress in the development of forecasting technologies, predicting extreme weather events still presents a lot of challenges. Conventional methods of weather prediction are characterized by the use of complex equations describing physical processes and a long period required to analyze the atmospheric information (Rasp et al., 2022).

Nevertheless, artificial intelligence can help predict weather faster and more effectively. However, there are some drawbacks related to the usage of AI for weather predictions. First of all, AI requires a large amount of information that may not always be available and consistent. It is worth saying that machine learning models can work as “black boxes” since it is hard to explain how they make predictions.

Additionally, AI models may struggle to predict rare or extreme weather events because such events occur infrequently and are not well represented in training datasets (Nguyen et al., 2024). This limitation reduces the reliability of AI systems in critical situations.

Therefore, there is a need to explore how AI can be effectively used in weather prediction while addressing these challenges. This research aims to analyze the role of AI in climate science and identify ways to improve its performance for real-world applications.

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IV. METHODOLOGY

The methodology adopted for this study is qualitative, which involves evaluating existing literature on the topic. The data collected in this study has been derived from secondary sources including research papers, academic journals, and online databases published between 2021 and 2025. Such an approach provides an insight into contemporary developments in artificial intelligence-based weather prediction.

The literature review approach has been adopted in this study. Research papers have been reviewed for identifying contemporary trends, methodologies, and insights into weather predictions using artificial intelligence techniques. Particular emphasis has been laid on the comparison of AI-based models with numerical weather prediction models. The study has also utilized the comparative analysis approach to highlight the strengths and weaknesses of AI-based models.

The comparative analysis approach has been used to assess the efficacy, efficiency, and effectiveness of various models in artificial intelligence. Furthermore, this approach highlights the potential application of AI in weather prediction.In

addition, the research considers the challenges associated with AI, such as data dependency and lack of interpretability. By analyzing these factors, the study aims to provide a balanced view of the effectiveness of AI in climate science.

No primary data collection, such as surveys or experiments, has been conducted in this research. The study is entirely based on existing literature and aims to provide a clear and realistic understanding of the role of AI in next-generation weather prediction systems.

V. ROLE OF ARTIFICIAL INTELLIGENCE IN WEATHER PREDICTION

The application of Artificial Intelligence (AI) in weather prediction involves the use of data-oriented approaches that can help in making predictions on atmospheric behavior using huge sets of meteorological data. Deep learning techniques have proven to be efficient and effective in providing predictions in such situations.

Deep learning involves the creation of multi-layer artificial neural networks which can help identify various atmospheric variables such as temperatures, pressures, humidity, and winds to make predictions.

One of the greatest advantages of using AI models for prediction of climate changes is their fast computation capability. Some models such as GraphCast can be used to predict climate globally within a few minutes while remaining accurate. Similarly, models such as FourCastNet make use of advanced neural operators that simulate atmospheric dynamics efficiently and enable high-resolution predictions without being computationally intensive.

Machine learning techniques are able to analyze historical weather patterns and predict warning signs of future severe climate patterns.

Key AI Models in Weather Prediction

- GraphCast (Google DeepMind): Generates global 10-day forecasts in under one minute using a graph neural network trained on ERA5 reanalysis data.
- FourCastNet (NVIDIA): Leverages Fourier neural operators for high-resolution global prediction with low computational overhead.
- Pangu-Weather (Huawei): Achieves medium-range forecast accuracy comparable to ECMWF with significantly reduced inference time.
- TeleViT: A vision transformer applied to wildfire and extreme event prediction with strong spatial pattern recognition.
- GeoViT: Designed for greenhouse gas monitoring, enabling superior environmental perception with reduced energy consumption

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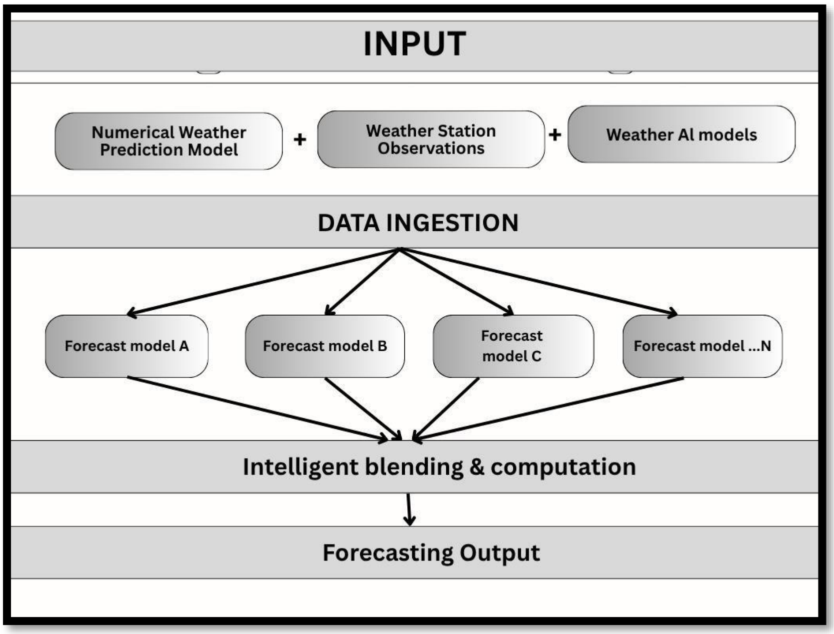

VI. AI IN EXTREME WEATHER PREDICTION

Early warning systems - AI models can study past and current data about climate changes and help in detecting the early indicators of any potential weather disasters to give early warnings for preparation purposes (Nguyen et al., 2024).

Flood prediction - The AI model is capable of predicting floods based on such information as rainfall, water levels in rivers, and moistness in the soil. It also helps in taking preventive measures when needed (Kumar et al., 2023).

Heatwave detection - By studying past weather temperature data, machine learning algorithms are able to identify trends and possible heat waves in the future, allowing governments to give out necessary alerts (Nguyen et al., 2024).

Storm and rainfall prediction - These types of predictions include monitoring patterns of clouds formation and atmospheric pressure to determine whether there is likely to be stormy weather. Predictions made with the help of an AI algorithm happen faster than traditional predictions (Bi et al., 2023).

Real-time data processing - This is achieved thanks to real-time analysis of satellite, sensor, and radar data.

VII. TOOLS AND TECHNOLOGIES USED IN AI-BASED WEATHER PREDICTION

Machine literacy(M): Used to dissect once rainfall data and find patterns for unborn vaticination (Camps- Valls et al., 2023).

Deep Learning (DL): Uses neural networks to handle complex data like satellite images and improves prediction accuracy (Nguyen et al., 2024).

Big Data Technologies: Helps in storing and processing large amounts of climate data from different sources (Rasp et al., 2022).

Cloud Computing: Provides high computing power to run AI models and store large datasets efficiently.
Data Visualization Tools: Used to display weather predictions in the form of graphs, maps, and charts.

VIII. APPLICATIONS IN CLIMATE SCIENCE

4.1 Agriculture: AI-based weather predictions assist farmers in making informed decisions regarding crop planting schedules, irrigation management, and harvest timing. In India, AI-supported monsoon prediction models offer multiple

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weeks of advance forecasting, helping farmers plan seasonal activities and reduce climate crop losses. AI-based weather predictions assist farmers in making educated decisions regarding:

- Plants growing
- Irrigation
- Timing harvest

In India, AI-supported monsoon prediction models offer multiple weeks' forecasts,

4.2 Climate Change Modeling: AI analyzes long-term climate patterns and forecasts global warming trends, assisting researchers in understanding temperature rise, ocean heat dynamics, sea-level changes, and carbon cycle disruptions—providing valuable insights for climate policy formulation.
AI is used to analyze long-term climate patterns and predict global warming trends. It helps researchers understand

- Temperature rise patterns
- Ocean changes
- Carbon cycle dynamics

4.3 Environmental Monitoring: AI systems actively monitor air pollution levels, water resource availability, and deforestation dynamics. Recent studies have achieved approximately 90% accuracy in predicting environmental changes such as lake shrinkage due to climate change, demonstrating the technology's large-scale environmental surveillance potential.
AI systems monitor:

- Air pollution
- Water resources
- Deforestation

Recent studies using AI have achieved high accuracy (around 90%) in predicting environmental changes such as lake shrinkage due to climate change.

IX. ADVANTAGES OF AI IN WEATHER PREDICTION

Speed: AI models generate forecasts in minutes instead of hours
Efficiency: Reduced computational costs compared to supercomputers
Accuracy: Improved short-term prediction performance
Scalability: Ability to process large and diverse datasets
AI models can also democratize forecasting, allowing smaller research institutions to develop prediction systems using GPUs instead of supercomputers.

Challenges and Limitations
Although it offers numerous benefits, AI used in weather forecasting poses several issues:

1.1 Data Dependency
AI models rely heavily on historical data. If the data is incomplete or biased, predictions may be inaccurate.
1.2 Prediction of Extremes
Studies reveal that artificial intelligence finds it difficult to forecast extreme weather conditions that break records. Traditional models tend to do better in such cases.
1.3 Generalization Problems
Artificial intelligence that is built using data from the past will have a problem generalizing when faced with changing climatic conditions, causing prediction biases.
1.4 Uninterpretable Nature
Most artificial intelligence algorithms have an unexplainable nature and cannot be understood

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X. COMPARATIVE ANALYSIS: TRADITIONAL NWP VS. AI-BASED MODELS

TABLE 2

The table below compares traditional NWP and AI-based forecasting systems across key performance dimensions:

Parameter	Traditional NWP	AI-Based Models
Processing Speed	Hours (supercomputer req.)	Minutes (standard GPU)
Computational Cost	Very High	Moderate to Low
Data Handling	Limited datasets	Large, diverse datasets
Short-term Accuracy	High	High (competitive)
Extreme Event Pred.	More reliable	Limited by training data
Interpretability	High (physics-based)	Low (black-box)
Real-time Forecasting	Slow	Fast and scalable
Best Use Case	Standalone	Hybrid with NWP

The analysis confirms that AI-based models offer compelling advantages in speed, scalability, and data handling, while traditional NWP models retain superiority in interpretability and extreme event prediction. Hybrid approaches that combine both paradigms represent the most promising direction for next-generation forecasting systems.

XI. CHALLENGES AND LIMITATIONS

TABLE 3

Despite its considerable potential, AI deployment in weather forecasting presents several important challenges:

Challenge	Description	Proposed Solution
Data Dependency	Incomplete or biased training data yields inaccurate predictions.	Invest in global data collection and augmentation techniques.
Black-box Nature	AI decisions are opaque, reducing trust among meteorologists.	Develop Explainable AI (XAI) frameworks for climate science.
Extreme Events	Rare events under-represented in training data.	Use synthetic data generation and transfer learning.
Generalization	Models fail under shifting climate conditions.	Incorporate adaptive and continual learning architectures.
Data-scarce Regions	Reduced accuracy in developing countries.	Leverage satellite data and edge computing for remote sensing.

These challenges highlight that AI cannot yet fully replace traditional meteorological systems, particularly in high stakes scenarios involving unprecedented events or data-poor environments. Addressing these limitations through continued research and infrastructure investment is essential.

XII. RESULTS AND DISCUSSION

The results obtained from this research show that there has been an immense contribution from Artificial Intelligence in modernizing weather prediction systems. For instance, unlike conventional NWP models, AI-based systems are fast, accurate at a short period, and versatile when it comes to handling massive volumes of data. Such characteristics are useful in areas that need quick decisions like storms alerts and disasters mitigation.

An outstanding result obtained in this research is the time saved by using AI-based models. Traditional weather modeling methods need supercomputers and a considerable amount of time before obtaining forecasts. On the other hand, artificial intelligence models can analyze similar volumes of data but provide forecasts much quicker and with fewer computing resources. That is, the speed of providing results is an asset of AI-based algorithms.

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Accuracy of short-and mid-range forecast is another achievement of Artificial Intelligence in predicting the weather. The training of such models on large data sets makes them recognize patterns of temperature, precipitation, and wind much easier. Thus, the forecast becomes more precise than conventional methods. Nevertheless, one needs to remember that this is possible only when quality data is available.

At the same time, the study highlights the growing importance of hybrid forecasting systems. Instead of replacing traditional models, AI is increasingly being used alongside them. This combined approach helps correct errors in physics-based models while maintaining scientific reliability. It suggests that the future of weather prediction lies in collaboration between data-driven and physics-based techniques.

Key Observations:
- AI significantly reduces forecast generation time
- Higher accuracy in short- to medium-term predictions (1–10 days)
- Better performance in data-rich regions
- Hybrid models provide more balanced and reliable results

Despite these advantages, there are still important challenges. AI models depend heavily on past data, which means they can struggle to predict extreme or rare weather events that have not been observed before. For example, unusual climate patterns or sudden disasters may not be accurately captured by AI systems alone.

Another issue is the quality and availability of data. In areas where weather data is limited or inconsistent, the performance of AI models decreases. This shows that AI cannot yet fully replace traditional systems, especially in developing regions with fewer monitoring resources.

There is also the concern of lack of transparency. Many AI models work like "black boxes", meaning their internal decision-making process is not easily understood. This can create trust issues, especially when forecasts are used for critical decisions such as evacuation planning or agricultural policies.

Limitations Identified:

- Difficulty in predicting extreme and unprecedented events
- Strong dependence on historical data quality
- Reduced accuracy in data-scarce regions
- Limited interpretability of AI models

In conclusion, the results suggest that AI is a powerful addition to weather prediction, but not a complete replacement for traditional methods. The most effective approach is a hybrid system that combines the strengths of both. With further improvements in data collection, model transparency, and extreme event prediction, AI has the potential to become a core component of future climate science.

XIII. FUTURE SCOPE

The rapid advancement of Artificial Intelligence presents significant opportunities for enhancing weather prediction systems in the coming years. While current AI-based models have demonstrated strong performance in speed and short-term accuracy, there is still substantial scope for further development and improvement.
Hybrid Forecasting Models: Integrating AI with traditional NWP will combine fast data processing and pattern recognition with physics-based scientific reliability.
Extreme Weather Prediction: Synthetic data generation, transfer learning, and advanced simulation techniques will improve AI model performance for rare events.
Real-Time Data Integration: Expanding IoT devices, satellite constellations, and remote sensing will provide higher-quality, higher-frequency inputs for more dynamic forecasts.
Explainable AI (XAI): Developing interpretable AI outputs is essential to build trust among meteorologists and policymakers for critical decision-making.

Edge Computing: Deploying AI forecasting on edge platforms will extend advanced prediction capabilities to developing regions with limited infrastructure.

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Long-Term Climate Modeling: Extending AI from short-term forecasting to decadal projections will help researchers understand climate change trajectories and tipping points.
Global Collaboration: International data sharing and collaborative model development will accelerate progress and ensure equitable access to advanced forecasting tools.

The future of weather prediction lies in hybrid systems combining AI and physics-based models. Emerging developments include:

- AI-powered global forecasting systems
- Real-time prediction models
- Integration with satellite and IoT data
- Improved extreme weather prediction

Next-generation AI models are expected to deliver higher accuracy, better generalization, and more reliable long-term climate predictions.

XIV. CONCLUSION

This study highlights the growing importance of Artificial Intelligence (AI) in transforming weather prediction and climate science. The findings show that AI-based models are capable of producing faster and, in many cases, more accurate forecasts compared to traditional numerical weather prediction systems. Their ability to process large volumes of data and identify hidden patterns makes them especially useful for short- and medium-term forecasting.

However, the research also makes it clear that AI is not a complete replacement for traditional methods. While it performs well under normal conditions, its dependence on historical data limits its ability to predict rare or extreme weather events. In addition, challenges such as data quality, model transparency, and reliability in data-scarce regions still need to be addressed.

One of the most important takeaways is that the future of weather prediction lies in hybrid approaches, where AI and physics-based models work together. Such integration combines the strengths of both systems—speed and pattern recognition from AI, and scientific accuracy from traditional models—leading to more reliable and balanced forecasts.

Looking ahead, continued advancements in data collection, computing power, and model development are expected to further improve AI-driven forecasting. With proper implementation and ongoing research, AI has the potential to play a crucial role in improving climate resilience, supporting disaster preparedness, and helping societies adapt to changing environmental conditions.

In conclusion, Artificial Intelligence is not just an emerging tool but a key component of next-generation weather prediction, offering promising opportunities while also requiring careful and responsible development.

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