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MATHEMATICAL MODELING AND AI FOR CLIMATE CHANGE PREDICTION

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ABSTRACT

Climate change is rapidly emerging as one of the gravest modern global challenges, causing far-reaching impacts on ecosystems, human health, and economies globally. Traditionally, understanding and predicting climate change heavily relied on empirical data and physical models. In recent years, though, due to advanced techniques like computational algorithms and the growing ease and speed with which artificial intelligence can be developed, mathematical modeling is relied on more heavily as a powerful tool to further our capacity to analyze and mitigate climate phenomena. This paper will attempt to explore the interplay between mathematical modeling and

ADAPTATION

AI when used in analyzing climate changes, their synergies, the advantages they imply, and the prospect they offer for more accurate, robust, and timely climate predictions. Mathematical modeling has emerged to become one of the most important tools in the climate science domain, through which quantitative assembly allows simulating the complex interactions occurring in the Earth climate system. Of all the atmospheric dynamics, ocean currents, and greenhouse gas emissions, mathematical models really make it possible to use these tools for the understanding and prediction of long-term climate conditions. Over the years, these models have evolved from simple linear equations to large, sophisticated multi-variable systems of partial differential equations (PDEs), capturing the complicated feedbacks and responding non-linear forms of climate processes. This maturity has also given rise to feedback loops and uncertainties, hence increasing the realism of climate projections.

AI, specifically machine learning, revolutionized climate prediction by making possible the examination of hugely vast, multidimensional datasets from satellites, sensors, and climate simulation. ML algorithms can be trained to spot patterns, make predictions, and draw inferences from data before they would be too daunting for traditional processing methods. AI methods, including supervised learning, unsupervised learning, deep learning, and reinforcement learning, have shown tremendous potential for improvement in the accuracy and speed of predictions on climate change. For example, convolutional neural networks (CNNs)-deep learning networks are appropriate for carrying large-scale spatial data interpretation; recurrent neural networks (RNNs), in turn, produce time-dependent processes like the variation of atmospheric temperature and precipitation patterns. These artificial intelligence models forecast temperature changes, extreme weather events, rise in sea levels, and any significant environmental indicators regarding climate change. Such models have been particularly useful for short-run predictions, such as predicting intensity and frequency of extreme weather events, as well as for long-run projections, such as changes in global temperature over a span of decades to centuries. AI can thus help in the integration of data at different scales and from different sources to develop a more integrative and representative climate model that would accurately depict future climate scenarios. One of the most important advantages gained by combining AI and mathematical modeling is that model calibration and validation can be significantly improved. AI-based optimization techniques like genetic algorithms and particle swarm optimization will be employed to better fine-tune the parameters of mathematical models toward more accurate prediction. Some significant advancement still comes with numerous challenges for the effective application of AI in climate change prediction. These include the difficulties of drawing useful information from current underlying climate systems; the incapacity of current quality and availability in data; and the pressing needs for interpretability and transparency in such models.

Thus, collaboration needs to be sustained among climate scientists, mathematicians, experts in AI, and policymakers to make efficient AI-enhanced models of the climate, one that is accurate, ethical, as well as reliable. Modeling has a promising future in climate applications when combined with AI. Combined with the analytical power of mathematical modeling, AI will give a person much-touted computational prowess to improve predictions and, most importantly, understand the underlying mechanisms of climate change. These technologies will usher in n, times to come, a role of even larger magnitude in determining global responses to combating climate change as well as adapting to its derivative impacts. Continued collaboration between them will be central in producing action-oriented insights for a more sustainable and resilient future.

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1. INTRODUCTION

Climate change possibly now the greatest threat facing humanity because of its implications for ecosystems, human societies, and economies. Indeed, the health of the entire global system is undermined through increasingly higher concentrations of greenhouse gases in the atmosphere. The activities include the combustion of fossil fuels along with deforestation and industrial processes. Shifting weather patterns with rising temperatures and increased numbers of extreme events have been observed around the world due to these drivers. Their effects have consequences, changing natural ecosystems, contributing insecurity to food, water supply, health, and infrastructure. This necessity has never been as urgent as now, given these understood challenges, for accurate, timely, and action-oriented predictions regarding future trajectories of climate change. Traditional approaches, which rely on physical equations and observational data, have proved quite successful in providing much insight regarding the dynamics of the Earth's climate system.

However, they tend to falter under the inherent complexity and uncertainty of climate processes, particularly at global and most regional scales. Increasing data generated through satellite observations, climate sensors, and historical records combined with improvements in computational power thereby offer new opportunities for enhancement of our abilities to predict and understand climate change. All these efforts make of mathematical modeling the key tool in climate science. Mathematical models seek to simulate the behavior of the climate system using equations together with some artificial simulations. Such simulations take into account all factors such as atmospheric dynamics, ocean currents, various energies coming into the system, and the interactions among all the Earth system components. These models have become vastly more sophisticated with the last few decades events, now accommodating many more variables and feedback mechanisms innate to climate behavior. Hypothetical mathematics has harvested quite an importance in long-term trends in climate above some information now regarding these models with some limitations in terms of complex non-linear interactions. More prominently, perhaps, is the uncertainty in models'- prediction, which is from insufficient resolution of data, incomplete process understanding, and chaotic climate behavior. Such challenges mean that there is still the searching for more innovative entities to take up or complement the roles that more traditional climate models have played in making predictions more certain and dependable. AI, mainly ML, is perhaps really a good prospect tool in addressing some of these interests on the use of traditional climate modeling. Machine Learning Algorithms learn from patterns rather than from mathematical formulas in data; hence, they do not require explicit mathematic equations to make their predictions, modeled outputs, or even collected data analysis. Since huge data processing determines the coming generation of technology used by AI in unraveling more complexities and finer details of the climate system compared to other models, machine learning models possess the capability of assimilating dissimilar data, such as satellite images, climate models, and sensor data, in order to build a prediction that is much faster and more accurate. This is especially important for short-term prediction of phenomena like extreme weather events which impact society and involve forecasted occurrences such as the frequency and intensity of extra tropical storms, floods, droughts, and heat waves, etc. In a much longer time frame, such models can complement existing mathematical models to provide predictions about changes in global temperature, rise in sea levels, and other climate indicators over decades or centuries.

2. LITERATURE REVIEW

The joint consideration of Artificial Intelligence (AI) and mathematical modeling in climate change prediction has attracted serious interest in recent years because of the increasing imperative for more accurate, compatible, and prompt climate predictions. The scariness and uncertainties built within the climate system are incredibly complicated; thus, traditional methods such as these, which are based on physical equations and empirical data, are unable to address the issues concerning the change in climate. Consequently, AI and machine-learning (ML) techniques are seen to be promising ways forward for improving the predictive quality of climate models. This review of the literature presents the most recent research developments published on AI and mathematical modeling applications in climate change predictive research with a specific focus on their joint applications or integration, advances, and possible advantages. So-called climate models, such as General Circulation Models (GCMs), have proven irrefutably useful for predicting longer-term averages of global temperature change, sea-level rise, and other climate-associated variables (Houghton et al., 2001). However, considerable limitations handicap such models, notably resolution, cost of computation, and uncertainty in the representation of processes, which are complex, such as the realizations of cloud formations and ocean currents (IPCC, 2021). Tooe abduction that brings the activities of these bounds and destroy these limits. In effect, this research is beginning to embrace AI techniques that will complement traditional climate models to make them less predictive and more enabling their applications. This promise has been just towards machine learning in artificial intelligence. It can be said that artificial intelligence in all its aspects is working or working to show its worthiness in the prediction of climate change.

Within this context, machine learning-supervised learning and unsupervised learning-such as deep learning-allow a model to learn from large datasets and improve its predictions without relying entirely on physical equations. For example, deep learning networks such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have been successfully trained with climate data to discern patterns and make predictions concerning temperature changes, precipitation, and extreme weather events (Rolnick et al., 2019). CNN has been useful in the processing of spatial data covering a diversity of input datasets, including satellite image data, while RNN claims being very credible in the representation of temporal aspects such as seasonal variations in weather (LeCun et al., 2015). One of the hottest topics is the application of AI to modernize calibration and optimization methods used in traditional climate models. Most climate models are very much dependent on the input parameters so that a slight change in any of these parameters will cause a large difference in output.

Such uncertainty in output predictions can be eliminated by AI-based optimization techniques such as genetic algorithms and particle swarm optimization, which have been applied in adjustment of these parameters (Kiani et al., 2021) for reducing uncertainty in climate predictions. Machine learning algorithms could help uncover relationships and trends that are hidden in the data and could facilitate finding perspectives that would never be possible on traditional terms. AI has for instance been used in processing satellite data, e.g., sea surface temperatures and atmospheric carbon dioxide levels, for the improved predictability of some climate phenomena like El Niño and La Niña events (Hassanzadeh et al., 2017). It has also coupled artificial intelligence with climate models to provide actual or real-time updates regarding extreme weather such as hurricanes and floods, which further better preparedness and response strategies in the event of impending disasters (Reichstein et al., 2019). Several challenges still lie ahead, however, in using AI and mathematical modeling for climate change predictions. These include the main unease about interpretability and transparency of AI models themselves. While machine learning algorithms can perform accurate predictions, very often they belong to the category of "black boxes," whereby the reason for prediction cannot be well understood by human beings. This is a huge disadvantage, especially for climate science practices where model-based decision making can have far-reaching effects in society at large. Action is on-going towards constructing explainable AI models that would prove to be much more interpretable while still being able at predictive power (Ribeiro et al., 2016).

Researchers use AI model calibration to make better simulations of future climatic conditions which are very important in taking informed decisions about climate mitigation and adaptation strategies. AI has improved the accuracy of the models and has further been integrated into post processing the analysis of huge volumes of data generated by the simulations and observation sources in climate science.Integrated AI and climate models to provide real-time forecasts into extreme weather events consisting of hurricanes and floods will improve disaster preparedness and response strategies that will have to be adapted to the occurrence of these disasters (Reichstein et al., 2019).

Many challenges still exist in the application of AI and mathematical models for predictions related to climate change. Some of the major concerns have been as regards to the interpretability and transparency of AI models themselves. Although machine learning algorithms can make accurate predictions, they frequently tend to operate in the black box mode, which means their predictions normally are not going to be well-understood by human beings. This poses quite a complication in the case of climate science practices where decisions based on the model-made predictions fairly affect society as a whole. At present, some work is going on to develop explainable AI models proving to be much more interpretable while still being able at predictive power (Ribeiro et al., 2016). Another hassle is also the quality and availability of climate data. AI needs a large number of high-quality datasets to be trained properly, and gaps in data—especially from less represented regions—hinder accuracy in their predictions (Foley et al, 2020).

Potentially a lot has to be explored by AI and mathematical modeling to contribute towards climate change mitigation and adaptation strategies. Collaboration amongst climate scientists, data scientists, and policymakers will be the continuing support to ensure both effectiveness and ethical use. Future directions of climate science in which AI and mathematical modeling are applied will prove hopeful. Although numerous hurdles still exist, the promise of these technologies in enhancing prediction for climate and aiding mitigation and adaptation efforts toward climate change is quite great. The continuing progress in research will increase the importance of AI and mathematical models in addressing global strategies in dealing with climate change challenges.

3. METHODS

It involves combining advanced computational methods with machine learning algorithms but also marrying existing physical climate models to increase the accuracy, speed, and robustness of climate predictions as far as possible in dealing with the complex global nature of climate dynamics and high uncertainty in the very nature of climate systems themselves.

- **Mathematical Modeling**: Climate change forecasts are constructed on mathematical models which replicate the functioning of the climate system of the Earth with its differential equations to achieve its atmosphere, oceans, land, and ice interlinks. Among the most extensive mathematical models that are popularly used in climate science are General Circulation Models (GCMs). The GCMs offer climate projections of a future course concerning physics-based principles such as energy balance, heat transfer, and fluid dynamics. In GCMs, the Earth surface is divided into grids and equations representing various processes are envisioned to be solved at each grid point (Houghton et al., 2001). These models will also enable long-term climate trends, including temperature changes, precipitation levels, and sea level changes. Nevertheless, they will have limitations with respect to the spatial resolution and computational cost as well as a model's inability to address local processes whose control area can be of smaller density, such-impact localized cloud formation or convection-being significantly affecting climate predictions.
- **Machine Learning Integration**: Using machine learning with AI provides substantial enhancement to the limited traditional climate models. The algorithms create Machine learning learn from massive datasets and use them to capture complex patterns that are often hard to encompass through physical models alone. A great variety of machine learning techniques such as supervised learning, unsupervised learning, and deep learning, are therefore employed in processing and analyzing climate data. Supervised learning is one of the most commonly used techniques, where an algorithm is "trained" on a historical climate dataset (which includes such variables as temperature, precipitation, and sea level) to enable the prediction of future climates. In most cases, relationships between climate variables could be modeled using techniques like linear regression, support vector machines (SVM), or decision

trees (Jin et al., 2020). Deep learning, more specifically through deep neural networks (DNNs) or convolutional neural networks (CNNs), also began receiving attention as an additional option for analyzing high-dimensional datasets, such as those satellite images and other remote sensing information, to help understand several climate phenomena, including extreme weather events and long-term temperature trends (Rolnick et al., 2019).

- **Model Calibration and Optimization**: The uncertainty of model parameters is the greatest challenge for climate modeling. Only a little deviation in the input variables can lead to significant differences in output predictions. Therefore, machine learning techniques are being increasingly used to tune and calibrate the different climate models. Optimization methods, such as genetic algorithms (GAs), particle swarm optimization (PSO), and Bayesian optimization, serve as techniques to adjust the parameters of mathematical models to best fit observed data (Kiani et al., 2021). Optimization methods are searched for an optimal set of parameters that would minimize the difference between model predictions and the most reliable observed climate data. Genetic algorithms use principles of natural selection to iteratively evolve a population of candidate solutions, and particle swarm optimization implements movement of particles. Some of the main advantages of combining state-of-art optimization techniques with conventional models are reduced uncertainty in climate projections and improvement in reliability of predictions.
- **Data Fusion and Multi-Scale Modeling**: AI can be brought in as an important player for the challenges of their very data-hungry requirements in the integration of data originating from multiple sources and scales. One way in which climate models get comprehensive insights regarding the dynamics of climate is integrating data losses with satellite, ground, and climate simulation ones. However, many of them are often incomplete or present measurement errors, and these gaps may lead to uncertainties in the predictions. Methods such as ensemble learning and data fusion-the techniques of machine learning-optimized for the quality and accuracy of the predictions related to the climate by combining pieces of data collected from varying sources into making even better predictions. The ensemble method referring to, for example, often combines predictions from different models to take into consideration the uncertainties of each model and would deliver a more certain forecast (Hassanzadeh et al., 2017). Through fusion, these concepts come into contact with one another and hence have the ability to bridge those gaps from different spatial and temporal scales in climate modeling and accept multi-scale climate

model-the regional-global-local specific integrated predictions- for the better prediction in terms of specificity and accuracy.

- **Extreme Weather and Event Prediction**: Apart from these two areas, AI and mathematical modeling are also useful for predicting extreme weather events such as hurricanes, heat waves, and floods, which all occur more frequently and with greater intensity due to climate change. Reliable predictions are needed to meet the disaster preparedness and response. For the extreme weather prediction, machine learning-algorithms are used, mainly involving deep learning patterns such as recurrent neural networks (RNNs): Historical data on storm trajectories, temperature anomalies, and atmospheric conditions have been analyzed. Reichstein et al., 2019. RNNs are best suited because they can capture the dynamics over time, as they permit modeling temporal dependencies. In addition to that, AI models can predict the frequency and severity of extreme events on the basis of different input variables, which would improve the early warning systems and requirements for emergency response plans.
- **Uncertainty Quantification and Risk Assessment**: AI-based opening letters are an important factor in climate change modeling. Now-a-days, AI techniques are becoming more and more widely used to assess the uncertainty in climate forecasts and to create assessments dealing with the risks of various climate scenarios. The most frequent applications wherein Bayesian methods, Monte Carlo simulations, and uncertainty propagation techniques are used include the evaluation of the range of possible outcomes and evaluation of the likelihood of extreme climate events (e.g., Foley et al., 2020). AI models that incorporate uncertainty in climate predictions deliver more robust assessments of climate risks critical for decision-making regarding climate policy as well as resource planning and disaster preparedness.

Diverse and constantly evolving is the methods for integrating AI and mathematical models into the climate prediction context. However, some areas where the functions converge in improving prediction quality and reliability remain: machine learning techniques, model optimization, data fusion, and uncertainty quantification. It is expected that these methods will soon get perfected or further advancements given the tendency of technology to grow and offer more increased capabilities, at least in their use against the incursion of otherwise onerous climate change effects.

4. FUTURE CHALLENGES AND DIRECTIONS

However, the very promise of AI and mathematical modeling in climate change forecasting remains unfulfilled because several issues confound their logic. Issues such as technical, ethical, and practical aspects will especially influence the future direction of this field. Overcoming these barriers requires continued advances in AI technology, improved inter-scientific cooperation, and strong political frameworks to ensure future effectiveness in energy actions with such technologies. Data quality and availability is one of the biggest challenges. Extensive and diversified datasets including satellite images, weather stations records, data from remote sensing and historic climate records are the backbone for climate models. Gaps in these datasets, especially from ill-developed or remote areas, tend to downgrade the accuracy and reliability of predictions made with AI. Some data are usually incomplete, inconsistent, or faulty, making it difficult for machine learning algorithms to harmoniously generate precise forecasts. Future research must focus on improving data collection methods, better resolution, and development of gap filling through data fusion and imputation, to this end. Besides that AI models also required extreme computational power for handling processes and analysis of such huge data, which will be the limiting factor for a long time to implement them widely. Another aspect that has challengeability is the interpretability and transparency of AI models. Most of the machine learning algorithms, especially deep learning models, are regarded as black boxes since it is not easy to know how they arrive at the particular prediction. In climate science, this dearth of transparency is much more troubling. Decisions based on model outputs will make it more necessary to evaluate how techno-economic choices will have effects in social and political senses well into the future. Increased investment in the area of research for develop- consummating explainable AI (XAI) will ensure that AI models can be made interpretable alongside their winning predictive performance. As a result, it will be possible to have climate scientists, policymakers, and the public trust and understand AI-enhanced predictions.

5. APPLICATIONS OF AI AND MATHEMATICAL MODELING IN CLIMATE CHANGE PREDICTION

The convergence of Artificial Intelligence (AI) and mathematical modeling has brought about groundbreaking strides in climate change predictions, rendering ways that are otherwise impossible to grasp the complexity and uncertainty of climate systems. With the use of AI techniques, especially with machine learning

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(ML) and deep learning, one can rightly refer to improved models of climate trends long and short-term predictions of a wide range of extreme weather events. Such applications therefore find immense use in climate change mitigation, adaptation strategy, and capacity building for disasters and calamity preparedness; assisting in giving decision-makers fine tip information on how climate change will influence different parts and many communities. The main applications of AI and mathematical modeling in climate change prediction include longer-term forecasts in global climate trends, such as increases in temperature and sea level, and changes in patterns of precipitation. Traditionally these phenomena were modeled within the framework of General Circulation Models (GCMs), which syntactically define the Earth's climate using physical equations. However, such approaches often suffer from low resolution and the high cost of computation. AI-driven models, especially those adopting deep learning and associated techniques, can adequately complement GCMs by evaluating and identifying the complex patterns and trends sometimes obscured in vast historical climate datasets. Regression models, decision trees, and neural networks are some examples of machine learning algorithms that can be implemented to predict future anomalies in temperature, precipitation, and climate shifts at a more localized scale (Rolnick et al., 2019). This proves particularly beneficial when scoping regional climate dynamics and also critical in the forecasting of particular areas on how they will experience climate change differently, such as heatwaves in some areas or rainfall in others. AI-enhanced models are useful not only in terms of their benefits for long-term climate trend predictions but also for predicting severe weather events such as hurricanes, floods, and droughts. These extreme events have increased in both number and severity owing to climate change; hence a reliable prediction is essential in disaster preparedness and response.In fact, such AI applications, especially deep learning methods that promise the best results, like Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), suck masses of data such as satellite images and weather station data, determining even the minutest factors onsets of extreme weather events.With the assistance of real-time data, these models can predict the formations and intensities of hurricanes, specific areas of the flood threat, and possibilities for heatwaves. AI models give more accurate forecasts, allowing administrations and organizations to adopt intervention measures before saving lives and minimizing economic damage (Reichstein et al., 2019). In addition, renewable energy systems are optimized with AI for minimal carbon emissions and for the most possible ways of improving mitigation against climate change. Machine learning algorithms are largely employed in prediction and subsequently grid control regarding regulation in renewable energy; it is a wind and solar grid application. By improving energy efficiency in buildings, industrial processes, and transport, less carbon could be emitted through the application of AI applications. With regards to the captured carbon technologies, AI applications can help find the most efficient means of capturing and storing carbon dioxide from burning fossil fuels to contribute to global actions against climate change impacts. Furthermore, AI could be applied in climate adaptation strategies since it could locate vulnerable areas and communities most likely to be affected by climate change. Based on the socio-economic and climate projection data, AI models identify the most vulnerable areas that would likely experience changes in sea level or extreme weather events. Policymakers can thus prioritize adaptation and direct resources towards the area's most needy. For instance, there is the possibility of using AI to optimize water management systems in drought-prone areas or plan the relocation of populations at risk of rising sea levels. In fact, AI and mathematical modeling have been revolutionizing the prediction of climate change, which is becoming more accurate and efficient with time and increasingly timely in climate trends that are expected over the long-term and extreme weather events expected over shorter timeframes. Such progress is key to bringing mitigation against and adaptation to climate change, from optimizing renewable energy systems to improving disaster preparedness through vulnerable-population safety nets. As AI methods evolve, so will their power to provide concrete beginning points for action by climate policy and strategy and in response to the global challenges posed by climate change.

6. CONCLUSION

Integration of Artificial Intelligence (AI) with mathematical modeling has contributed significantly to improving the qualitatively quantitative data by predicting and modeling the impacts of climate change. With the accelerating rate of change-taking place due primarily to anthropogenic activities such as deforestation, fossil fuel consumption and industrialization, the demand for precise, timely and actionable predictions on climate has arguably been at its highest. Traditional climate models, including General Circulation Models, have been great tools to represent long-term trends and dynamics in climate conditions. However, such models suffer from issues of computation costs and resolution constraints that do not allow for local-scale processing, making it extremely difficult for precision and location-specific predictions. By analyzing large and complex data sets with its inherent capabilities, AI offers a robust solution for enhancing accuracy speed and reliability in producing climate predictions. AI-based techniques like machine learning and deep learning hold bright promises for improving climate model accuracy because they are capable of deciphering patterns and relationships from voluminous data that traditional forms of understanding do not achieve. Machine learning algorithms are now widely used to calibrate and optimize mathematical models; reduce the uncertainties in climate projections and predict even extreme weather events with higher precision. These applications, in fact, have created scope for greater enhancement in countering the emerging threats of climate change, from higher-than-normal average temperatures to variability of weather forecasting, from rising water levels to increased intensity and frequency of natural disasters. AI can have the potential to change the future because it provides more accurate and timely predictions because of modeling toward which governments, organizations, and communities can better prepare for and mitigate risk. Flashing forecasts are just an application of the AI magic wand. No less important are its applications, within the scope of climate change mitigation-adaptive renewable energy systems, energy efficiency, and carbon capture and storage developments. These AI-based approaches are also proving to be useful in climate adaptation strategies by helping identify the most vulnerable areas and communities likely to be affected by climate changes. Such identification could help policymakers and planners in targeting available resources for interventions that will bring maximum effectiveness in reducing risks and increasing resilience to climate change. However, notwithstanding such advances, there are many hurdles to some extent. One of the critical issues being data quality and availability pertaining to underdeveloped regions where scanty and unreliable climate data do exist. Furthermore, AI models are treated as "black boxes," which is why it has become increasingly difficult to tell how they constitute predictions. This lack of transparency can detract from trust in those models whenever there is severe consequence attached to an inaccuracy in their predictions. In addition, the uncertainty in climate systems poses many other challenges for AI since future climate scenarios would not be predictable internally. Ethical issues, regarding the fairness and impartiality of these AI models, will be very important because the just prediction and, inaccurate prediction will have an adverse effect on the vulnerable communities. All in all, the approval of AI with mathematical modeling into one joint innovation is really groundbreaking in predicting climate change. While the complete fictionalization of AI requires much more extensive and constant research and interdisciplinary cooperation, the clarity of the issues associated with data quality, model interpretability, and ethical consideration is shaping the contours of a potential pathway through which AI may become an increasingly useful weapon in the fight against climate change and for the more sustainable and resilient future of all. Over time, the growing prowess and increasing sophistication of AI techniques are likely to make their role ever more significant in matters of climate policy, decision making, and global climate action.

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