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AI-DRIVEN SOLUTIONS FOR CLIMATE CHANGE: FORECASTING AND MITIGATION APPROACHES

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***Abstract*—** Artificial intelligence (AI) is increasingly being used across various domains, including data management, predictive analysis, and disaster preparedness, helping people navigate and mitigate potential risks. It also offers multiple solutions to select the most appropriate course of action. Governments and companies worldwide are implementing initiatives, programs, and frameworks aimed at achieving common goals, such as combating climate change and minimizing the impact of natural disasters. This post examines recent AI developments aimed at slowing global warming.

AI technologies and methods are being explored to tackle the complex issue of climate change. Extensive research over the past few years has highlighted AI's potential in reducing climate-related risks. AI-based solutions in energy, manufacturing, agriculture, forestry, and disaster management can significantly enhance climate change adaptation and mitigation efforts, making them a crucial tool in research, engineering, and policymaking.

Given AI's growing role in climate action, especially in India, it's essential to assess i

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I. INTRODUCTION

Extreme and unpredictable changes in the climate are a cause of serious concern globally today. In India, the impact of climate change is already profound. Moreover, several recent reports, such as the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2022: Impacts, Adaptation and Vulnerability", have warned of increased risks to the lives and livelihoods of people—besides the growing threat to natural habitats—from the recurring climate variabilities. [1] This calls for urgent nationwide measures to mitigate the adversities, as well as to enable adaptation. Among the many approaches, strategies, and technologies that are being explored to tackle the complex problem of climate change, the use of artificial intelligence (AI) [1] is gaining prominence. It is, indeed, an appropriate time to utilize AI to predict, evaluate, and assess the risks and uncertainties associated with climate change, to strengthen climate action in India.

Artificial Intelligence and Its Emergence

Prominent computer scientist and inventor John McCarthy, widely recognized as the "Father of Artificial Intelligence", described AI as the "science and engineering of making intelligent machines, especially intelligent programs". His vision and ideas changed the global dynamics in the field of technology and sparked off international debates, policy dialogue, and deliberations related to the use of technologies (AI, machine learning, computer vision, and internet of things) for data analytics, predictions, and forecasting.

In India, the growth of AI deployment can be interpreted as an S-shaped curve, manifesting a relatively slow beginning but steady gradual acceleration, owing to rising global competition and increasing awareness. AI can accelerate economic growth by enabling automation of complex real-world tasks across industries, complementing human capabilities, improving capital efficiency, and propelling innovation.

The reported statistics and data projections on AI's potential for boosting economic growth and employment generation in the country are promising.

Climate Change and Its Impact

With more than 80 % of its population living in districts that are highly prone to extreme hydro- met disasters (Mohanty & Wadhawan, 2021), India's vulnerability to climate change is extreme. The country's growth is intricately linked to climate risks, with a direct bearing on sustainable development and investment efforts.[2] Besides threatening investments in infrastructure (such as housing, transport, and industries), especially along the coasts, climate risks have a disproportionate impact on vulnerable communities with low adaptive capacities, posing a critical threat to India's sustainable development (Mohanty & Wadhawan, 2021).

Like most countries, India has been struggling with intensifying climate change. This year (2022), the country went through one of the most intense heatwaves in decades. The year has already seen cyclone Asani claim several lives and damage thousands of acres of horticulture, paddy, and other crops across Andhra Pradesh; and extreme rainfall trigger floods and landslides in the Northeast, claiming lives and livelihoods and causing widespread destruction of crops and infrastructure.

Contributions of artificial intelligence to climate science

Artificial intelligence (AI) is making important contributions to the scientific understanding of climate change. [3] While AI applications are still in relatively early stages of development, the progress to date suggests real opportunity for better monitoring of anthropogenic climate impacts, better understanding of how the Earth's climate is likely to evolve and better predictions of climate impacts.

Improving climate model performance

The best scientific understanding of climate dynamics and forecasts of climate impacts are based on computer simulations of complex climate models. To validate these simulations, their results are compared across models ("model intercomparison") and to historical actual weather data ("hindcasting").[4] AI can help improve this comparison process, identifying biases in specific models and extracting the most useful physical results from increasingly massive amounts of climate model output data.

AI can also complement conventional physics-based climate modeling in hybrid approaches, dramatically reducing the need for certain very intensive computations or improving the resolution of model outputs [5]. In some cases, AI can analyze the voluminous output of high-resolution climate models and assess potential biases in their predictions. A Stanford study using AI to analyze maps of temperature anomalies, for example, suggested that climate models underestimate the average rate of warming and that temperature increases are likely to exceed 1.5 °C by 2030–2035. Already, AI has improved both the pre-processing and post-processing of climate models and numerical weather prediction.

A potential drawback of incorporating AI into climate simulations is less reproducibility (meaning that calculations cannot necessarily be repeated and arrive at essentially identical results). The complexity and probabilistic nature of some AI and machine learning (ML) techniques make this more challenging.

II. ARTIFICIAL INTELLIGENCE FOR CLIMATE SECURITY

Climate security is a field of research and an area of policy that focuses on the impact of climate change on peace and security. Research to date has established that the current climate crisis has significant implications for peace and security especially in conflict-affected and fragile countries. Climate change increases the intensity and frequency of extreme weather events, affects long-term climate trends, and accelerates environmental degradation.

These physical changes can, in turn, be the source of dramatic societal disruptions and insecurity at various scales. For example, they can cause livelihood conditions to deteriorate and expose vulnerable populations to food insecurity. As well as triggering mass migration, the adverse impacts of climate change on livelihood and food security can generate or amplify sociopolitical grievances, which can be exploited by political elites or armed groups.[7] This set of interconnected challenges is captured in the term 'climate-related security.

The role of AI in predicting to the impacts of climate change

In Angela Merkel's words, "Climate change knows no borders. It will not stop before the Pacific islands and the whole of the international community here has to shoulder a responsibility to bring about a sustainable development.". Climate change is a global problem and call for a knowledgeable response from all countries in order to be effectively addressed. Considerable attention has been given to climate change by the scientific community, government bodies and the public media. However, many issues are not fully understood. It is important that the professional operational community of meteorologists, hydrologists, and oceanographers become more knowledgeable on this subject in order to monitor climate change and incorporating its perspectives into their own work, to help governing bodies understanding the scientific issues, and providing information to the general public.

Prediction of climate change

Scientists have developed several computer-run simulations, or models, that combine and express in mathematical form what we know about the processes that control the atmospheric and hydrologic systems. [8] The most advanced climate models are called General Circulation Models, or GCM's. These models are the primary tools used by scientists to try to predict the impacts of increased greenhouse gas concentration .[6] The strength of these models is their ability to replicate input-response activities and relationships within complex systems that are far too elaborate for simple interpretation or logic. They have the ability to integrate various feedback processes in order to determine their effects on overall impact, and quickly generate different scenarios under varied assumptions about human activities.

To predict climate change, various means are possible. Based on the existence of climate change related to human activities, the IPCC (Intergovernmental Panel on Climate Change) has created a number of emission scenarios, called the

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RCP (Representative Concentration Pathway). [9] Their purpose is to obtain a simple but possible representation of the future world on different aspects. They are based on assumptions about the evolution of the "driving forces" determining greenhouse gas (GHG) emissions.

Understanding and predicting the impact of climate hazards

Climate change will increase the frequency and intensity of natural disasters, with their consequent political, economic and social impacts. These impacts could exacerbate existing conflict risks and escalate social tensions, potentially leading to an increased likelihood of conflict and violence. Modelling climate hazards and forecasting climate change-related disasters and climate variability are, therefore, crucial steps for effect- ively managing climate-related security risks. In this context, AI holds great potential, as it is able not only to help predict climate hazards but also to assist humanitarian responders to plan timely interventions either in the form of preventive measures or humanitarian relief.[8] This section covers these two aspects, starting with how AI can help with early warning of near-term hazards, then looking at forecasting long-term climate trends.

III.HIGH-POTENTIAL OPPORTUNITIES

Greenhouse Gas Emissions Monitoring

Good information on the sources of greenhouse gas (GHG) emissions is essential for responding to climate change. Accurate and timely data are needed to design mitigation strategies, prioritize abatement opportunities and track the effectiveness of climate policies.[9] Historically, however, data concerning sources of GHG emissions have often been partial and approximate, with significant time lags. [10] In many cases, a lack of definitive information on GHG emissions has been an important hurdle to climate action.

Artificial intelligence (AI) is helping to address this challenge. AI tools can analyze vast amounts of data from Earth-observation satellites, airplanes, drones, land-based monitors, the Internet of Things (IoT), social media and other technologies. This capability dramatically improves our ability to monitor GHG emissions from specific sources accurately in near real-time.[11] AI-enabled emissions monitoring has the potential to accelerate climate mitigation in many areas.

Incumbent GHG emissions monitoring

Scientists began regularly measuring GHG concentrations in the atmosphere in the 1950s. These measurements have shown a steady increase in GHG concentrations (see Figure 2) and have been instrumental in raising awareness of the climate crisis. These data, from ground-mounted instruments and Earth-observation satellites, such as NASA's OCO series and JAXA's GOSAT/IBUKI series (see Figure 3-2), are foundational for climate science.[12] However, they provide very limited or no information on the sources, spatial distribution, timing and rates of GHG emissions.

To understand the sources of GHG emissions, the climate community primarily uses estimated emission factors based on generic categories of equipment and processes.[13] Unfortunately, these emission factors often systematically underestimate real emissions. In addition, the use of emission factors creates no incentive for improving operational performance.

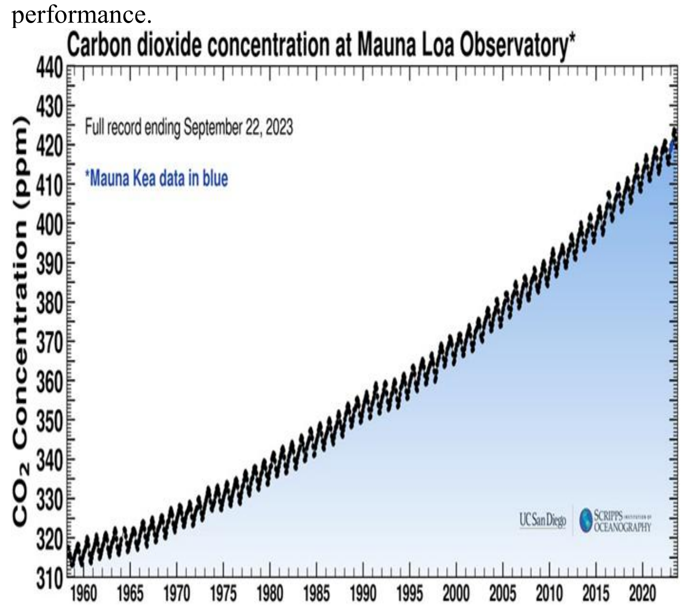

Figure 1. The Keeling Curve, showing measurements of CO2 concentrations at the Mauna Loa Observatory in Hawaii

Different GHGs pose very different detection and measurement challenges.

•CO2 emissions are mainly caused by fossil fuel combustion and deforestation.[14] CO2 emissions from fossil fuel combustion can be estimated with reasonable accuracy using fuel-consumption data, while deforestation emissions can be estimated with a lower level of accuracy using land-use-change data.

•CH4 emissions, in contrast, come from a range of sources (the energy sector, food system and waste management) and are much less correlated with consumption. Energy-related methane emissions are largely avoidable byproducts of fossil fuel production and transport, uncorrelated with consumption rates and very unevenly distributed across fossil-fuel supply chains.

AI-enabled GHG emissions monitoring

The use of satellites, drones and ground sensors to measure GHG emissions at the source has increased significantly in recent years.[15] These instruments produce vast amounts of data. AI technologies are essential to process and analyze these data. Progress on the "software" side—the capacity to process and analyze raw satellite imagery and other data at scale in near-real time—is a critical enabler of advances on the "hardware" side.

Further progress in AI, together with a new generation of satellites, will further improve methane- emissions monitoring and abatement. Progress in real-time carbon-emissions monitoring, as well as in measurement and monitoring of natural carbon sinks—such as vegetation—offers the same potential.

AI has been particularly important in improving methane-emissions monitoring. AI helps to (1) process data from methane sensors at scale, (2) combine input from multiple satellites to overcome each particular satellite's limitations and (3) integrate satellite information with data generated by other types of sensors to build multi-scale monitoring and reporting systems.

Processing data at scale

AI algorithms that process large amounts of remote-sensing data related to methane have been developed by scientists at leading research institutions, including the Netherlands Institute for Space Research (SRON), the French Laboratory for Climate and Environmental Science (LSCE) and the Wofsy group at Harvard University.

AI-enabled global methane monitoring has shown that super-emitters are more ubiquitous than previously thought and that eliminating most super-emitters from the oil and gas industry could be achieved at negligible cost.[16] Eliminating energy-related super-emitters would help significantly reduce anthropogenic methane emissions, which could cut the increase in global average temperatures by 0.3 °C by 2045 and by 0.5 °C by 2100.12, 13 This set of abatement measures—the fastest known way to reduce global warming—is entirely dependent on the use of AI.

IV. AI FOR CLIMATE CHANGE MITIGATION

Artificial intelligence (AI), and machine learning in particular, can improve social and engineering research for climate change mitigation - but considerable challenges lie ahead. We argue that the successful application demands careful design of algorithms and consideration of domain knowledge, calling for engineers that are both trained in statistical machine learning and have expertise in the respective climate change mitigation field.

Mitigation of climate change and Adaptation to climate change

Mitigation and adaptation, these two components of the fight against climate change have often been treated independently of one another.

At first glance, in fact, they oppose terms of reference. One is preventive, the other curative. The necessary strategies lead one to the global management of a global public good and the other to the development of region-wide plans.[17] One is quantifiable with a universal measure - tons of CO2 emitted or avoided - the other is based on various indicators that are difficult to compress to a universal index. One seems urgent: we must reduce emissions now avoid the worst consequences of climate change; the other seems more distant: the most serious effects will take place rather in the second half of the twenty-first century.

A. Mitigation of climate change

According to the UNEP, Climate Change Mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. It can be as complex as a plan for a new city, or as a simple as improvements for a high-tech subway systems or bicycling paths. Mitigation is about addressing the causes of climate change by reducing greenhouse gas emissions that cause global warming. For this, two types of action are possible:

•The first type of action is to reduce the sources of emissions in the various sectors of activity, for example by substituting electric-powered cars to gas cars, by better isolating buildings to reduce their heating requirements, or by replacing electricity production from coal through the development of renewable energies.

•Second type of action: absorb CO2 from the atmosphere by developing "carbon sinks". These can be natural, such as forest, or artificial, like the technology of "carbon capture and storage" which consists of recovering the CO2 emitted in large quantities by heavy industries and storing it underground.

The climate change mitigation requires all countries, keeping in mind their responsibilities and capabilities, to formulate and implement programs containing measures to mitigate climate change.[18] Such programs target economic activity with an aim to incentivize actions that are cleaner or disincentive those that result in large amounts of GHGs.

B. Adaptation to climate change

Climate change exposes economies, societies and ecosystems to serious and very diverse risks. These risks include damage to coastal infrastructure, the evolution of infectious diseases or the degradation of food security. Adapting to the adverse effects of climate change is, along with mitigation, a major area of action for all the countries.[19]The world is already experiencing changes in mean temperature, shifts in the seasons, and an increasing frequency of extreme weather events. These are set to continue, for the global climate system has great inertia. Adaptation is therefore essential.

The Paris Agreement aims to strengthen the global climate change response by increasing the ability of all to adapt to adverse impacts of climate change and foster climate resilience.

It defines a global goal on adaptation – the goal is:

• To enhance adaptive capacity and resilience;

• To reduce vulnerability, with a view to contributing to sustainable development;

• To ensure an adequate adaptation response in the context of the goal of holding average global warming well below 2 degrees C and pursuing efforts to hold it below 1.5 degrees C.

For example, UK launched an adaptation program in 2012, and is taking adaptation measures such as for flood risk management, water resources, freshwater ecology, as the high-priority areas. In the improvement project at the Thames Estuary, the Thames Barrier which expands 18 km has been installed to protect the lowlands from flooding. The gates are closed about 10 times a year during storm surges to prevent flooding.

V. Conclusion

Rapid developments in the use of AI for GHG emissions measurements are opening new opportunities for climate action on many fronts and at many levels. AI-enabled GHG emissions data provide fresh fodder for climate research and may lead to new and more effective climate policies, such as the methane rules currently under development in various jurisdictions.

Improving optimization, such as for planning problems. Many power grid optimization problems involve work with large, nonlinear models. AI can speed computation, improve feature extraction and help solve “optimization unsolvable” problems such as stochastic planning. Data support for these model-based problems is generally less critical than in other areas.

Widening the aperture to include the greenhouse gas impacts of AI applications and broad societal impacts of AI, the uncertainties become even greater.

There is significant potential for the overall greenhouse gas benefits of AI to exceed its costs. This could happen, for example, if strategies for minimizing emissions from AI succeed and some of the emissions-reducing applications of AI discussed in this roadmap deliver significant results. However, the opposite is possible as well. AI could increase greenhouse gas emissions if strategies for reducing emissions from AI fail and applications of AI that increase emissions overwhelm beneficial applications.

As the global economy and population have expanded, energy demand has increased exponentially. Traditional patterns of energy production have proved to be detrimental to the environment, with excessive emissions of harmful gases causing global warming and extreme weather events such as tornadoes, hail, and thunderstorms causing severe damage to human habitats and posing a serious threat to human life and property. Artificial intelligence technology is emerging as a new tool in the energy sector, offering a promising direction for combating climate change to address these issues and mitigate their adverse environmental effects. Artificial intelligence contributes to climate change mitigation in the energy sector by predicting energy demand and enhancing energy efficiency to reduce environmental pollution. Numerous nations use artificial intelligence to improve energy efficiency and reduce energy waste.

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