NEW BUSINESS OPPORTUNITIES EMERGING FROM ADVANCES IN WEATHER AND CLIMATE FORECASTING

— THE FUTURE OF WEATHER AND CLIMATE FORECASTING TRANSFORMED BY AI —

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SUMMARY

- The application of AI to conventional numerical methods has improved the accuracy of weather and climate forecasting, leading to what can be described as a revolutionary leap. Backed by technological development from Big Tech, it is also gaining attention as an advanced information infrastructure.
- Forward-looking companies are moving to incorporate increasingly accurate weather and climate data into their own businesses. In agriculture, it is being applied to yield forecasting, and in the energy sector, to forecast supply and demand for renewable energy.
- Advances in AI-based weather and climate forecasting are seen as a business opportunity, with expectations for business expansion not only within Japan but globally, contributing to a more resilient society.

1. THE REVOLUTION IN WEATHER AND CLIMATE FORECASTING DRIVEN BY AI

Advances in AI technology are significantly transforming the field of weather and climate forecasting. By combining AI models with the numerical simulations performed on supercomputers—used for forecasting since the 1980s—or by using AI models alone, forecast accuracy has been shown to improve. This indicates that regions and communities without access to supercomputers may have greater opportunities to make use of weather and climate forecasting technologies.

1-1. FROM CONVENTIONAL NUMERICAL WEATHER PREDICTION TO AI-BASED FORECASTING

To forecast weather and climate, it is essential to understand atmospheric conditions. In the 20th century, a method was proposed to describe atmospheric conditions by solving equations using variables such as air pressure, temperature, and wind speed. However, in the era before computers, performing such massive calculations was not feasible.

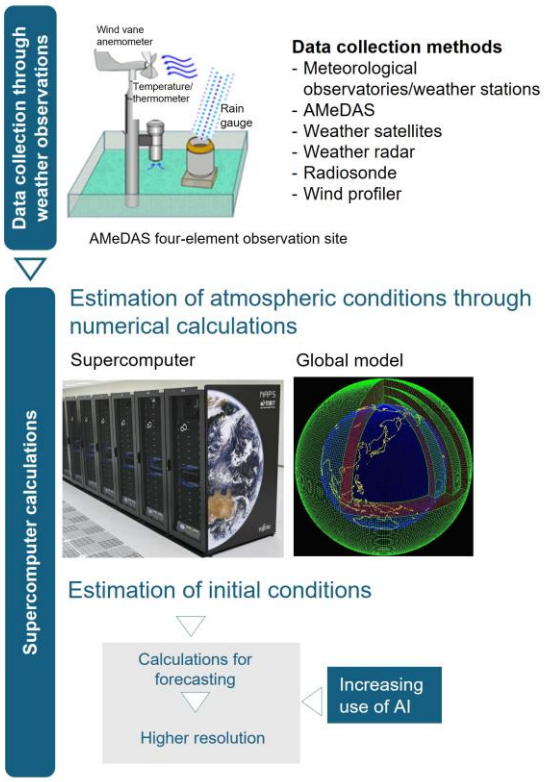
Since the 1950s, the emergence of supercomputers capable of performing massive calculations made it possible to numerically predict the weather by simulating atmospheric conditions through solving differential equations based on physical laws. At the European Centre for Medium-Range Weather Forecasts (ECMWF), a central institution in weather forecasting, around 800 million[1] data points are collected daily from satellites

[1] Key facts and figures | ECMWF

and other sources. These data can vary depending on the manufacturer of the measuring equipment or the installation site. They may also contain anomalies caused by human error. After removing unreliable observations from the collected data, values from the previous numerical forecast model[2] are added and weighted through a process called data assimilation, which generates the initial values[3]. To forecast future weather and climate, physical variables such as temperature and wind speed are calculated by supercomputers. The forecasting model used in this process is called a global model[4]. This divides the atmosphere covering the Earth into a grid in both horizontal and vertical directions and solves the physical equations within each grid cell. Improvements in supercomputer processing power have enhanced forecast accuracy. However, increasing resolution dramatically raises computational costs and energy consumption, making it difficult to generate forecasts at a reasonable cost.[5]

A recent trend in the field is AI-based weather and climate forecasting, which involves creating AI models that predict future weather patterns using existing data (Figure 1). The use of AI is enabling regions without access to supercomputers to obtain high-accuracy weather and climate forecast information.

Figure 1: Process of numerical weather prediction



Source: Compiled by MGSSI based on materials from the Japan Meteorological Agency "2024 Guide to Numerical Weather Prediction," "Glossary: Climate Models," Automated Meteorological Data Acquisition System (AMeDAS), 2024 Press Release, and Philosophical Transactions of The Royal Society A, 2021, Vol. 379 "Can deep learning beat numerical weather prediction?"

1-2. ACCELERATING MOVES BY BIG TECH AND FURTHER ADVANCES

In the development of AI-driven weather forecasting technology, tech companies such as Alphabet (US), Microsoft (US), Huawei (China), and NVIDIA (US) are making notable moves. Research and development gained particular momentum after 2023, when Huawei's AI weather forecasting model, Pangu-Weather, surpassed ECMWF's numerical weather forecasts in both accuracy and speed (Figure 2). Pangu-Weather learns three-dimensional atmospheric data by dividing the atmosphere horizontally and vertically, enabling AI to predict future weather conditions in three dimensions and outperforming previous two-dimensional AI weather forecasting.[6]

[2] This is known as the first guess. https://www.jma.go.jp/jma/kishou/books/nwpkaisetu/latest/1_3.pdf
[3] The initial values are those that serve as the starting point for the next forecast calculation.
[4] A global model is a numerical forecasting model that calculates the atmospheric state of the entire Earth.
[5] Scalability | ECMWF
[6] Accurate medium-range global weather forecasting with 3D neural networks | Nature

Figure 2: Main moves by Big Tech

Year	Alphabet	Huawei	Microsoft	IBM	NVIDIA
2020	Announced Met-Net-1, an 8-hour precipitation forecasting model				
2021	Announced Met-Net-2, a 12-hour precipitation forecasting model				
2022					Released FourCastNet, developed jointly with the UK Met Office
2023	- Announced Met-Net-3, a 24-hour local weather forecasting model - Announced GraphCast, a 10-day global weather forecasting model	- Announced Pangu-Weather, trained on 3D weather data. Forecast accuracy equivalent to conventional numerical weather prediction - Made available on the ECMWF website	Announced ClimaX, a machine learning-based weather forecast	Developed a new AI model for climate prediction with NASA	
2024	- Announced GenCast, a 15-day weather forecasting model - Announced NeuralGCM, a low-computation, high-accuracy weather forecasting model - Announced SEEDS, a generative AI–based model		Announced Aurora AI, a large-scale model for weather and atmospheric forecasting	Announced Prithvi WxC, an AI model for climate forecasting, in partnership with NASA	Announced a digital twin of Earth's climate
2025	- Launched WeatherNext, an AI weather forecasting service for businesses - Released a hurricane-specific AI model, previewed in Weather Lab - Delivered monsoon forecasts to Indian farmers via SMS using NeuralGCM	Announced Pangu models 5.5 and their application in forecasting wind and solar power generation	- Announced the Aurora AI Foundation Model. Generates 10-day weather forecasts in seconds - Announced integration of Aurora into MSN Weather	Announced the AI model "Surya" in partnership with NASA. Predicts how solar activity may affect operations in space	- Announced the AI climate model cBottle - Announced Huge Ensembles (HENS), a machine learning tool for predicting extreme weather

Source: Compiled by MGSSI based on various materials

In 2025, Google Cloud,[7] the cloud computing service division of Google, launched a business-oriented service called WeatherNext.[8] [9] The service provides access to models developed before 2025 by Google DeepMind, Alphabet's AI research and development unit, including GraphCast and GenCast.[10] GraphCast is a deterministic model[11] capable of generating 10-day global forecasts in under one minute. GenCast, on the other hand, can generate 15-day global ensemble forecasts[12] in about eight minutes. Since GraphCast produces only a single forecast, it has limitations in addressing uncertainty beyond the 10-day range. In contrast, its successor GenCast can generate multiple forecasts, positioning it as a complementary model to GraphCast.

Development of foundation models for weather and climate forecasting is also progressing. A foundation model is an AI model pre-trained on global-scale weather and climate patterns, which can be fine-tuned to deliver specific forecasts with high accuracy and low cost (Figure 3). Microsoft's foundation model Aurora has reportedly been able to predict sandstorms in Iraq one day in advance.[13]

[7] Google Cloud Summary | Get started | Google Cloud Documentation

[8] 229 things we announced at Google Cloud Next '25 – a recap | Google Cloud Official Blog

[9] During the writing of this report in November 2025, Google announced WeatherNext2, capable of generating weather forecasts eight times faster than WeatherNext. WeatherNext 2: Google DeepMind's most advanced forecasting model

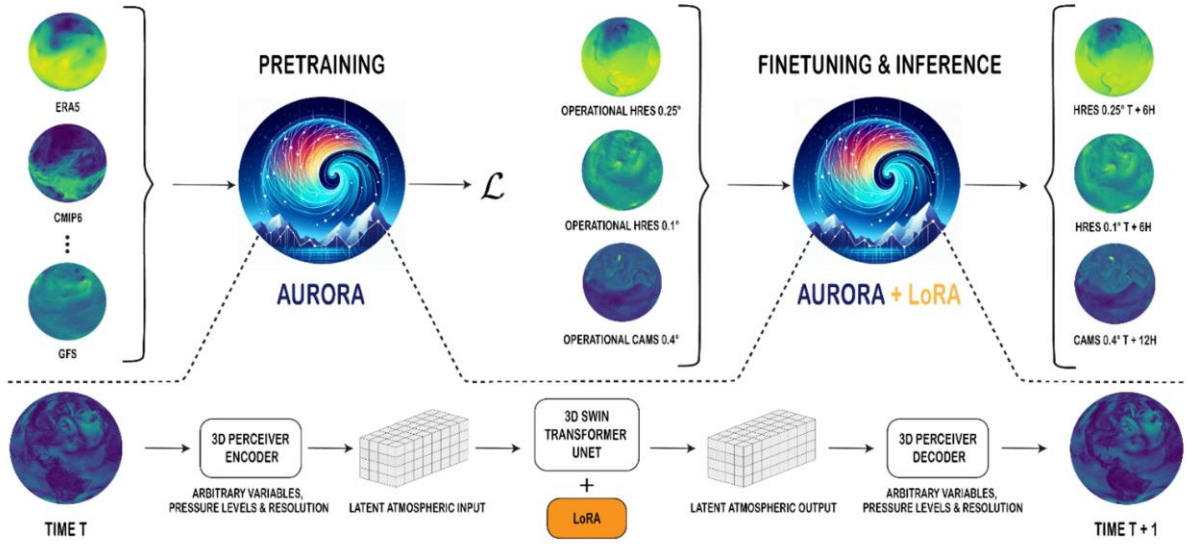
[10] Transforming energy operations with AI-powered weather forecasting | Google Cloud Blog

[11] A model in which the state of the weather is uniquely determined by performing numerical calculations based on physical laws from a single set of initial values

[12] Forecasts are generated using multiple initial values and boundary conditions to obtain multiple predicted values, as even slight differences in initial values can lead to large differences in the forecast results

[13] From sea to sky: Microsoft's Aurora AI foundation model goes beyond weather forecasting - News Center Japan

Figure 3: Aurora (Microsoft's foundation model)



Pre-training
Training on massive amounts of weather and climate data, such as ERA5*
* The fifth-generation reanalysis dataset provided by the European Centre for Medium-Range Weather Forecasts (ECMWF).

Fine-tuning
Adapted for specific tasks and higher resolution using high-resolution data such as HRES**
** One of ECMWF's highest-resolution ensemble forecasting models.

Source：https://www.microsoft.com/en-us/research/project/aurora-forecasting/

In 2025, NVIDIA announced its generative AI foundation model[14], cBottle (short for Climate in a Bottle).[15] Weather forecasting using global models on supercomputers typically requires handling massive datasets of tens of petabytes[16], but cBottle compresses this to roughly one-three-thousandth of that size. The model is trained to generate high-resolution atmospheric states that closely resemble real-world climate conditions from coarse input data at a resolution of about 100 km. As a result, users can generate data at a 5 km resolution using minimal data input. By compressing such massive data volumes, simulations that would take several days on a supercomputer can be completed in minutes.

AI-based weather forecasting systems that do not require supercomputers have also been proposed. To improve the accuracy of foundation models for weather and climate forecasting, such as DeepMind and Huawei's AI forecasting models and NVIDIA's cBottle, it is essential to train the models using large datasets. In principle, the larger the dataset, the higher the forecast accuracy. As a result, training has typically relied on massive datasets processed with supercomputers. In contrast, in 2025, the University of Cambridge announced Aardvark Weather, an AI weather forecasting system that does not require a supercomputer. In research using Google DeepMind's GraphCast and Huawei's Pangu-Weather, the prediction component of conventional numerical weather forecasting is replaced by AI models. However, the data assimilation process preceding the prediction still depended on supercomputers. Aardvark Weather is being developed with the aim of replacing the entire processing pipeline with a single machine learning model. It is already capable of assimilating raw data from satellites and observation stations to generate forecasts. Aardvark Weather has been shown to achieve forecast accuracy comparable to that of the US National Weather Service with just 10% of the data typically required in conventional numerical forecasting.

[14] It is referred to as a generative AI foundation model because it generates physically meaningful climate patterns from coarse data.
[15] New NVIDIA Earth-2 Generative AI Foundation Model Simulates Global Climate at Kilometer-Scale Resolution | NVIDIA Blog
[16] 1 petabyte (PB) is equivalent to 1,024 terabytes (TB).

2. KNOCK-ON EFFECT ON AGRICULTURE AND ENERGY SECTORS

The agriculture and energy industries stand to benefit significantly from advances in weather and climate forecasting technologies. In agriculture, these technologies are increasingly being applied to crop yield forecasting, while in the energy sector, they are especially being used to forecast demand for renewable energy. Leading companies have begun incorporating the information gained from such applications into their own business operations.

2-1. WEATHER AND CLIMATE FORECASTING AS INFORMATION INFRASTRUCTURE

Big Tech anticipates that weather and climate information will become critical infrastructure and is advancing research and development to enhance the value of its own services and products. Google Cloud's WeatherNext is also available on the company's platforms, such as Google Earth Engine[17] and BigQuery[18], enabling it to drive users toward its data analysis and cloud services.[19] For NVIDIA, developing models like cBottle helps demonstrate the importance of its GPUs for high-load weather and climate forecasting, thereby driving demand for its hardware. Institutions like ECMWF, which use supercomputers for weather forecasting, are also beginning to integrate AI through models such as the AIFS (Artificial Intelligence Forecasting System).

2-2. APPLICATION TO RESILIENCE-FOCUSED AGRICULTURE

In agriculture, weather has a major impact on crop yields. Although weather is a natural phenomenon and cannot be controlled, the adverse effects of climate change have reached a level that can no longer be ignored. For example, issues are becoming increasingly apparent in our daily lives, such as rising crop prices caused by yield declines due to abnormal weather events like droughts and heatwaves.[20] As the food and agriculture supply chain grows more unstable, companies are now expected to strengthen the resilience of their own supply chains, as well as follow existing trends such as improving production efficiency and environmental consideration.

Big Tech may further enhance the accuracy of weather and climate prediction technologies in the future. For agribusinesses in particular, gaining access to high-precision forecasts of extreme weather events that could significantly affect crop yields ahead of competitors will become increasingly important. In addition to yield forecasting, these technologies could be applied to irrigation management, inventory adjustments for crop protection and fertilizers, and the development of crop varieties adapted to climate change. Potential users include not only grain traders, agricultural technology providers, trading companies that handle agri-inputs, and seed developers.

As global warming shifts the regions suitable for farming over the medium to long term, such forecasts are also expected to support exploration of new agricultural zones.

ClimateAi[21] (US) provides climate forecasts at a global 1 km mesh resolution, up to six months in advance.[22] In a collaboration with seed company Advanta Seeds (United Arab Emirates), ClimateAi successfully predicted rainfall two months ahead of time and earlier than competing services. This enabled the company to sell seeds before the rainfall and ahead of competitors, resulting in a 5% to 10% increase in sales. In addition, ClimateAi's climate forecasting technology is now being used to estimate the cost-effectiveness of agricultural investments. NEC (Japan) has combined its own agriculture-related data with ClimateAi's long-term forecasting technology, which projects climate change more than ten years ahead. This was used to analyze how adaptation measures

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17 Google Earth Engine

18 BigQuery | AI data platform | lakehouse | EDW | Google Cloud

19 Google Introduces A.I. Agent That Aces 15-Day Weather Forecasts - The New York Times

20 Maximilian Kotz *et al* 2025 *Environ Res. Lett.* **20** 081001, Climate extremes, food price spikes, and their wider societal risks - IOPscience

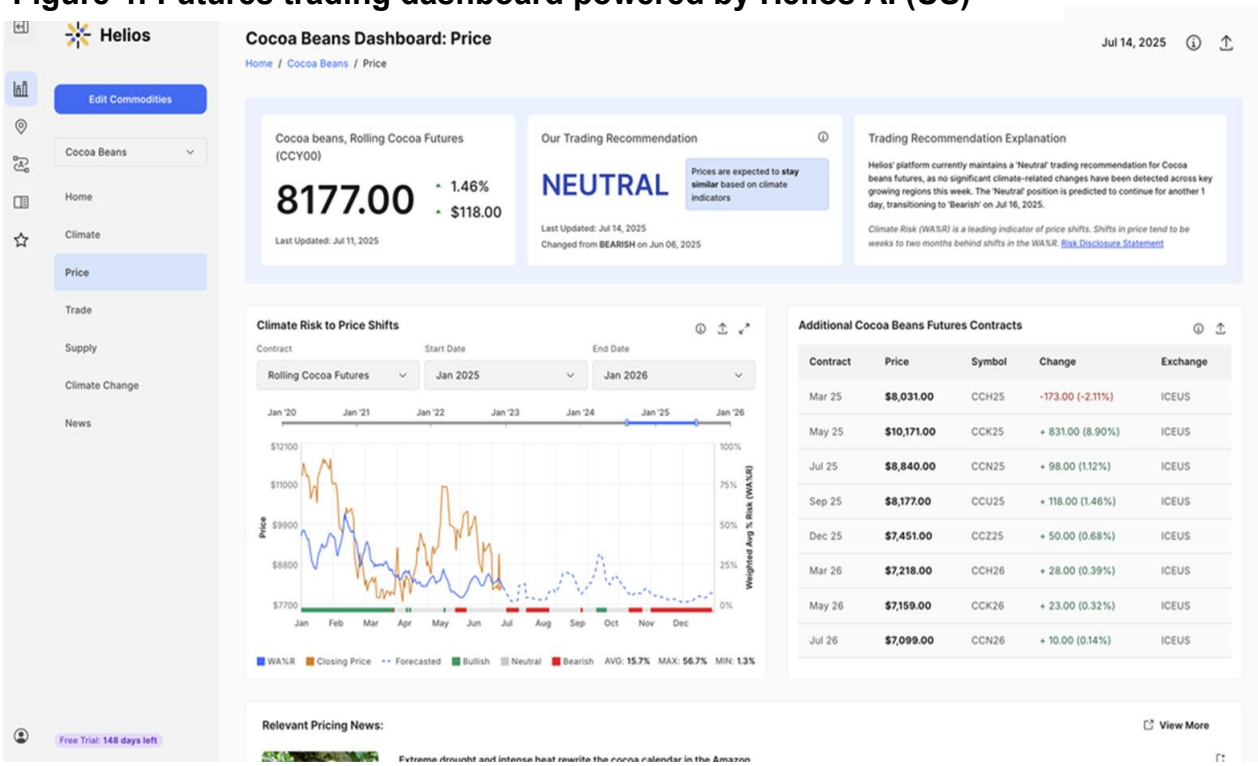
21 Minimize Climate Risk | Maximize Future Opportunities | ClimateAi

22 Examining Hitachi's Global Supply Chain Risk Model Using ClimateAi - Research & Development: Hitachi

such as installing irrigation systems and switching to climate-resilient crop varieties would impact return on investment for cacao and rice cultivation in Africa.[23]

Helios (US)[24] provides a service that forecasts price movements in agricultural futures trading based on climate predictions. In addition to weather data from the past ten years, the company incorporates statistics from the US Department of Agriculture and geopolitical news to forecast prices for 75 different crops (Figure 4). Its platform centers on the supply chain rather than focusing on yield forecasts, and in 2025, a partnership with major US retailer Walmart was reported.[25] With over 4,600 stores across the US, Walmart appears to be aiming to assess climate risks in its increasingly unstable supply chain and stabilize its procurement operations.

Figure 4: Futures trading dashboard powered by Helios AI (US)



Source: http://platform.helios.sc

2-3. ENERGY

The generation output of renewable energy sources such as solar, wind, and hydro is affected by weather conditions such as sunlight, wind patterns, and rainfall. High-precision weather forecasts improve the accuracy of power generation predictions, enabling renewable energy operators to optimize their generation plans and allowing power generation and transmission companies to adjust supply and demand balances more efficiently.

Since 2022, the development of AI-based weather forecasting models and the use of satellite data and IoT sensors have improved the accuracy of localized, short-term forecasts, leading to the emergence of businesses that link weather forecasting with renewable energy operations.

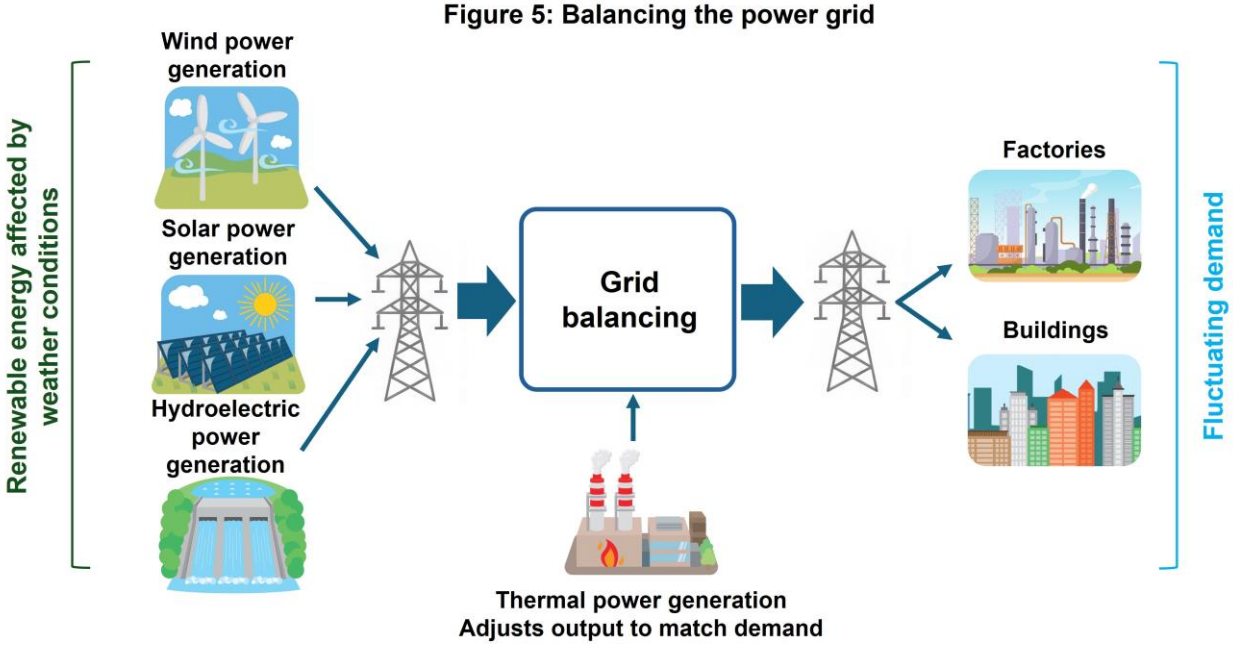
As the share of renewables increases, maintaining the stability of the power grid will become even more important. Power generation forecasts based on high-precision weather predictions will also be utilized for

[23] NEC and ClimateAi Develop Conceptual Model to Promote Climate Change Adaptation in Agriculture: Press Release |NEC
[24] Helios AI
[25] Walmart to deploy AI price forecasting tool | Grocery Dive

managing battery storage, ensuring appropriate operation of thermal power backup, and securing balancing capacity in electricity trading markets to prepare for supply-demand gaps (Figure 5).

Over the medium to long term, these technologies are expected to be used in the energy sector for identifying suitable locations for renewable energy and for addressing challenges associated with the expansion of renewables, such as dunkelflaute[26].

Figure 5: Balancing the power grid



Source: Compiled by MGSSI

Amperon (US)[27] is a company specializing in forecasting electricity supply, demand, and pricing based on weather predictions using machine learning. Founded in 2018 and headquartered in Texas, it operates in North America, Europe, and Australia. The company provides high-precision short-term forecasts ranging from 5 minutes to 14 days for demand, pricing, and renewable energy generation, and leverages real-world data from over 10 million electricity meters as long-term market data. Its clients include electricity traders and renewable power generation businesses, and the company is particularly strong in managing market risk and balancing renewables, storage, and thermal power generation.

StormGeo (Norway)[28] has developed a weather model that trains AI specifically for the early detection of extreme weather events. Data in the range of 15 to 20 terabytes per day is processed to generate forecasts from over 100 weather models based on more than 200 observation inputs. Its proprietary AI weather model uses pattern recognition to predict extreme events such as cold waves and intense high- or low-pressure systems earlier than conventional numerical forecast models. StormGeo provides services across a wide range of sectors, including renewable energy, electricity markets, and shipping. In the offshore wind power and shipping industries, the company has a proven track record of improving safety and efficiency by combining meteorological and oceanographic data through AI-based forecasting. For shipping route optimization, it has achieved up to a 6% reduction in fuel consumption through speed adjustments, and up to 20% when combined with wind propulsion technologies.

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[26] Dunkelflaute is a German term meaning “dark lull.” It refers to periods when overcast skies and low wind conditions lasting from several days to weeks lead to reduced solar and wind power generation.

[27] Amperon Holdings, Inc.

[28] StormGeo AS

3. FUTURE PROSPECTS

In weather and climate forecasting, AI is now being used to predict weather patterns, raising expectations for accuracy improvements and cost reductions in traditional numerical forecasting using supercomputers. While challenges specific to AI have been pointed out, its rapid advancement holds the potential to exceed the performance and limitations of conventional forecasting methods. If used appropriately, AI could become a key technology for predicting events that significantly impact our daily lives, including extreme weather.

3-1. INTEGRATION OF AI AND NUMERICAL WEATHER PREDICTION

AI enables high-precision forecasting by analyzing vast amounts of data. However, because it does not base its predictions on an understanding of physical laws, it is difficult to explain the basis of its forecasts. The Japan Meteorological Agency has conducted comparative studies of numerical weather prediction and AI-based models. Findings indicate that AI performs well in predicting typhoon paths, while numerical models remain more accurate in forecasting intensity, such as wind strength. Accordingly, efforts are underway to develop hybrid models that combine AI and numerical forecasting to leverage the strengths of both approaches.

AI is trained using data from the past 40 years or so. Although temperature and humidity data exist from around the 1940s, data from 1979 onward, when remote sensing technologies advanced, are more suitable for training AI. At the same time, AI cannot predict extremely rare but potentially catastrophic weather events such as once-in-a-century hurricanes, which were not observed during that training period. To address this, AI models that also incorporate physical models have been proposed. One such approach is Physics-Informed Machine Learning (PIML), which embeds physical laws as prior knowledge into the model. This method is being studied as a promising way to enable the prediction of extreme weather events.

3-2. FORECASTING EXTREME WEATHER AND CLIMATE CHANGE WITH AI

AI-based weather and climate forecasting is expected to contribute to early warning and risk management for extreme weather events. By analyzing massive volumes of historical weather data along with real-time observations from satellites and ground stations, the accuracy of predicting the probability and path of typhoons, heavy rainfall, heatwaves, and other events is expected to improve. If realized, this would make it possible to optimize the timing of warnings, allowing municipalities and businesses to issue evacuation orders promptly or adjust logistics plans accordingly. In the event of a disaster, real-time analysis of meteorological data could be used to issue short-term forecasts, supporting guidance on safe evacuation routes, and the development of protective measures for infrastructure such as electricity, water, and sewer systems. Extreme weather events like heatwaves, cold snaps, torrential rain, and powerful typhoons are expected to increase due to climate change. Even now, forecasting such events with numerical models remains difficult, raising questions as to whether AI can significantly improve prediction accuracy. However, the high processing speed and real-time capabilities of AI are expected to provide critical functionality for planning and implementing extreme weather countermeasures.

3-3. INFLUENCE OF THE UNITED STATES

The Trump administration, known for its skeptical stance on climate change, reportedly plans to reduce the staff of the National Oceanic and Atmospheric Administration (NOAA) by approximately 20% of its roughly 13,000 employees.[29] Budget cuts of USD 1.3 billion have also been reported. These cost-cutting measures have raised concerns about a decline in functions critical to public safety in the US, such as the forecasting of extreme weather disasters.

In addition to staffing and budget cuts, the Trump administration has also moved to delete climate-related data. The National Climate Assessment, a report on climate change published every four years, was scheduled for

[29] More NOAA Employees May Be Let Go, Making 20% of Staff Cut - The New York Times

release in 2027. However, its publication process has been halted due to the dismissal of the staff involved.[30] The administration has also decided to discontinue the NOAA National Centers for Environmental Information database[31], which has tracked billion-dollar-scale disasters since 1980.[32] Furthermore, the administration has blocked US researchers from participating in the Intergovernmental Panel on Climate Change (IPCC), an international initiative. This could diminish the influence of the US on global climate change measures over the medium to long term.

3-4. JAPAN'S EXPECTED RISE IN PRESENCE

In the field of climate change mitigation, the relative presence of countries and regions such as Europe, China, and Japan is expected to increase. In addition, as discussed in this report, AI—an especially fast-growing technology—is also gaining influence in weather and climate forecasting. The increasingly visible adverse impacts of climate change are a global problem, and efforts to address them require cooperation that transcends national and regional boundaries. In particular, disasters caused by extreme weather tend to become more severe, and they are beginning to exceed what existing social infrastructure can accommodate. Under these circumstances, accurately forecasting weather and climate is a fundamental technology that underpins the maintenance of social infrastructure and supports resilience.

The Japan Meteorological Agency is preparing a detailed report titled *Climate Change in Japan 2025*[33], which presents observational findings and future projections related to climate change in the country. According to the report, an increase in extremely hot days and tropical nights, more frequent heavy rainfall, and stronger typhoons are projected, making it clear that Japan is not exempt from the impacts of climate change.[34] AI-powered weather forecasting services that offer high accuracy at low cost present an opportunity to introduce new business models in Japan and revitalize the industry. Globally, they also offer the potential to develop business solutions tailored to regional needs.

[30] National Climate Assessment website goes dark : NPR

[31] Billion-Dollar Weather and Climate Disasters | National Centers for Environmental Information (NCEI)

[32] Trump admin ends extreme weather database that has tracked cost of disasters since 1980 | CNN

[33] Japan Meteorological Agency | Climate Change in Japan

[34] Some projections indicate that certain impacts in Japan may be more severe than the global average, such as the significant rise in average sea surface temperatures around Japan. These trends are linked to region-specific factors and are expected to affect sectors such as coastal fisheries.