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# Deep Neural Networks for Weather Forecasting

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Numerical Weather Prediction focuses on taking current observations of weather and processing these data with computer models to forecast the future state of weather and is used to produce short- and medium-range weather forecasts from 10-15 days of the state of the atmosphere. A weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth. Electromagnetic radiation is energy emitted by all matter above absolute zero temperature ex., visible light, infrared light, heat, microwaves, and radio and television waves and Electromagnetic radiation is absorbed mainly by several gases in the Earth's atmosphere, among the most important being water vapor, carbon dioxide, and ozone. The paper proposed methodology involves training deep neural networks to take reanalysis weather data at a given point in time as input, and then produce reanalysis weather data at a future point in time as output. We used a single point in time for both input and output

**Keywords –weather prediction, computer models ,Electromagnetic radiation.**

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## 1. Introduction

**N**umerical Weather Prediction (NWP) data is the weather forecast data that we care the most about on a regular basis. NWP focuses on taking current weather observations and combining those data with computer models to forecast future weather conditions. Current weather observations serve as inputs to the numerical computer models through a process known as data assimilation that produces temperature outputs, precipitation, and hundreds of other meteorological elements from the oceans to the top of the atmosphere.[1]

Global Numerical Weather (NWP) models are used to create a short and medium-range atmospheric weather predictory (out to 10-15 days) with a horizontal resolution usually 10-25 km and a 10-30 m vertical resolution near the surface, which in the stratosphere rises to 500 m-1 km. And Modern forecasts require a definition of the current atmospheric state, known as the initial conditions, as the point of departure from which numerical weather prediction models can advance in time using the physical laws of atmospheric motion.[2]

A weather satellite is a kind of satellite used primarily for monitoring Earth's environment and climate. However, these weather satellites are more than clouds and cloud systems. City lights, fires, pollution effects, auroras, sand and storms of dust, covered snow, ice mapping, sea border currents, energy flow and modern atmospheric satellite data recording include temperature and moisture, wind fields and trace gas concentrations, other environmental information gathered through weather satellite and transformed by satellite observations. [1]

Electromagnetic radiation is a form of energy emitted by all matter above absolute zero temperature (0 Kelvin or -273 ° Celsius). Examples of electromagnetic energy are x-rays, ultraviolet rays, visible light, infrastructure light , heat, microwave and wavy radio or television. Electromagnetic radiation and water vapor, carbon dioxide and ozone are the primary reflection or absorbance in the environment of several pollutants in the earth's atmosphere. The atmosphere transmits some radiation, such as the visible light. These regions of the spectrum with wavelengths that can pass through the atmosphere are referred to as "atmospheric windows." Some microwaves can even pass through clouds, which make them the best wavelength for transmitting

Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

satellite communication signals.[3]

## 2. Literature Review

**Numerical weather forecasts** are one of the main meteorological research topics. A predictive number of meteorological elements such as air pressure, temperature , water vapor content, condensation frequency, wind direction, and wind velocity can be measured quantitatively for the estimation of their prospective values. More recently, due to improvements in meteorological observation devices, meteorological models, computer technologies and numerical weather prediction (NWP) the accuracy of the numerical weather prediction has been improved using the mathematical model of atmosphere and oceans to forecast weather based on current weather conditions, and The NWP method is flawed in that the equations used by the models to simulate the atmosphere are not precise. This leads to some error in the predictions. Despite the disadvantages of this method, this method can be works well by developing techniques to improve the handling of errors in numerical predictions and Increase the qualifications of forecaster to interpret the computer forecast.[4]

**It is very important to study radiation** and know how it effect the earth climate, Radiation is energy in the form of waves or streams of particles it can transport energy even without a medium, it is the only way in which the earth interacts with the rest of the universe. . There are many kinds of radiation all around us . Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals. in fact radiation can determine the earth’s climate as, Radiation is why it is usually warmer during the day, when the sun shines, than at night, and why the surface air temperature is higher on cloudy nights than clear ones.[5]

The earth 's outer atmosphere is continually bombarded by cosmic radiation. Usually, cosmic radiation consists of fast moving particles that exist in space and originate from a variety of sources, including the sun and other celestial events in the universe. Even within the earth-atmosphere system radiation can be a powerful player in determining the local energy .Cosmic rays are mostly protons but can be other particles or wave energy. Some ionized radiation penetrates the atmosphere of the earth and is absorbed by human in natural exposure to radiation.[6]

Radiation is defined as energy traveling in the form of a particle or wave through space or matter. In two respects it can be produced either by radioactive decay of an unstable atom (radionuclide) or by the interaction between a particle and matter. It is spontaneous and unpredictable and the radiation type is dependent on the actual radionuclide. Some characteristics of radioactive decay are: Radiation emissions as a result of interaction depend on the incoming and the material that is hit by radiation and, if adequate information is understood, are theoretically predictable. Radiation interacts essentially indifferent ways with the Earth’s atmosphere which is primarily made of gases, liquids and solids in the form of aerosols and clouds.This interaction considers great tools for different sciences.[5]

The type and energy of radiation is defined. The radiation types are divided into two main categories: particulate and electromagnetic. Particulate radiation consists of particles of mass and energy that are electrically charged or not. Radiation can also measure the condition of the atmosphere from a distance (usually from the ground or outer space) so that the basis for remote sensing is considered.[4]

Electromagnetic radiation and remote sensing have a very powerful and effective role in monitoring weather conditionssuch as

**Electromagnetic radiation**is the very basis for remote sensing technology. Everything emits electromagnetic radiation. In fact, radiation produced by all objects over the absolute zero temperature. Because even a medium is not available to carry Energy, radiation is the only way the planet communicates with the rest of the world. The Wave Theory, in which its intensity, frequency and wavelength are represented, can explain the electromagnetic radiation. Remote sensing instruments on satellites attempt to accurately measure electromagnetic energy from the earth and atmosphere. Deeper understanding of remote sensing capabilities and limitations requires a deeper understanding of electromagnetic radiation.

**Remote sensing**is the process by measuring the reflected and emitted radiation from a distance (typically from satellites or aircraft) to detect and monitor the physical characteristics of a zone. Special cameras collect remotely sensed images, help scientists "sense" things about Earth and predict weather or watch volcanoes erupt, as well as help them watch dust storms. [3]

Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

Meteorology for satellites refers to the earth's and oceans study using data derived from remote sensing devices flying on the Earth's orbiting satellites. And meteorology, like any other science, depends on its subject matter being carefully and accurately measured. The atmosphere is observed by meteorologists using two basic methods.[7]

1-Direct methods, also referred to in situ as "in-situ" methods, measure the air properties in contact with the instrument being used.

2-Indirect methods, also called remote sensing, collect information without physical interaction with the area of the measured atmosphere. Arm satellites with remote sensing devices in space enables us to monitor planet Earth from a distance continuously. [8]

A satellite is an object around a bigger object, such as a planet. Satellite Orbits An example of a natural satellite is the earth's moon, and an orbit is the curve path that a celestial object (e.g. star, sun, moon, asteroid and spacecraft) is taking around another object due to gravity.

**Basics of Satellite Orbits**

•Ground Track: The part of the earth that lies beneath the satellite orbit

•A satellite in an orbit with inclination angle (theta) cannot pass directly over any location on Earth with latitude greater than (theta).

•A satellite launched from a site at latitude (theta) follows an orbit with inclination greater than or equal to (theta).

•From a launch site at latitude (theta) it is not possible to launch a satellite into an orbit with inclination less than (theta).

•A launch site that is not on the equator cannot

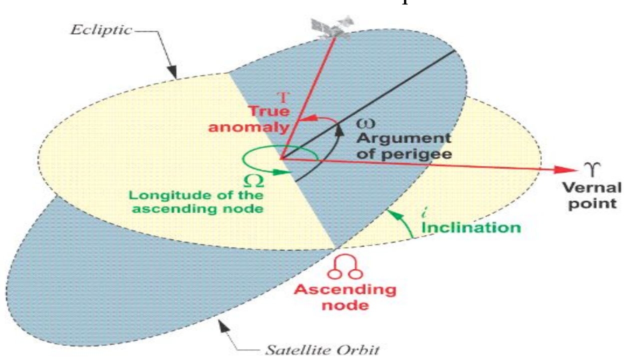



Figure 1 basics of satellite orbits

place a satellite directly into an equatorial orbit.

**Geostationary orbit (GEO)**

The satellite seems to be in a fixed position to an observatory on the ground in a geostationary orbit. The geostationary satellite revolves around Earth at a constant speed once a day, round the Earth from west to east after Earth's rotation in 23 hours and five-six minutes and four seconds. It makes GEO satellites appear "stationary" in a fixed position.[9]

In order to perfectly match Earth’s rotation, the speed of GEO satellites should be about 3 km per second at an altitude of
35 786 km. This is much farther from Earth’s surface compared to many satellites.

**Polar orbiting** satellites fly several hundred km over the earth's surface with a rotation period of about 110 minutes. They can cover most of the earth's surface except for regions immediately

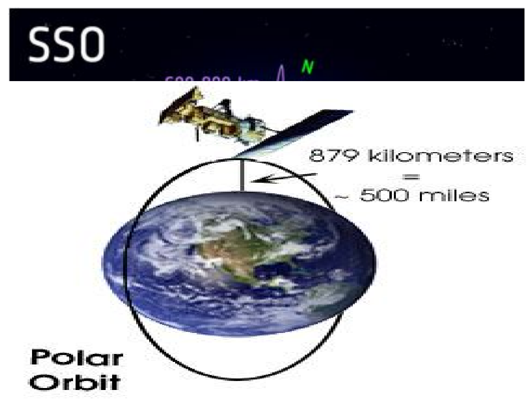



**Figure 2 Geostationary orbit (GEO)**

adjacent to the poles. They have an inclination

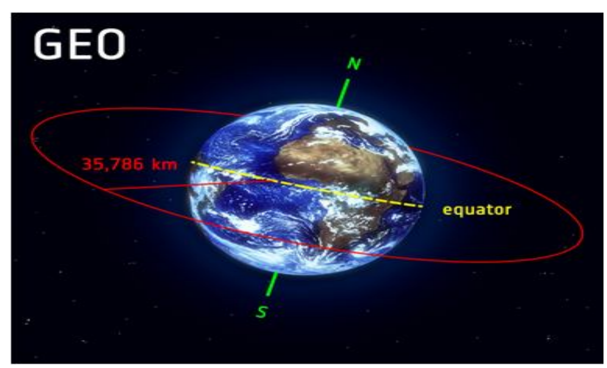



**Figure 3 polar orbit**

which measures the angle at which they cross the equator and which determines how close they get to passing directly over the poles. They are also called sun.

**Sun-synchronous orbit (SSO)** is a particular kind

**Figure 4 Sun-synchronous orbit**

Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

of polar orbit. Satellites in SSO, travelling over the Polar Regions, are synchronous with the Sun. This means they are synchronized to always be in the same ‘fixed’ position relative to the Sun.[2] This means that the satellite always visits the same spot at the same local time for example, passing the city of Parisevery day at noon exactly.

The instruments that measure electromagnetic energy are called radiometers and there are two kinds of radiometers imagers and sounders. Imagers have two main types that are utilized in satellite meteorology the first One measures the amount of visible light from the sun reflected back to space by the Earth's surface or by clouds. The second measures the amount of radiation emitted by these entities.[3]

The other type of radiometer are called sounders which flown on weather satellites and provide vertical profiles of temperature, pressure, water vapor and critical trace gases in the earth's atmosphere.

**Satellite images** are one of the most powerful and important tools used by the meteorologist. They are essentially the eyes in the sky. These images reassure forecasters to the behavior of the atmosphere as they give a clear, concise, and accurate representation of how events are unfolding. Forecasting the weather and conducting research would be extremely difficult without

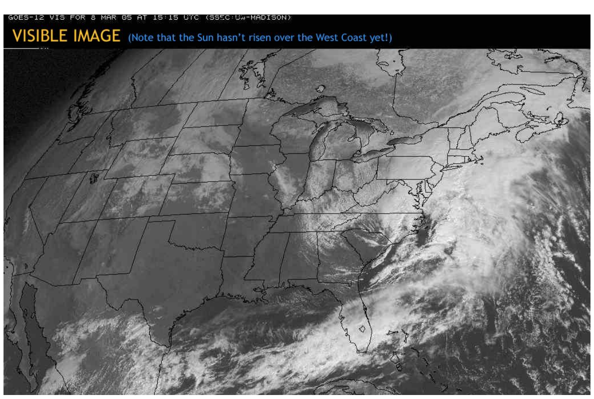
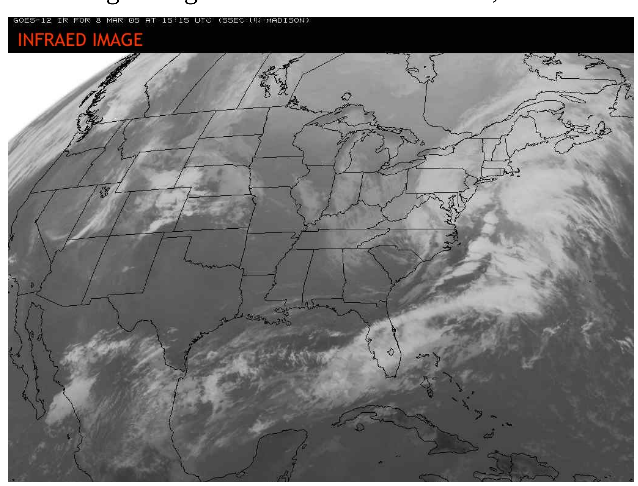



**Figure 5 visible imagery**

satellites and Satellite images aid in showing what cannot be measured or seen. In addition the satellite images are viewed as truth. There is no chance for error. Satellite images provide data that can be interpreted 'first-hand' and there are of the three types of satellite imagery.

**VISIBLE IMAGERY**: Visible satellite pictures can only be viewed during the day, since clouds reflect the light from the sun. On these images, clouds show up as white, the ground is normally grey, and water is dark. In winter, snow-covered ground will be white, which can make distinguishing clouds more difficult. To help differentiate between clouds and snow, looping pictures can be helpful; clouds will move while the snow won't. Snow-covered ground can also be identified by looking for terrain features, such as rivers or lakes. Rivers will remain dark in the imagery as long as they are not frozen. If the rivers are not visible, they are probably covered with clouds. Visible imagery is also very useful for seeing thunderstorm clouds building. Satellite will see the developing thunderstorms in their earliest stages.[5]

**INFRARED IMAGERY**: Infrared satellite pictures show clouds in both day and night. Instead of using sunlight to reflect off of clouds, the

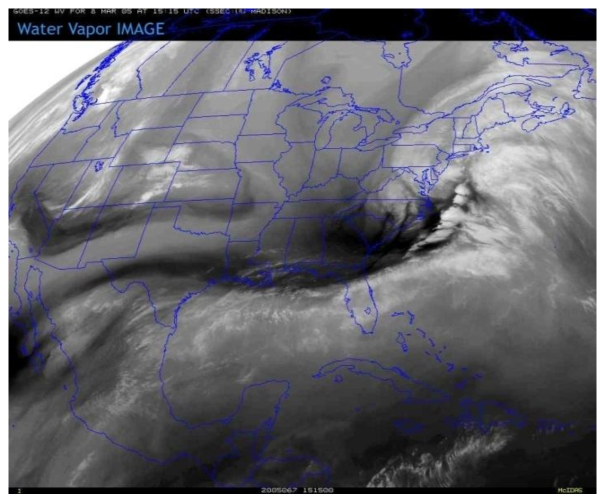


Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

clouds are identified by satellite sensors that measure heat radiating off of them. The sensors also measure heat radiating off the surface of the earth. Clouds will be colder than land and water, so they are easily identified. Infrared imagery is useful for determining thunderstorm intensity. Strong to severe thunderstorms will normally have very cold tops. Infrared imagery can also be used for identifying fog and low clouds.[7]

**WATER VAPOR IMAGERY**: Water vapor satellite pictures indicate how much moisture is present in the upper atmosphere (approximately from 15,000 ft to 30,000 ft). The highest humidity will be the whitest areas while dry regions will be dark. Water vapor imagery is useful for indicating where heavy rain is possible. Thunderstorms can also erupt under the high moisture plumes.[8]

**Usefulness of using these three images together for weather forecasting** Putting all three types of satellite images together it becomes apparent the significance of the weather event. The visible image shows the 3-D nature of the low pressure system and the developing storms. The infrared helps specify which cloud areas are likely causing the most notable weather.[4] The water vapor indicates where the most moisture in the upper levels is located and the associated jet stream. Satellite images are taken several times an hour. Looping them together shows the formation and likely propagation of significant weather features and analysis of visible satellite images allows meteorologists to locate thunderstorms, hurricanes, frontal systems, and fog. Weather events can be tracked using time sequences of satellite image.



Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

## 3. Methodology

In this paper, we present an AI-based system that trains deep networks for fast and accurate numerical weather forecasting. The major technical contributions include the design of the 3DEST architecture and the application of the hierarchical temporal aggregation strategy for medium-range forecasting. By training the models on 39 years of global weather data, Pangu-Weather produces better deterministic forecast results on reanalysis data than the world's best NWP system, the operational IFS of ECMWF, while also being much faster. In addition, Pangu-Weather is excellent at forecasting extreme weather events and performing ensemble weather forecasts. Pangu-Weather reveals the potential of using large pre-trained models for various downstream applications, showing the same trend as other AI scopes, such as computer vision26,27, natural language processing28,29, cross-modal understanding30 and beyond.

3DEST architecture. Based on the standard encoder–decoder design of vision transformers, we adjusted the shifted-window mechanism19 and applied an Earth-specific positional bias. b, Hierarchical temporal aggregation. Once given a lead time, we used a greedy algorithm to perform forecasting with as few steps as possible. We use FM1, FM3, FM6 and FM24 to indicate the forecast models with lead times being 1 h, 3 h, 6 h or 24 h, respectively. A0 is the input weather state and Aˆ t denotes the predicted weather state at time t (in hours). [9]

The methodology involves training deep neural networks to take reanalysis weather data at a given point in time as input, and then produce reanalysis weather data at a future point in time as output. We used a single point in time for both input and output. The time resolution of the ERA5 data is 1 h; in the training subset (1979–2017), there were as many as 341,880 time points, the amount of training data in one epoch. To alleviate the risk [10]

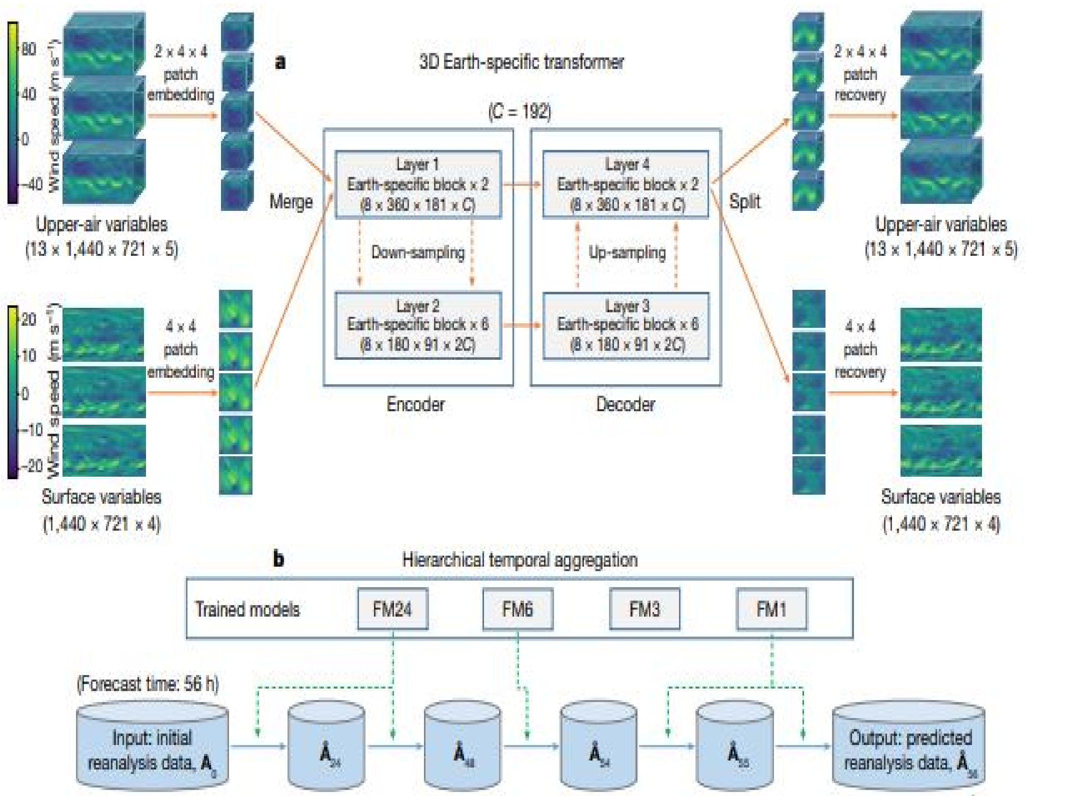



Figure 8 Network training and inference strategies

Volume: 15 Issue: 02 Pages: 5915– 5923 (2023) ISSN: 0975-0290

of over-fitting, we randomly permuted the order of sample from the training data at the start of each epoch. We trained four deep networks with lead times (the time difference between input and output) at 1 h, 3 h, 6 h and 24 h, respectively. Each of the four deep networks was trained for 100 epochs, and each of them takes approximately 16 days on a cluster of 192 NVIDIA Tesla-V100 GPUs. The architecture of our deep network is shown in Fig. 9a. This architecture is known as the 3D Earth-specific transformer (3DEST). We fed all included weather variables, including 13 layers of upper-air variables and the surface variables, into a single deep network. We then performed patch embedding to reduce the spatial resolution and combined the down-sampled data into a 3D cube. [12]The 3D data are propagated through an encoder–decoder architecture derived from the Swin transformer19, a variant of a vision transformer20, which has 16 blocks. The output is split into upper-air variables and surface variables and is up-sampled with patch recovery to restore the original resolution. To inject Earth-specific priors into the deep network, we designed an Earth-specific positional bias (a mechanism of encoding the position of each unit; detailed in Methods) to replace the original relative positional bias of Swin. This modification increases the number of bias parameters by a factor of 527, with each 3D deep network containing approximately 64 million parameters. Compared with the baseline, however, 3DEST has the same computational cost and has a faster convergence speed.[11]

We evaluated Pangu-Weather on the ERA5 data18, which is considered the best known estimation for most atmospheric variables21,22. To fairly compare Pangu-Weather against FourCastNet2 , we trained our 3D deep networks on 39 years of data (from 1979 to 2017), validated them on 2019 data and tested them on 2018 data. We studied 69 factors, including 5 upper-air variables at 13 pressure levels (50 hPa, 100 hPa, 150 hPa, 200 hPa, 250 hPa, 300 hPa, 400 hPa, 500 hPa, 600 hPa, 700 hPa, 850 hPa, 925 hPa and 1,000 hPa) and 4 surface variables. When tested against reanalysis data, for each tested variable, Pangu-Weather produces a lower RMSE and a higher anomaly correlation coefficient (ACC) than the operational IFS and FourCastNet, the best NWP and AI-based methods, respectively

Ten variables were compared in terms of latitude-weighted RMSE (lower is better) and ACC (higher is better), where the first five variables were reported in FourCastNet and the last five were not. Here, Z500, T500, Q500, U500 and V500 indicate the geopotential, temperature, specific humidity, and the u-component and v-component of wind speed at 500 hPa, respectively. Z850 and T850 indicate the geopotential and temperature at 850 hPa, respectively. T2M indicates the 2-m temperature, and U10 and V10 indicate the u-component and v-component of 10-m wind speed, respectively

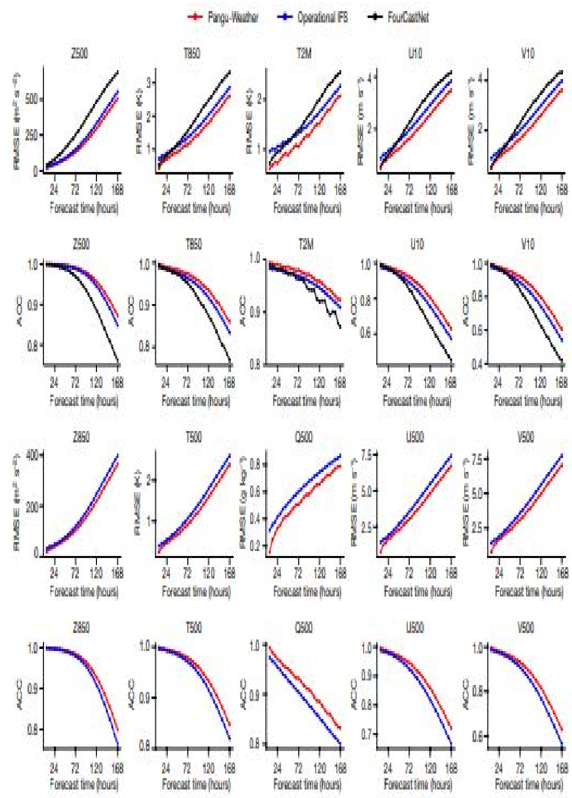



**Figure 9 Pangu-Weather produces higher accuracy than the operational IFS**

Pangu-Weather statistically produced more accurate tracking resultsthan ECMWF-HRES for these cyclones. The 3-day and 5-day mean direct position errors for cyclone eyes were reported at 120.29 km and 195.65 km for Pangu-Weather, which are smaller than 162.28 km and272.10 km for ECMWF-HRES, respectively. The breakdowns of

trackingerrors with respect to regions and intensities are provided in Extended
Data Fig.10.

The advantage of Pangu-Weather becomes more significantas the lead time increases. We also show the tracking results of the twostrongest cyclones in the western Pacific, Kong-rey and Yutu, in Fig.9.
See the supplementary material for a detailed analysis.Despite the promising tracking results, we point that the direct comparisonbetween Pangu-Weather and ECMWF-HRES is somewhat unfair,because ECMWF-HRES used the IFS initial condition data as its input,whereas Pangu-Weather used reanalysis data.[15]
As an AI-based method, Pangu-Weather is more than 10,000-timesfaster than the operational IFS. This offers an opportunity for performing
large-member ensemble forecasts with small computationalcosts. We investigatedFourCastNet2 to study a preliminary ensemble
method that adds perturbations to initial weather states. We then generated99 random perturbations (detailed in Methods) and addedthem to the unperturbed initial state. Thus, we obtained a 100-memberensemble forecast by simply averaging the forecast results. As shownin Fig.10, for each variable, the ensemble mean is slightly worse thanthe single-member method in the short-range (for example, 1 day)weather forecasts, but significantly better when the lead time is5–7 days. This aligns with FourCastNet2, indicating that large-member ensemble forecasts are especially useful when single-model accuracyis lower, yet they present the risk of introducing unexpected noise toshort-range forecasts. Ensemble forecasting presents more benefitsto non-smooth variables such as Q500 (500 hPa specific humidity) andU10 (10 m u-component of wind speed). In addition, the spread-skillratio of Pangu-Weather is smaller than 1, indicating that the current ensemble method is somewhat under dispersive. Compared with NWPmethods, Pangu-Weather largely reduces the cost of ensemble forecasting, allowing meteorologists to apply their expertise to control noiseand improve ensemble forecast accuracy.

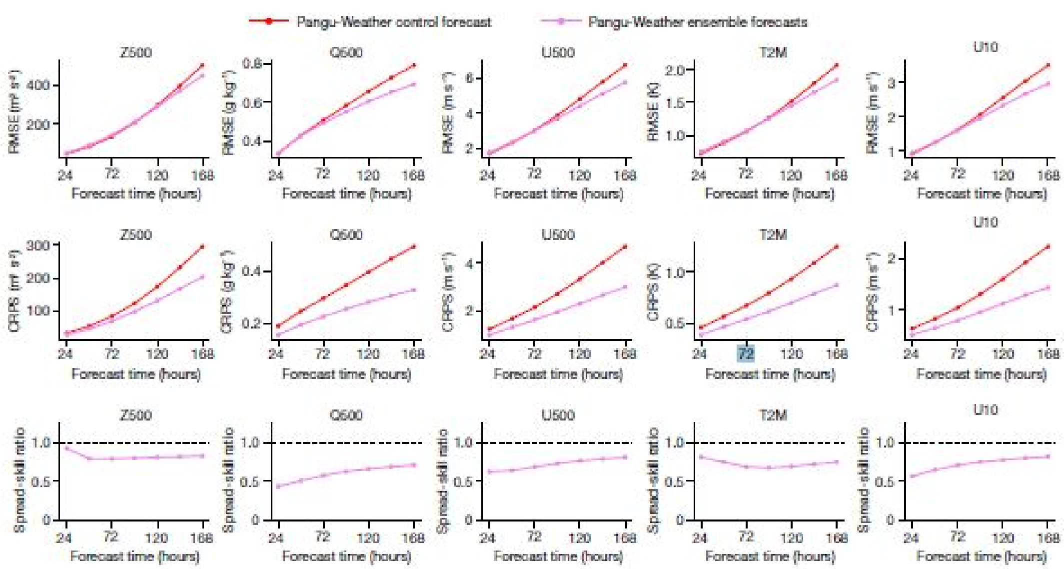



**Figure 10 Ensemble forecast results of Pangu-Weather**

## 4. Conclusions

This research is focus on weather prediction and how it occur depending on the current weather observations relayed from weather satellitesstart with the Definition of NWP and the importance of the study of radiation Then explain the role that the electromagnetic radiation, and the remote sensing, play for weather observations. Satellite orbits and the Instruments that measure electromagnetic energy showing the three satellite images and how these three imagesis very usefulness when using them together for weather forecasting.we present Pangu-Weather, an AI-based system that trains deep networks for fast and accurate numerical weather forecasting. The major technical contributions include the design of the 3DEST architecture and the application of the hierarchical temporal aggregation strategy for medium-range forecasting. By training the models on 39 years of global weather data, Pangu-Weather produces better deterministic forecast results on reanalysis data than the world's best NWP system, the operational IFS of ECMWF, while also being much faster. In addition, Pangu-Weather is excellent at forecasting extreme weather events and performing ensemble weather forecasts. Pangu-Weather reveals the potential of using large pre-trained models for various downstream applications, showing the same trend as other AI scopes, such as computer vision26,27, natural language processing28,29, cross-modal understanding30 and beyond. Despite the promising forecast the RMSE of theensemble mean forecast (lower is better) for three upper-air variables (Z500, Q500 and U500) and two surface variables (T2M and U10). We also followed arecent work35 to plot two metrics, the CRPS (lower is better) and the spread-skillratio (an ideal ensemble model produces spread-skill ratios of 1.0, shown as the dashed lines), which further demonstrate the properties of our ensemble forecast results. Here, Z500, Q500 and U500 indicate the geopotential, temperature and the u-component of wind speed at 500 hPa, respectively. T2M indicates the 2-m temperature and U10 indicates the u-component of 10-mwind speed.

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