Weathering the Future:
The AI Forecast Revolution

Presentation on *Artificial Intelligence*

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1. Introduction

Fig.1: Typhoon caused harm to citizens. [1]

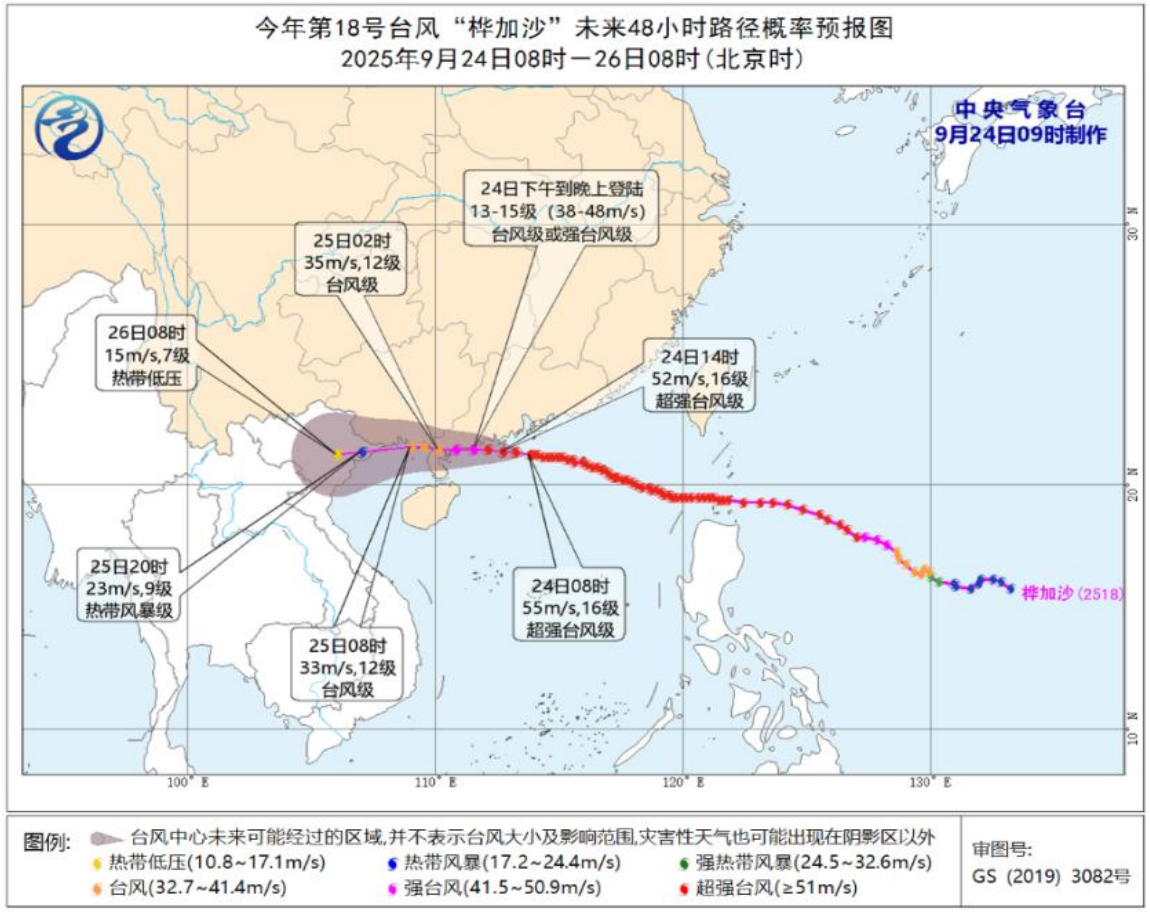


Fig.2: Typhoon Forecast. [2]

17 People Killed

32 Injured

17 Missing

690,000+

People Affected [3]

How can **AI** help improve **weather forecasting** to save **people's lives**?

2. The Evolution of Forecasting

~ 1950s | ~ Present | Now

Manual Forecasting

Human Experience,
Subjective

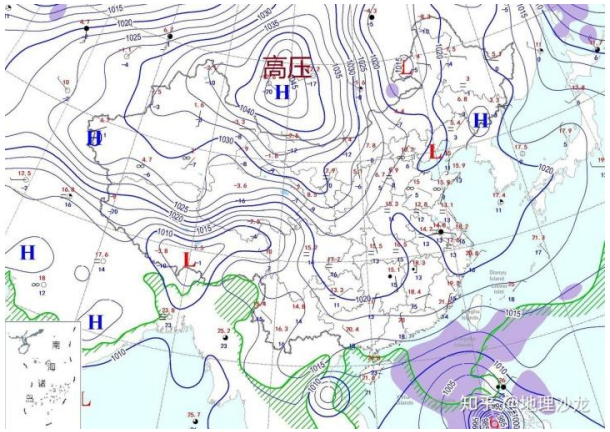


Fig.3: Manual Forecast Reference Map.

Numerical Weather Prediction

Physics-Driven,
Computationally
Expensive

$$
\begin{aligned}
&\text{transport} && \text{pressure gradient} \\
\frac{\partial U}{\partial t} &= -\frac{\partial Uu}{\partial x} - \frac{\partial Vu}{\partial y} - \frac{\partial \Omega u}{\partial \eta} && -\alpha\mu_d\frac{\partial p}{\partial x} - \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial x} + R_u + Q_u \\
\frac{\partial V}{\partial t} &= -\frac{\partial Uv}{\partial x} - \frac{\partial Vv}{\partial y} - \frac{\partial \Omega v}{\partial \eta} && -\alpha\mu_d\frac{\partial p}{\partial y} - \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial y} + R_v + Q_v \\
\frac{\partial W}{\partial t} &= -\frac{\partial Uw}{\partial x} - \frac{\partial Vw}{\partial y} - \frac{\partial \Omega w}{\partial \eta} && -g\left(\mu_d - \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\right) + R_w + Q_w \\
\frac{\partial \mu_d}{\partial t} &= -\frac{\partial U}{\partial x} - \frac{\partial V}{\partial y} - \frac{\partial \Omega}{\partial \eta} && \uparrow \\
\frac{\partial \Theta}{\partial t} &= -\frac{\partial U\theta}{\partial x} - \frac{\partial V\theta}{\partial y} - \frac{\partial \Omega\theta}{\partial \eta} && +R_\theta + Q_\theta \\
\frac{\partial \mu_d q_j}{\partial t} &= -\frac{\partial Uq_j}{\partial x} - \frac{\partial Vq_j}{\partial y} - \frac{\partial \Omega q_j}{\partial \eta} && +R_{q_j} + Q_{q_j} \leftarrow \text{numerical filters, physics, projection terms} \\
\frac{\partial \phi}{\partial t} &= -u\frac{\partial \phi}{\partial x} - v\frac{\partial \phi}{\partial y} - \omega\frac{\partial \phi}{\partial \eta} && +gw \leftarrow \text{geopotential eqn term}
\end{aligned}
$$

Fig.4: NWP Formula.

AI Forecasting

Data-Driven,
Lightning-Fast

Physical laws

↓

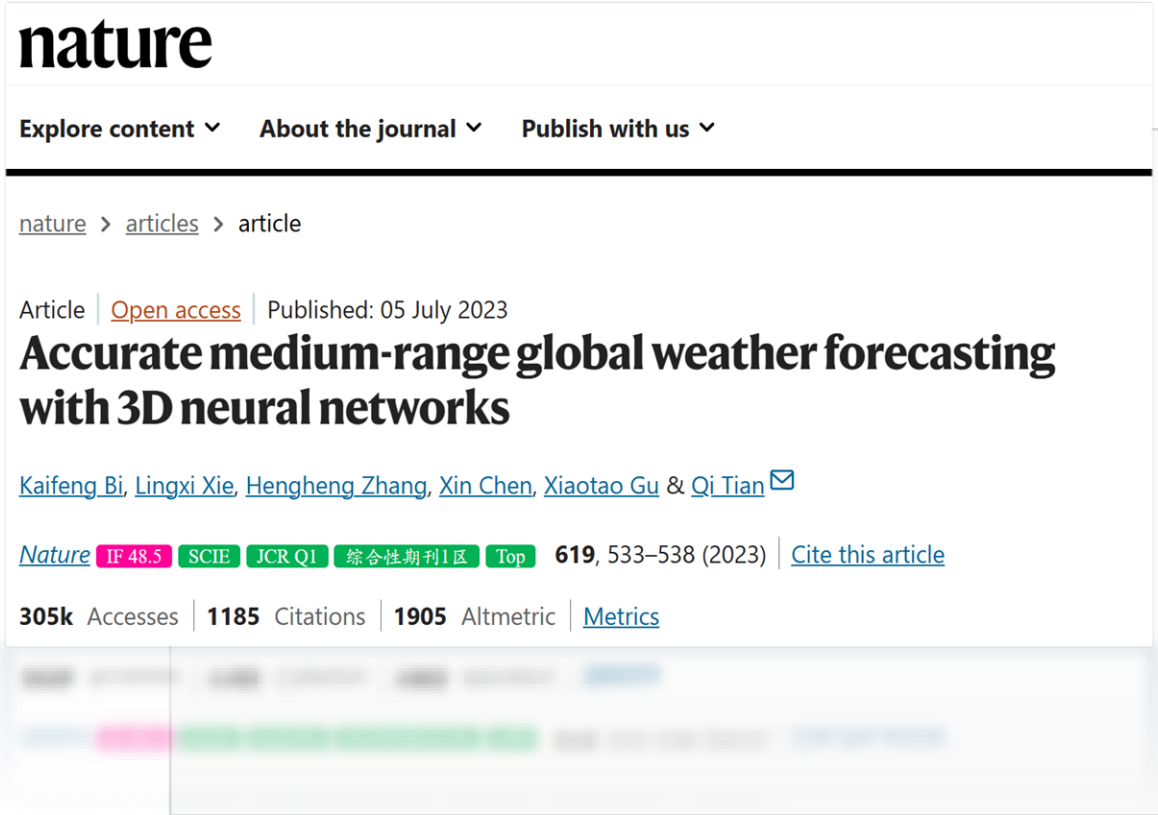
Hybrid AI + Physics

3.1 Research Direction 1: Deep Learning to Accelerate NWP

Pangu-Weather [4]

Huawei, Nature 2023

3D neural network
trained on **~40 years** of ERA5 data,
with **0.25°** global resolution.



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Accurate medium-range global weather forecasting with 3D neural networks

Kaifeng Bi, Lingxi Xie, Hengheng Zhang, Xin Chen, Xiaotao Gu & Qi Tian ✉

Nature IF 48.5 SCIE JCR Q1 综合性期刊1区 Top **619**, 533–538 (2023) | Cite this article

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Achieving

Accuracy

Overall Higher

than ECMWF IFS

Speed

Up to **10,000**×

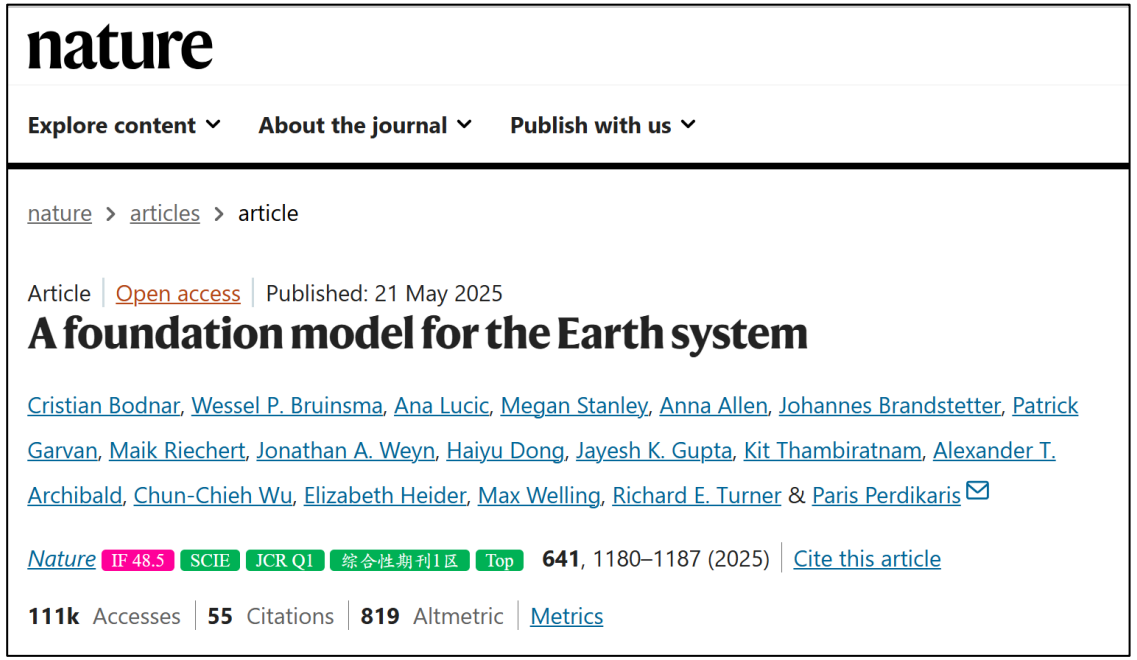
Hours → Seconds

3.2 Research Direction 2: Foundation Models for Weather and Climate

Aurora [5] Microsoft, Nature 2024

Overview

- **Large-scale** Earth system foundation model
- Trained on **1M+ hours** of heterogeneous data
- **3D Transformer backbone**



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A foundation model for the Earth system

Cristian Bodnar, Wessel P. Bruinsma, Ana Lucic, Megan Stanley, Anna Allen, Johannes Brandstetter, Patrick Garvan, Maik Riechert, Jonathan A. Weyn, Haiyu Dong, Jayesh K. Gupta, Kit Thambiratnam, Alexander T. Archibald, Chun-Chieh Wu, Elizabeth Heider, Max Welling, Richard E. Turner & Paris Perdikaris

Nature IF 48.5 SCIE JCR Q1 综合性期刊1区 Top **641**, 1180–1187 (2025) | Cite this article

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Covers **atmosphere**, **ocean waves**, **air quality**, **extreme events**, etc.

3.3 Additional Emerging Topics

Data Preprocessing & Gridding

Diffusion Models

- **CorrDiff [6]**: generative diffusion downscales 25 km global fields to 2 km.
- **Diffusion-based probabilistic downscaling [7]**: generate high-resolution climate ensembles for risk assessment.

Extreme Event Attribution

Transformer-based Models

- **ML-based extreme event attribution** (Systematic Review 2024) [8].
- **Transformer architectures** (EarthFormer, TeleViT) **for extremes** (Nat. Commun. 2025 review) [9].

Typhoon Track Analysis

- **Long-term typhoon trajectory prediction** (ICLR 2024) [10].
- **Deep learning for tropical cyclone tracks and intensity** (npj Clim. Atmos. Sci. 2025; Ocean Modelling 2024) [11].

4. Discussion

How can AI weather models be used in operational forecasting?

- ✓ **Hybrid Forecasting:** AI enhances NWP via downscaling & bias correction.
- ✓ **Rapid Nowcasting:** AI provides fast short-term forecasts for rainfall & storms.

What are the major challenges?

- ✓ **Limited Generalization:** AI struggles with rare/extreme events.
- ✓ **Trust & Reliability:** Black-box models lack interpretability and operational stability.

Thank you for listening!

Q & A

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Reference

[1] The Red Note. A look back at the legendary work-from-home photos of Shenzhen residents after Typhoon Mangkhut in 2018 [EB/OL]. 2023. [2025-11-18]. https://www.xiaohongshu.com/discovery/item/64c269a1000000000800fa05. (Chinese)

[2] China Meteorological Administration. Strong rainfall in Sichuan, Shaanxi, Shandong, and other areas, super typhoon "Hagupit" approaching the South China coast [EB/OL]. 2025-09-22. (Chinese)

[3] Xinhua News Agency. Typhoon "Hagupit" has caused 17 deaths, 32 injuries, and 17 missing persons in Taiwan [EB/OL]. 2025-09-24(19:34:12). https://www.news.cn/20250924/a6c03703ede341739cd926bda543f012/c.html[4] Bi, K., Xie, L., Zhang, H. et al. (Chinese)

[4] Accurate medium-range global weather forecasting with 3D neural networks. Nature, 619, 533–538 (2023). https://doi.org/10.1038/s41586-023-06185-3.

[5] Bodnar, C., Bruinsma, W.P., Lucic, A. et al. A foundation model for the Earth system. Nature, 641, 1180–1187 (2025). https://doi.org/10.1038/s41586-025-09005-y.

[6] Mardani, M., Brenowitz, N., Cohen, Y. et al. Residual corrective diffusion modeling for km-scale atmospheric downscaling. Commun Earth Environ, 6, 124 (2025). https://doi.org/10.1038/s43247-025-02042-5.

[7] Ling, F., Lu, Z., Luo, JJ. et al. Diffusion model-based probabilistic downscaling for 180-year East Asian climate reconstruction. npj Clim Atmos Sci 7, 131 (2024). https://doi.org/10.1038/s41612-024-00679-1.

[8] Materia, S., Palma García, L., van Straaten, C., O, S., Mamalakis, A., Cavicchia, L., Coumou, D., de Luca, P., Kretschmer, M., & Donat, M. (2024). Artificial intelligence for climate prediction of extremes: State of the art, challenges, and future perspectives. Wiley Interdisciplinary Reviews: Climate Change, 15(5), e914. https://doi.org/10.1002/wcc.914.

[9] Camps-Valls, G., Fernández-Torres, MÁ., Cohrs, KH. et al. Artificial intelligence for modeling and understanding extreme weather and climate events. Nature Communications, 16, 1919 (2025). https://doi.org/10.1038/s41467-025-56573-8.

[10] Park, Y.-J., Seo, M., Kim, D., Kim, H., Choi, S., Choi, B., Ryu, J., Son, S., Jeon, H.-G., & Choi, Y. (2024). Long-term typhoon trajectory prediction: A physics-conditioned approach without reanalysis data. In Proceedings of the International Conference on Learning Representations (ICLR 2024).

[11] Hao, P., Zhao, Y., Li, S., Song, J., & Gao, Y. (2024). Deep learning approaches in predicting tropical cyclone tracks: An analysis focused on the Northwest Pacific Region. Ocean Modelling, 192, 102444. https://doi.org/10.1016/j.ocemod.2024.102444