AOMSUC-15 FYSUC-2025

FIFTEENTH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE

THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

Data-driven Global Short and Medium Range Forecasting System (CMA-AIM-GFS-Fengqing)

Reporter： Gong Yu

National Meteorological Center

30 Nov. 2025

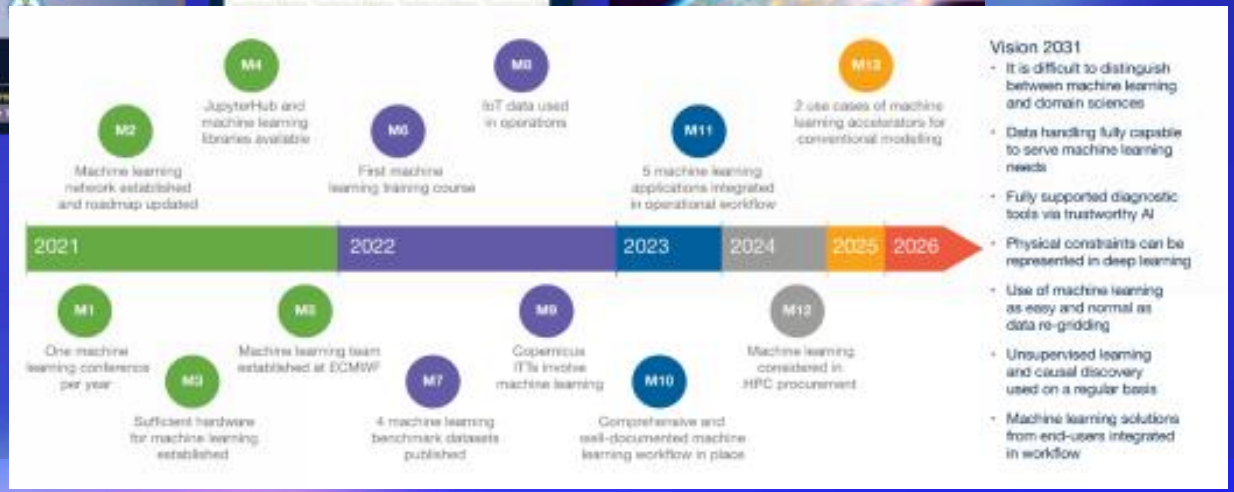
Content

Developing Trend of AI in the International Meteorological Field

- AI being applied across the workflow - observations, mechanism understanding, models, forecasts
- Particularly strong interest around use of AI in weather forecasting models
- According to a decision at the 2023 World Meteorological Congress (CG-19), the WMO is undergoing a strategic shift to integrate AI technology to advance Earth system science.

The May 2023 WMO World Meteorological Conference (Cg-19) had a heated discussion on the weather application and development of AI

At the WMO INFO-COM3 meeting in April 2024, AI was believed to strongly support the "Comprehensive Early Warning Initiative"



The CMA Takes the Lead in Implementing the Research of Meteorological AI Models

- On July 20, 2023, the CMA officially disseminated the "**The 2023-2030 Work Plan to Harness AI in operational weather forecasting**", outlining the strategic development roadmap.

Foundational Support

1. Develop **benchmark datasets** for AI applications. The scale of GPU extends from **3 to 30 PFlops**. Establish open platforms for development and testing.

Data-driven models

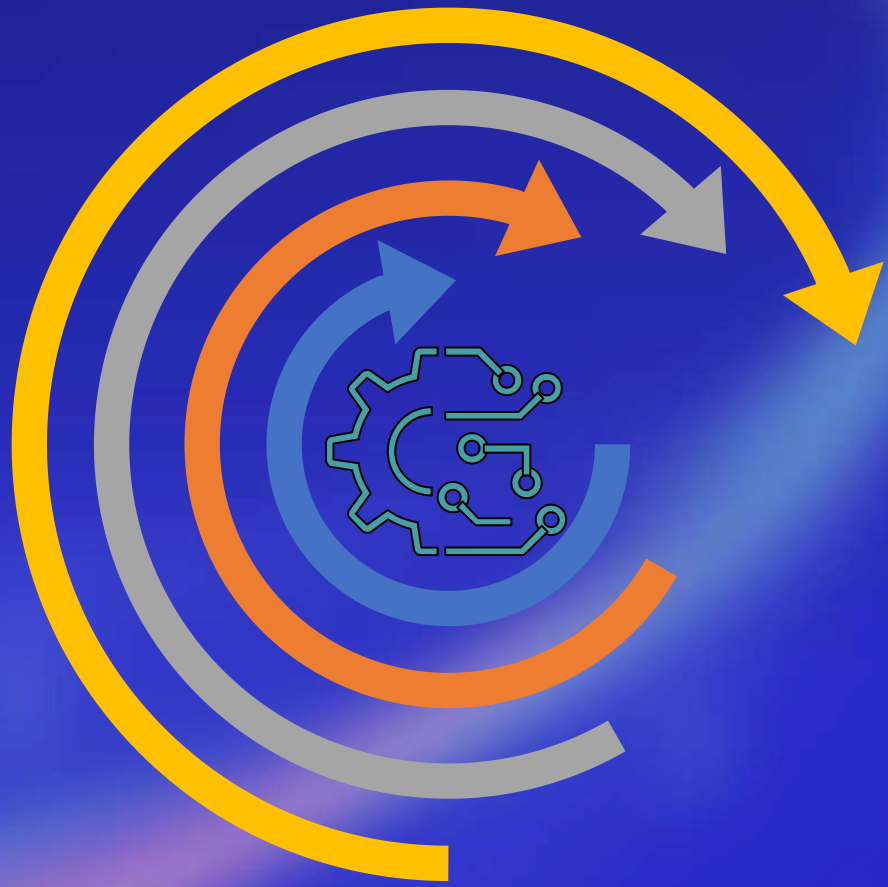
2. Construct **seamless weather forecast AI models** with physical conception. Advance the evaluation and implementation of data-driven models in weather and climate forecasting services.

Extensively applied across various stages

3. Implement the integration and application of AI in **monitoring and early warning, weather and climate prediction, numerical weather prediction, and sector-specific services**.

Regulatory and policy framework

4. Establish a key **research laboratory**, enhance the research team and technical training programs, and improve the establishment of **standards and guidelines.**



Xiong'an AI Meteorological Research Institute

雄安气象人工智能
创新研究院

Core Objectives

- The CMA has specifically established the Xiong'an AI Meteorological Research Institute, gathering talents from various fields to commit to the innovative research and development of data-driven model.

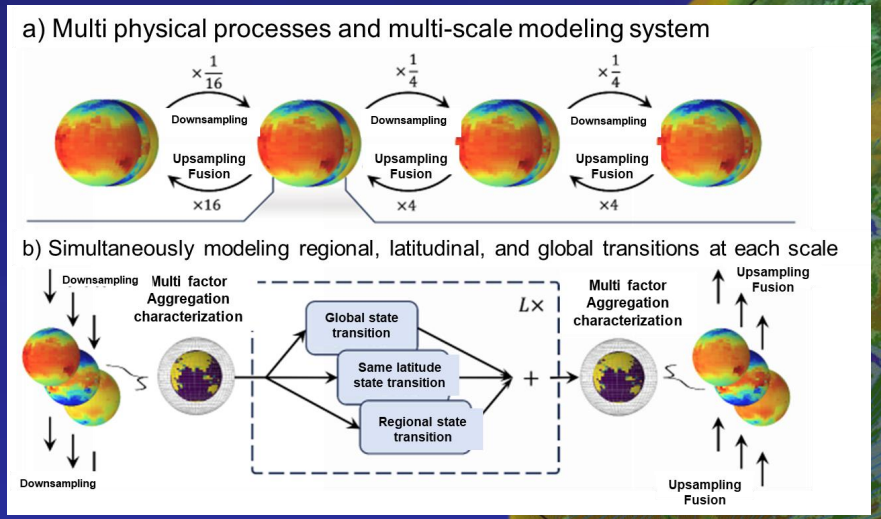
NMC R&D Directions:

- Data-driven deterministic and ensemble model developing (Fengqing).
- Pre-research on end-to-end meteorological models.
- Developing Data-driven’s adaptation models for Hazard weather.
- In-depth testing, verification and feedback on data-driven models.

Fengqing: CMA’s Global AI Weather Model

Fengqing (风清): A Physics-Informed Global AI Model

- Fengqing integrates deep learning with physical principles for fast and accurate global forecasts.
- Key Features:
  - Parameters: 3 billion
  - Scope: Global 3D atmosphere forecast
  - Range: Up to 15 days
  - Speed: ~3 minutes per inference
  - Open: *https://github.com/nmcdev/CMA-AIM-GFS-Fengqing*



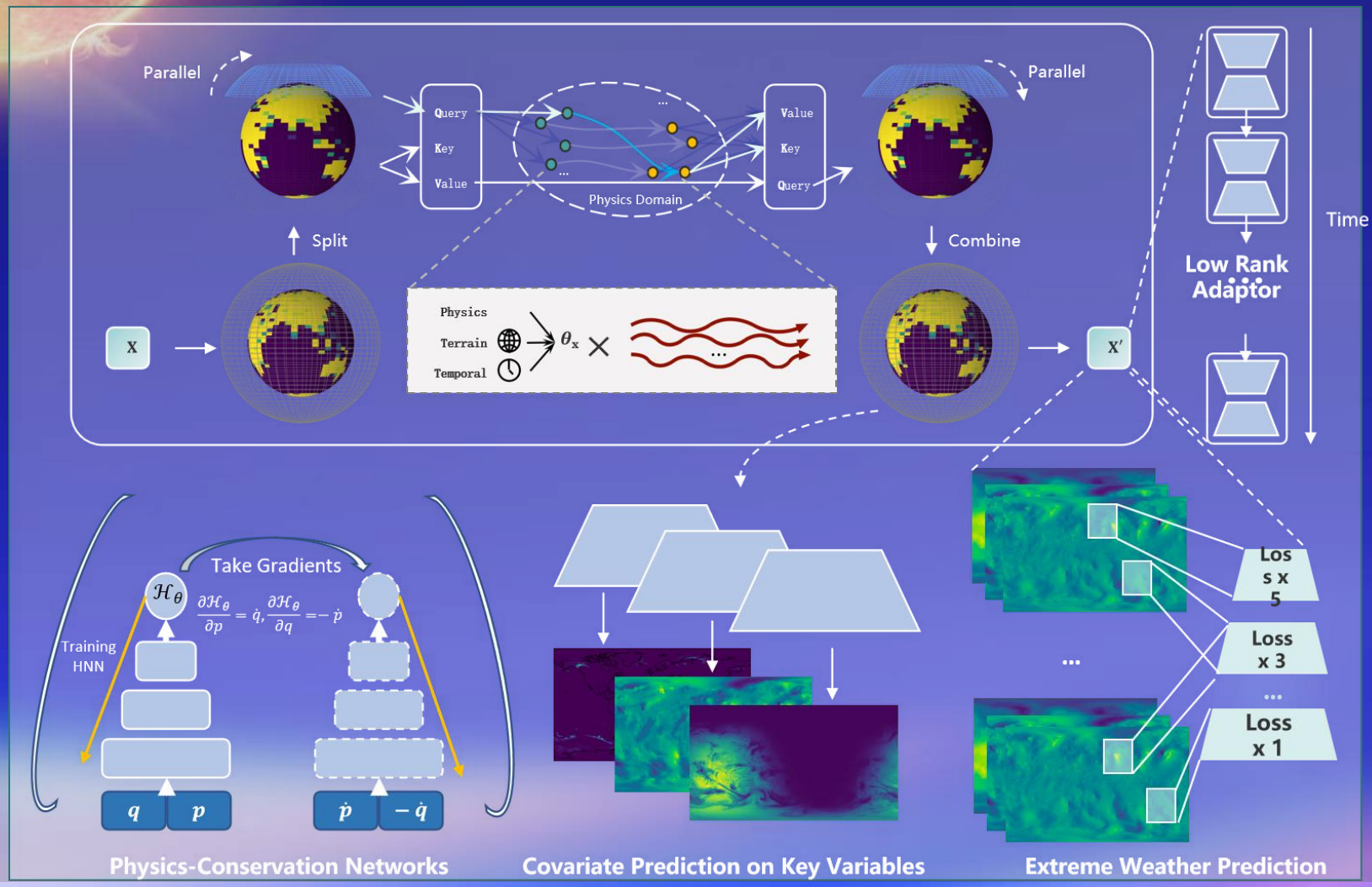
Modeling the multi-scale physical state transitions of atmospheric processes

2023.1-2023.7	2023.7-2023.12	2024.1-2024.6	2024.7-2024.9	2025.1-2025.7
Pre-research work on data-driven models	Early version development	FengQing V1.0 Official Release	Operational Application	Technological Breakthroughs
Collaborate with Tsinghua University to initiate AI model R & D	Based on the Transitor architecture	2024 June: CMA officially launched the Fenglei Model	2024 September: pass the operation access review by CMA	Fengqing 1.5 Physical-contrained AI model

Content

Fengqing V1.5

A physical constrained global short and medium range weather forecasting AI model



1. Physics Conservation

Adaptive Hamitonian Learning

2. Key Elements Forecast

Covariate Prediction paradigms.

3. Precipitation Forecast

Improved Accuracy and Intensity

4. Extreme Weather

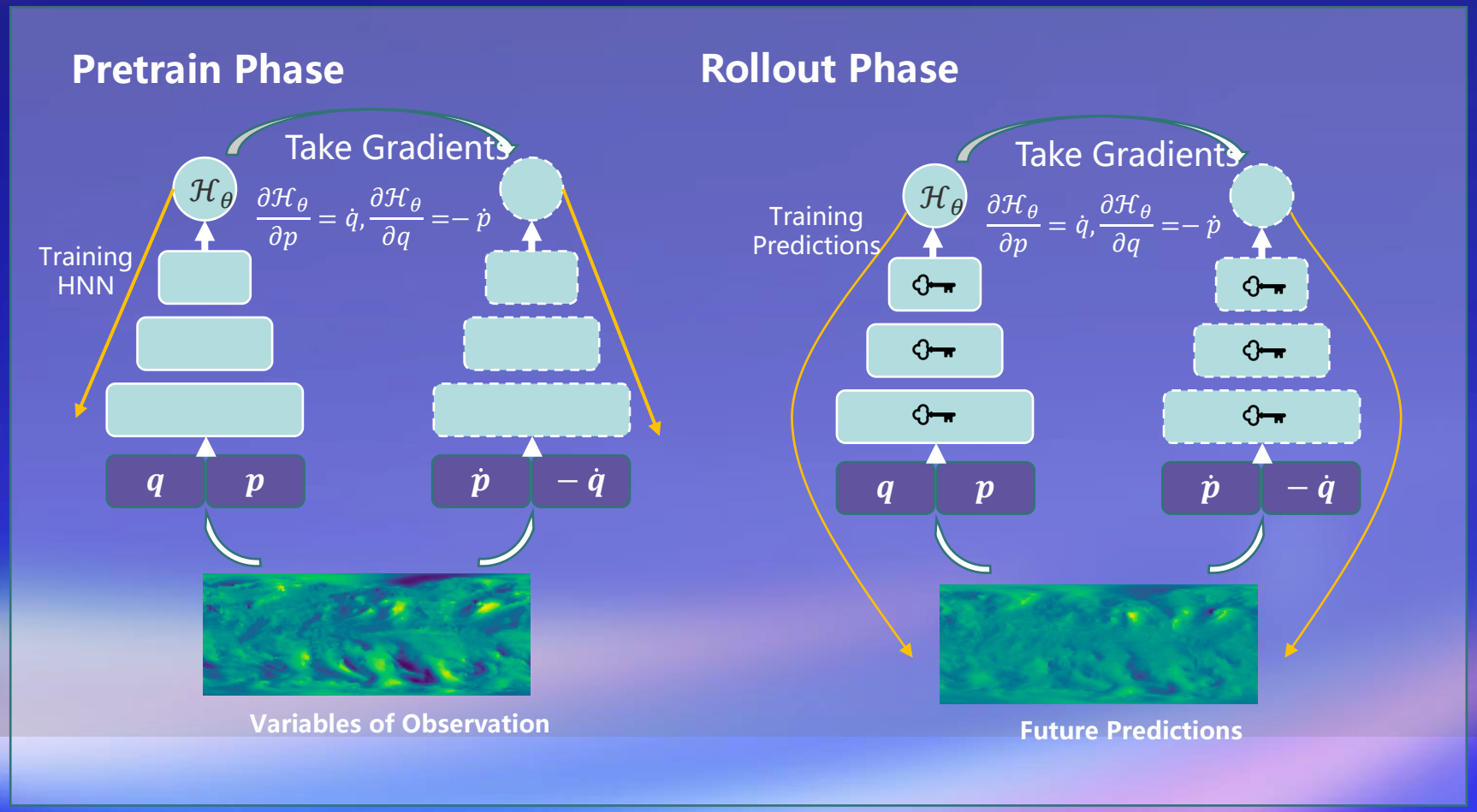
Effective Reweighting Strategy

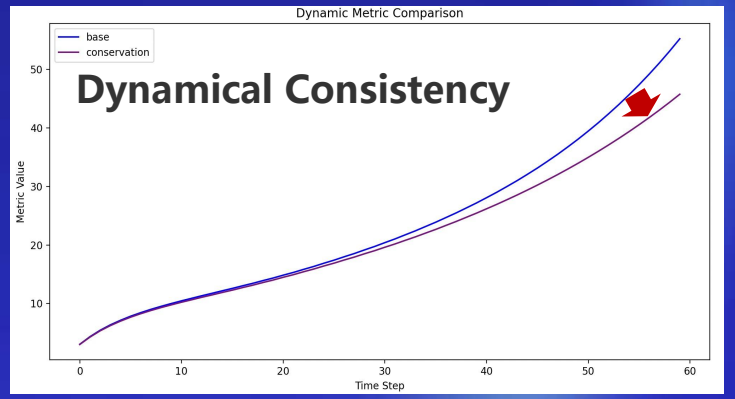
• Upgrade 1: Physics-Conservation Networks

We propose an adaptive framework to learn the complex conservation relationships among physical variables, serving as soft constraints for future predictions.

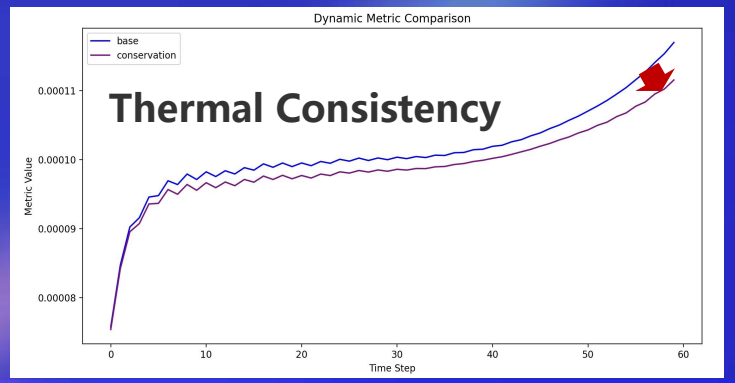
✓ **Hamiltonian Neural Network** formulates Hamiltonian of the atmospheric dynamics.

✓ **Two-Phase Strategy** ensure physically consistent long-term evolution with HNN.





Improved Physically Consistency on Vorticity

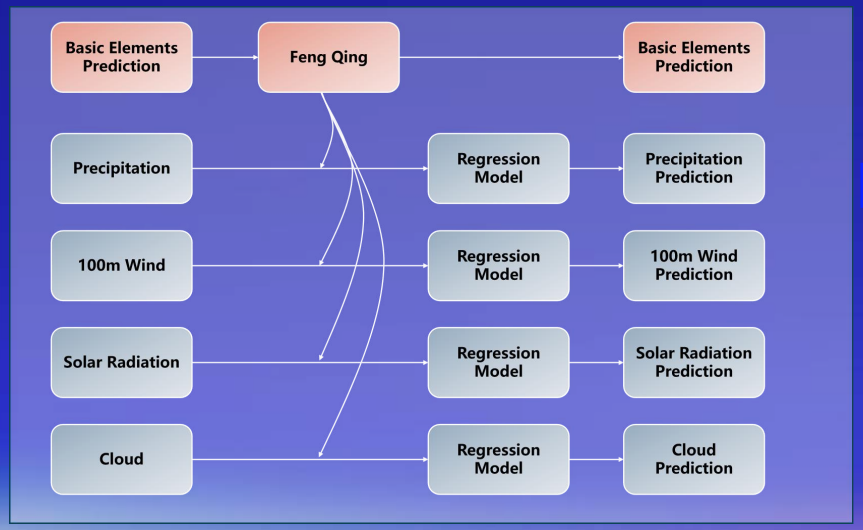


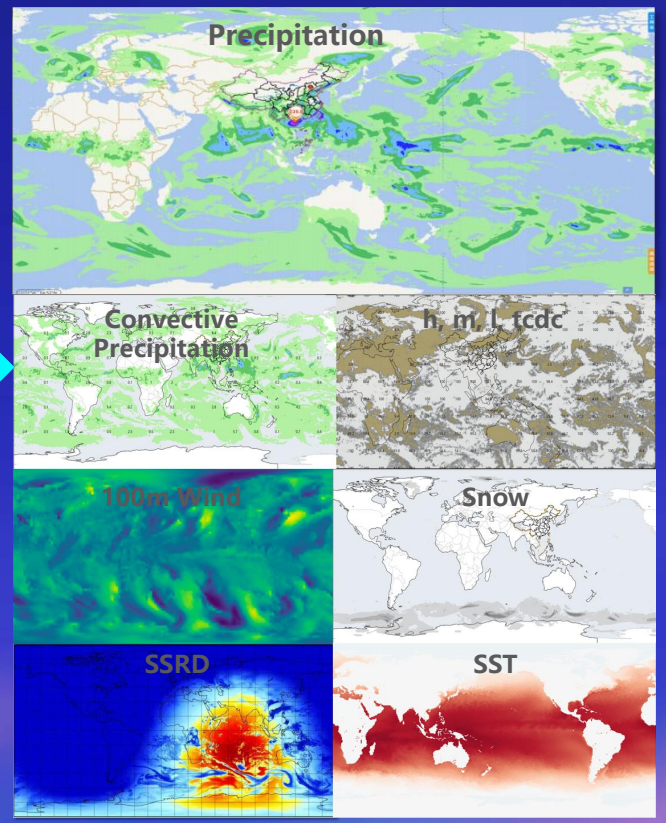
Improved Physically Consistency on Advectio

• Upgrade 2: Enhanced Prediction of Key Weather Elements

- The second upgrade introduces **a new architecture for forecasting Key variables** like precipitation, wind, and solar radiation. The Covariate Prediction Structure coordinates these predictions, **ensuring consistency between linked variables** (e.g., cloud cover and solar radiation) to avoid conflicts and improve accuracy.

Covariate Prediction Structure



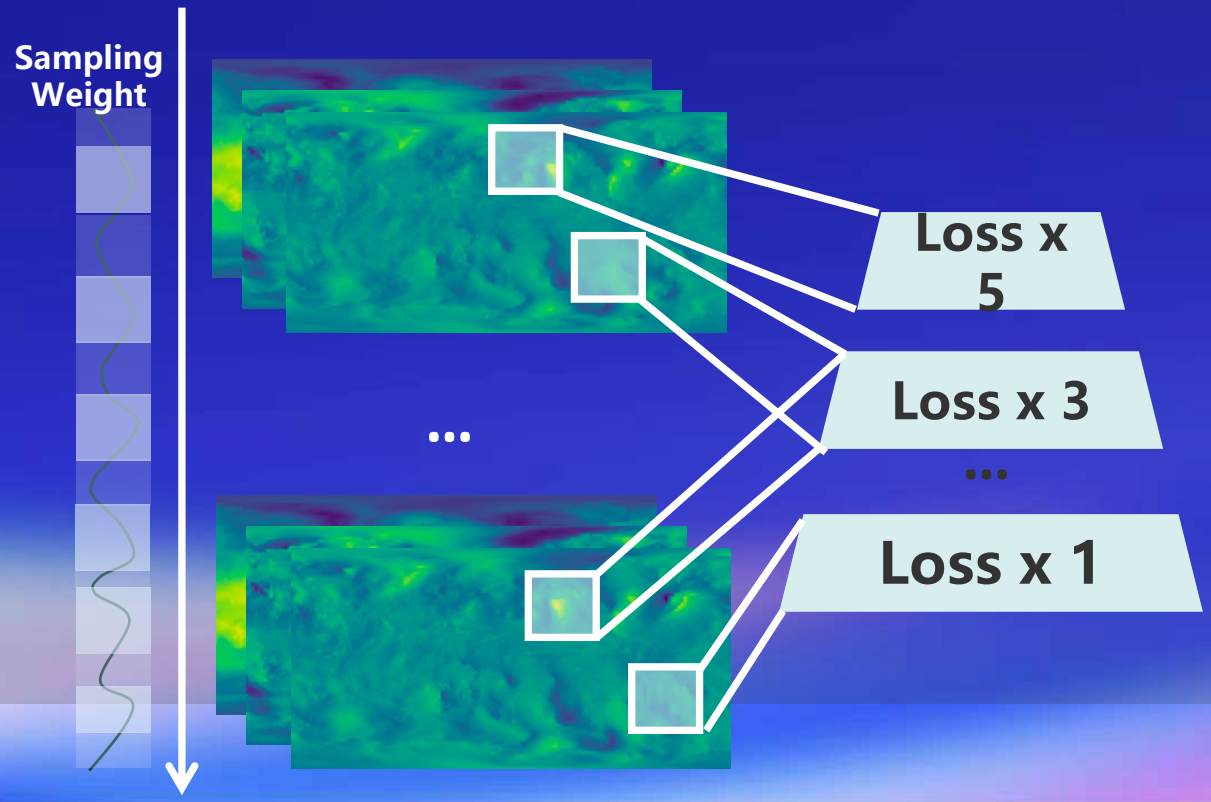


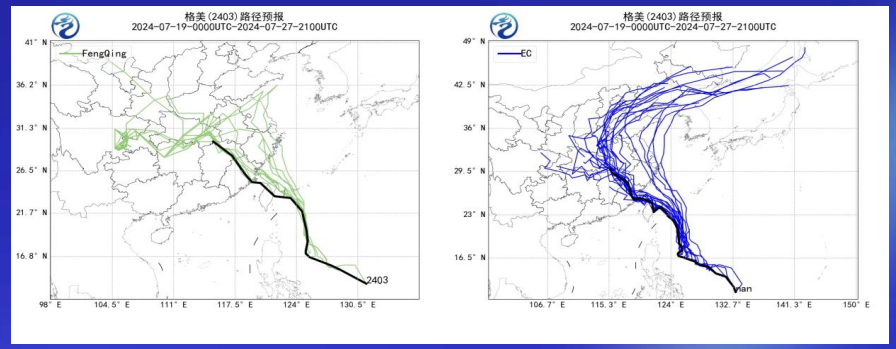
Directly addresses the needs of critical sectors like energy, agriculture, and water management et al.

• Upgrade 3 Hazard Weather Optimization

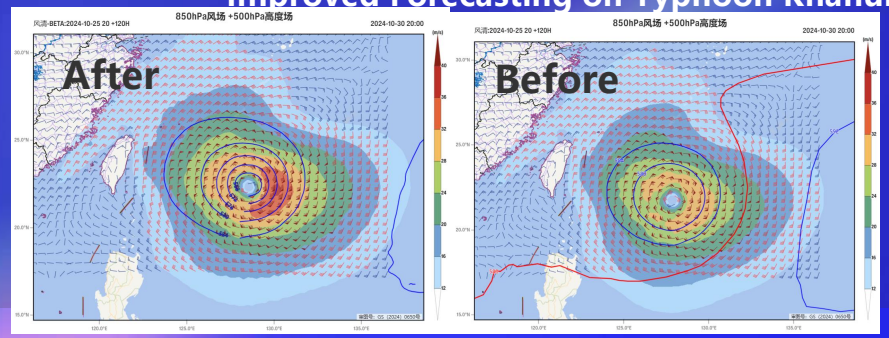
An effective training strategy tailored to extreme weather enhances the model’ s capability in forecasting high-impact events such as typhoons.

- ✓ **Meteorology-based optimization stragety,** through strong wind or high gradient area to objectivly identify hazard weather area, ensures higher focus on high-impact zones.
- ✓ **Frequency-aware sampling** during extreme weather seasons prioritizes high-risk periods.





Improved Forecasting on Typhoon Khanun



Improved Forecasting on Typhoon intensity

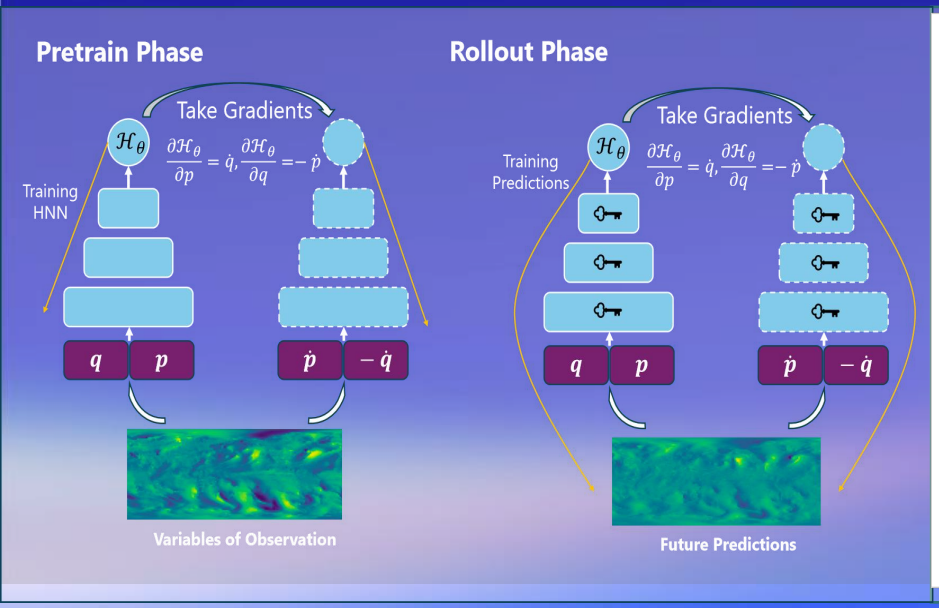
Content

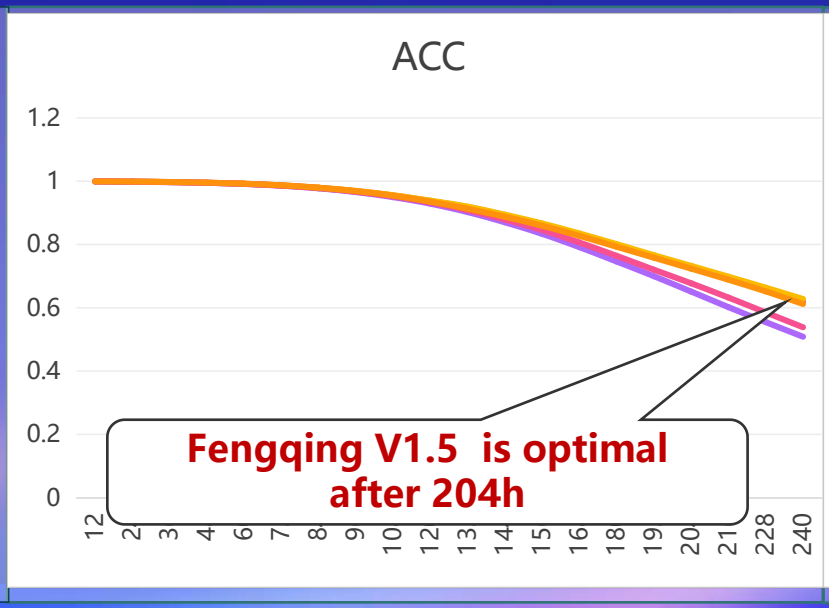
• Physics-Conservation Networks

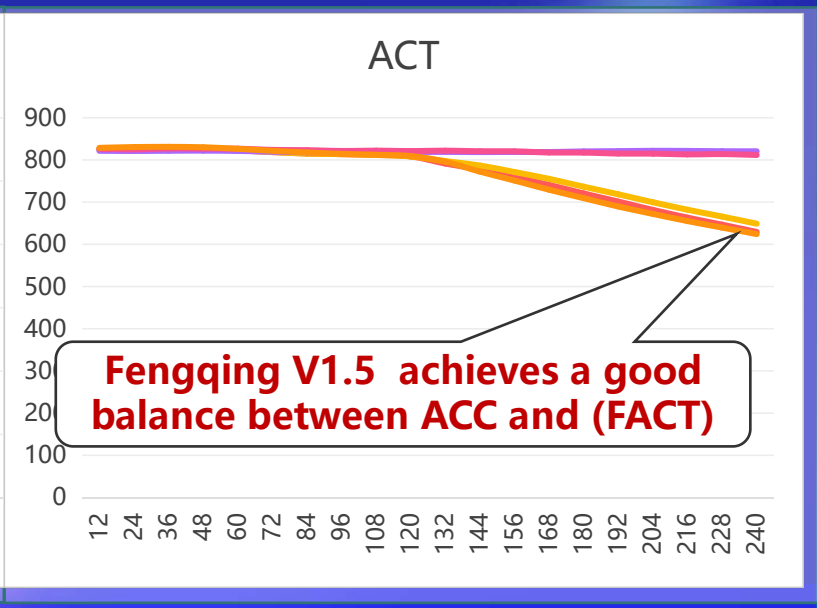
- **Focus on evaluating the two main attributes of model prediction: consistency (Consistency) and discrimination ability (Discrimination). Consistency checks whether the forecast matches the observed distribution, while discrimination power evaluates the ability to predict different weather events.**

✓ FengQing’ s 500hPa geopotential height anomaly correlation coefficient (ACC) ranks among the top, with affective forecast days up to 10.5 days.

✓ FengQing’ s achieves a good balance between ACC and Forecast activity (FACT) compared with the others.

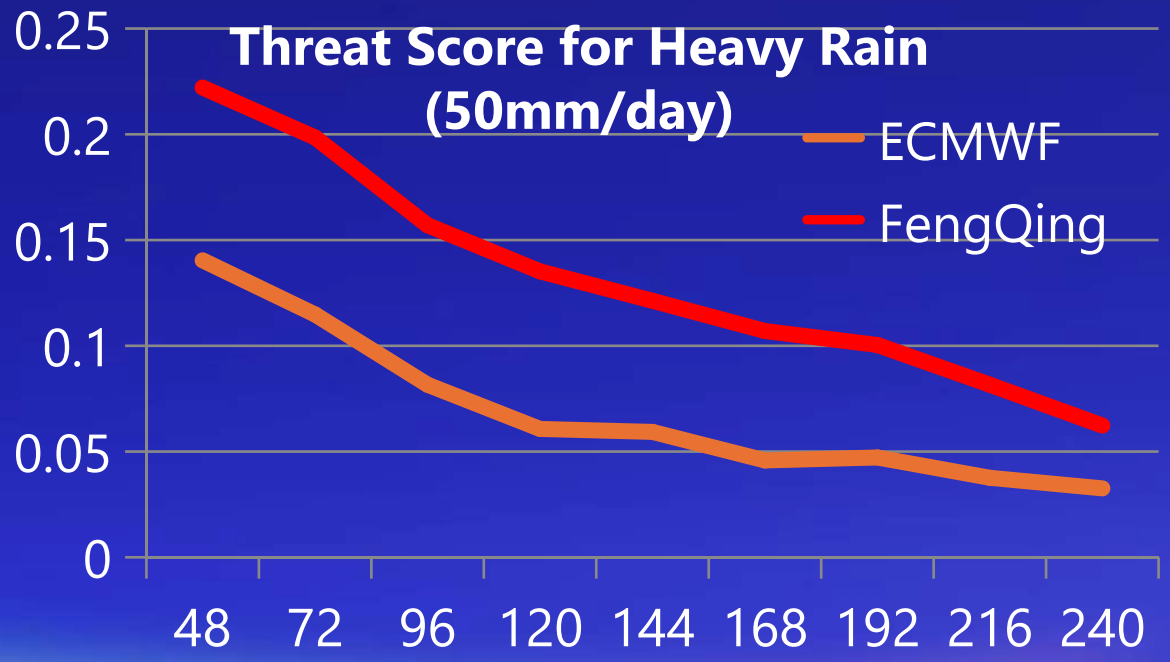




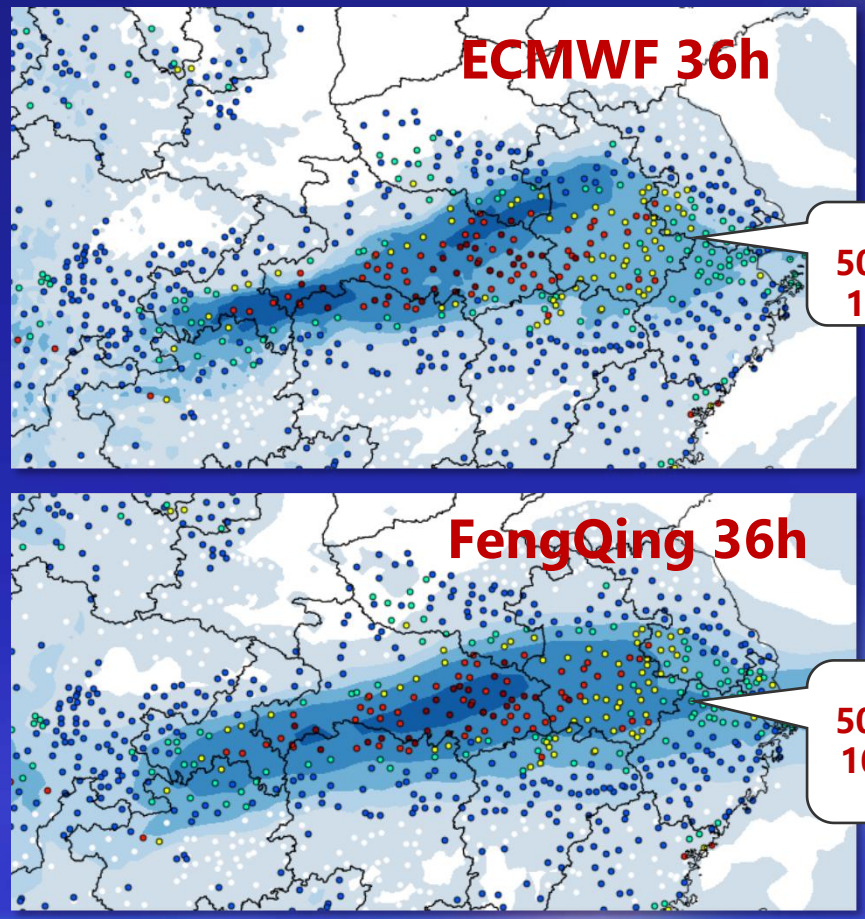


Enhanced Forecast of Precipitation

- The covariate prediction strategy leads to improved precipitation forecasting, achieving gains in both accuracy and physical consistency, especially on heavy rains.

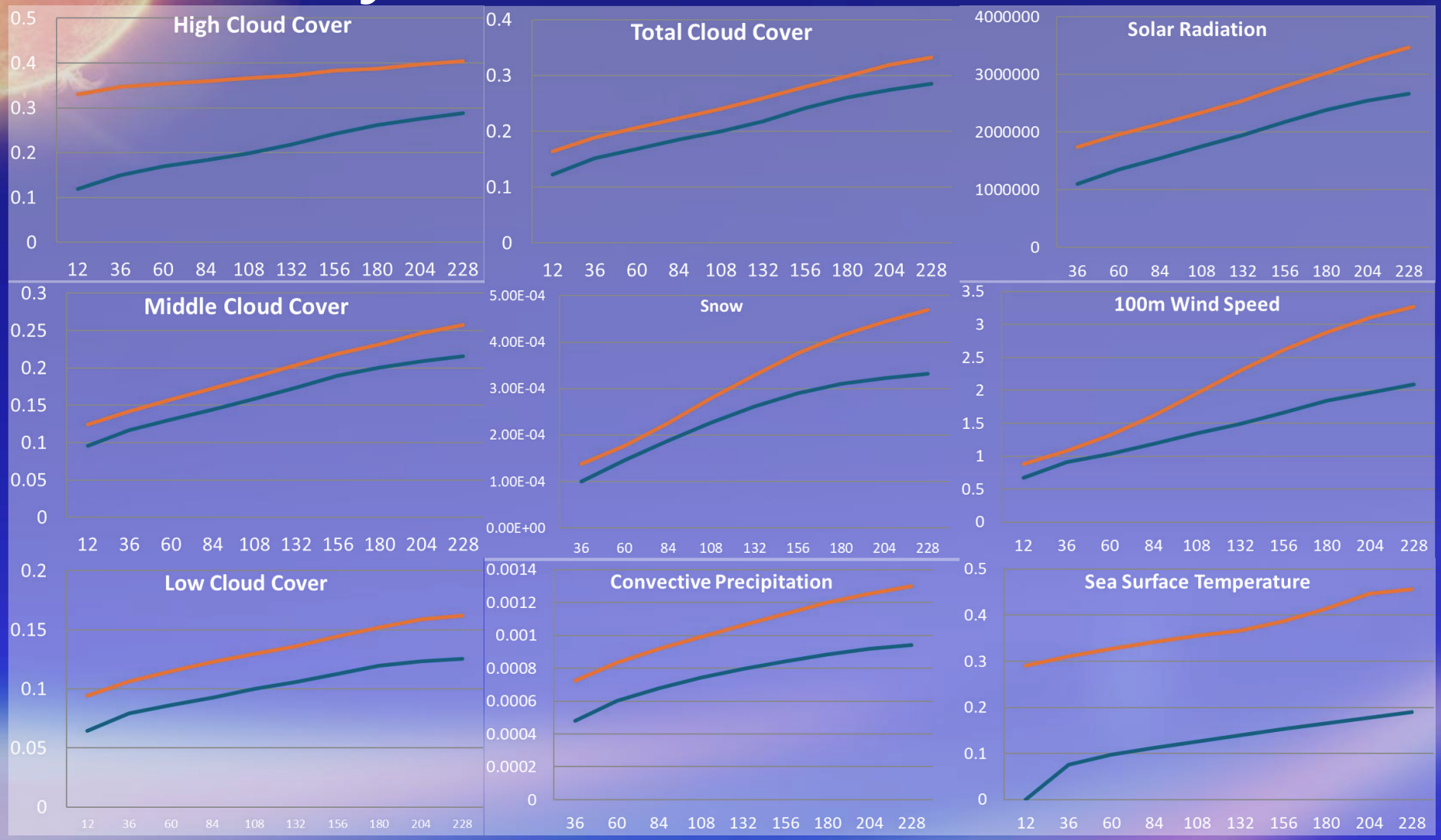


24-hour cumulative precipitation forecast for China region from April to September 2024 based on site observation verification



24 hours accumulated precipitation forecast of **MeiYu Events**

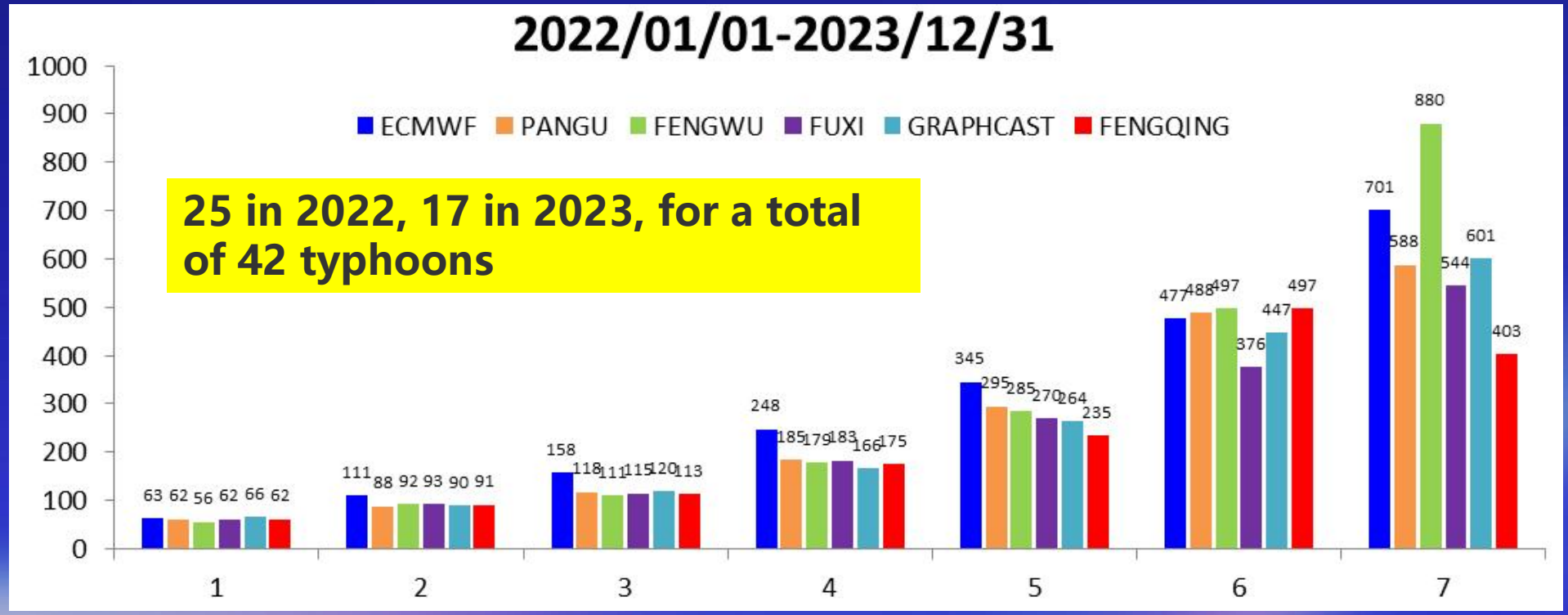
• Other 9 Key Weather Elements (MAE)



Outperforms ECMWF IFS in Mean Absolute Error (MAE) for many of these key surface variables.

• Typhoon Trcaks

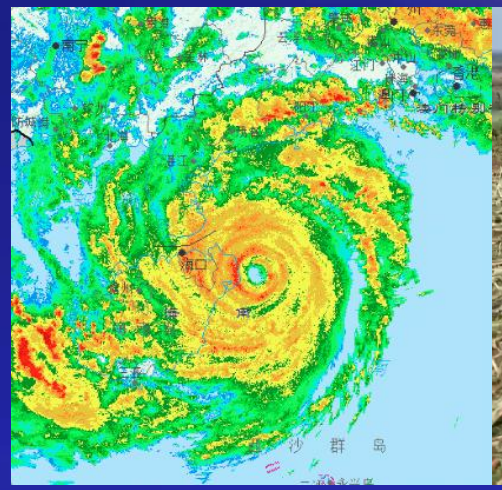
➢**FENGQING: the bias of typhoon tracks forecast is low, especially in the long-term range(5 days and 7 days)**

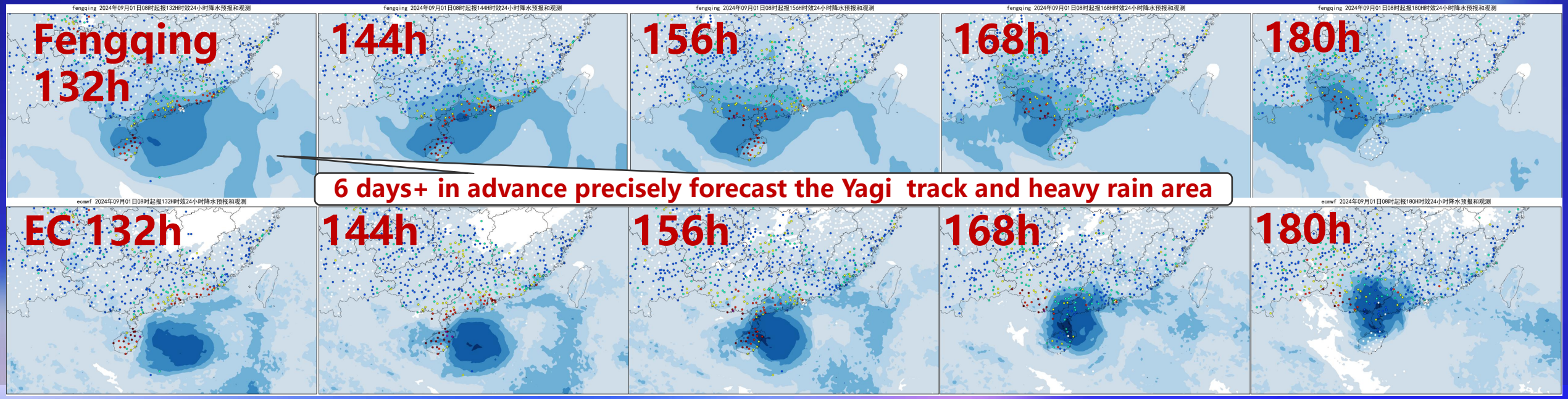


*PANGU, FENGWU, FUXI, GRAPHCAST are all public version obtained from github.

• Verification

- **Super Typhoon Yagi**
- **Accurate forecasting provides strong support for disaster weather Early warning**
  - ✓ Better Typhoon Track forecast
  - ✓ **Better precipitation area forecast**

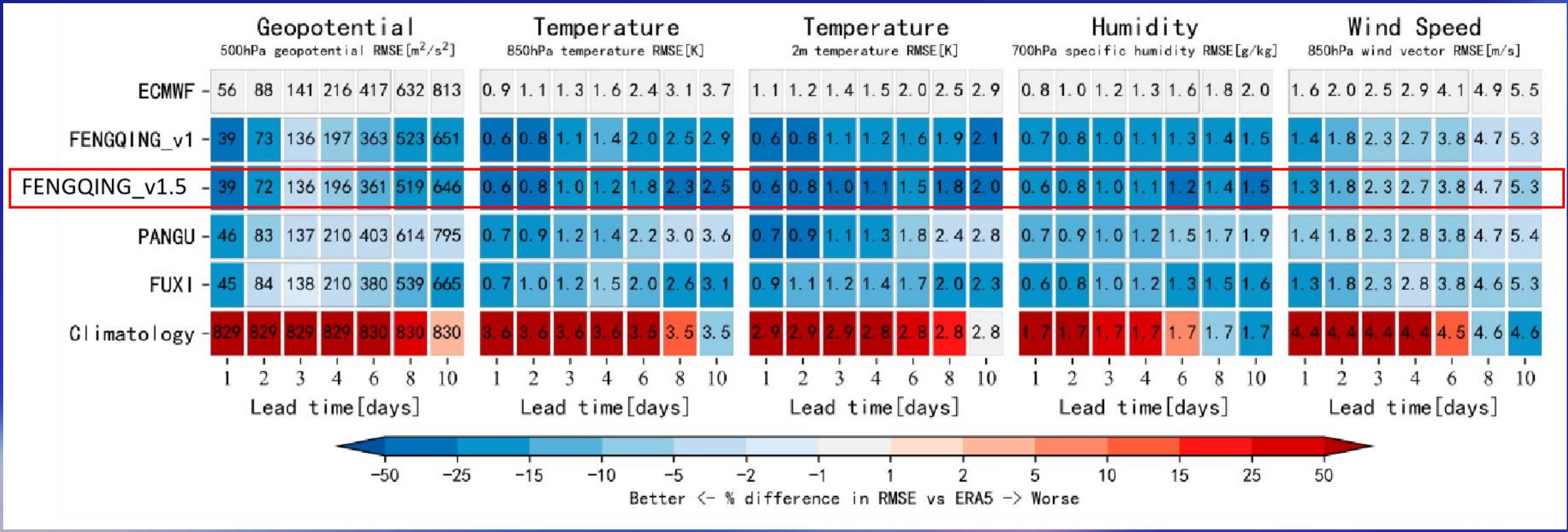




• Typical Forecasts Elements

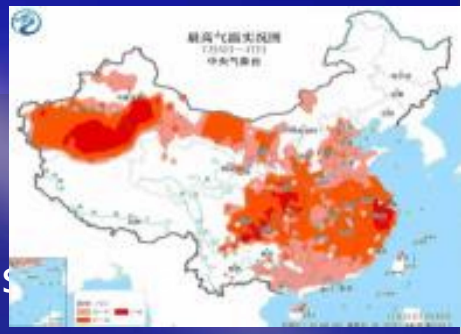
RMSE scores shows that, the prediction of 500 hPa geopotential height, 850 hPa temperature, 700 hPa humidity and 2m temperature especially in the short-term (1-2 days) and long-term (8 days) duration, RMSE is generally lower than other AI models.

□Especially for the 2m temperature, the FENGQING model forecasts are generally optimal.

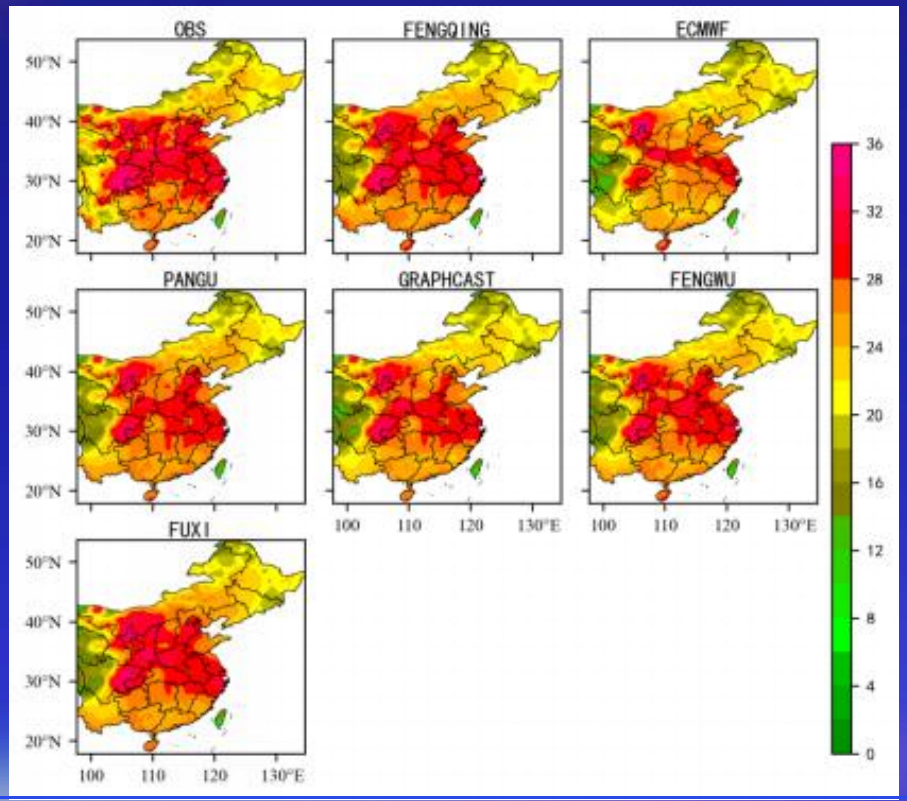


• Hazard Weather Events —— Heatwaves

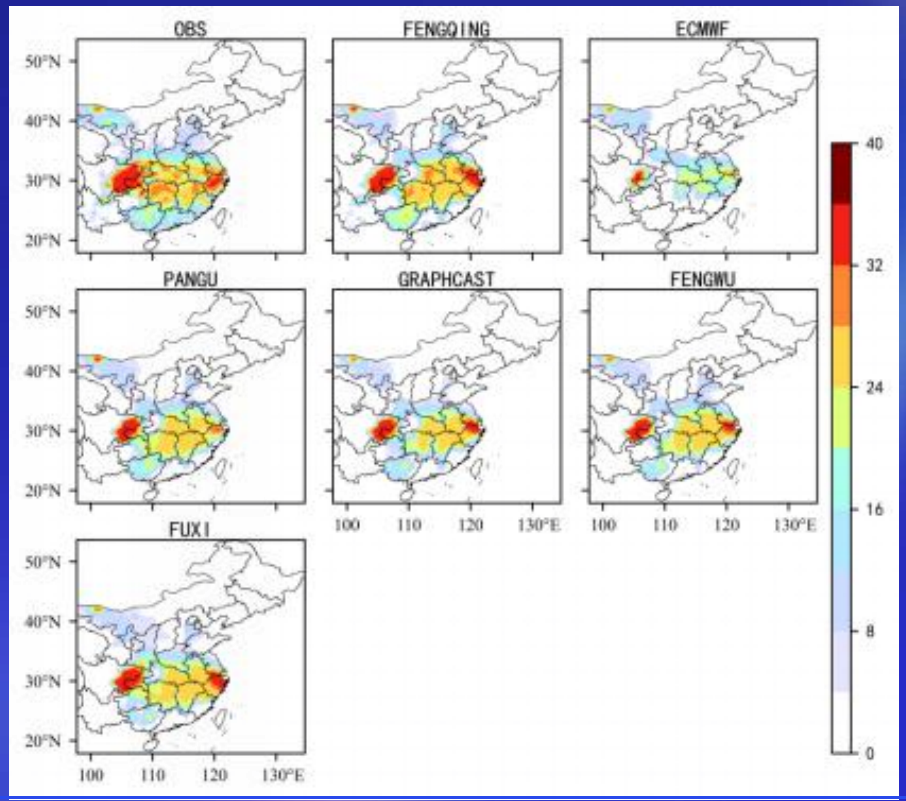
- Heatwaves in 2022 is widespread, affecting southern China from July 5 to 17.
- The high temperature range and intensity of AI model are better than ECMWF; the wind model is



2m temperature spatial distribution forecasted by models with the lead time of 72h



Times of > 30℃ during the heatwave event (0705-0716) forecast

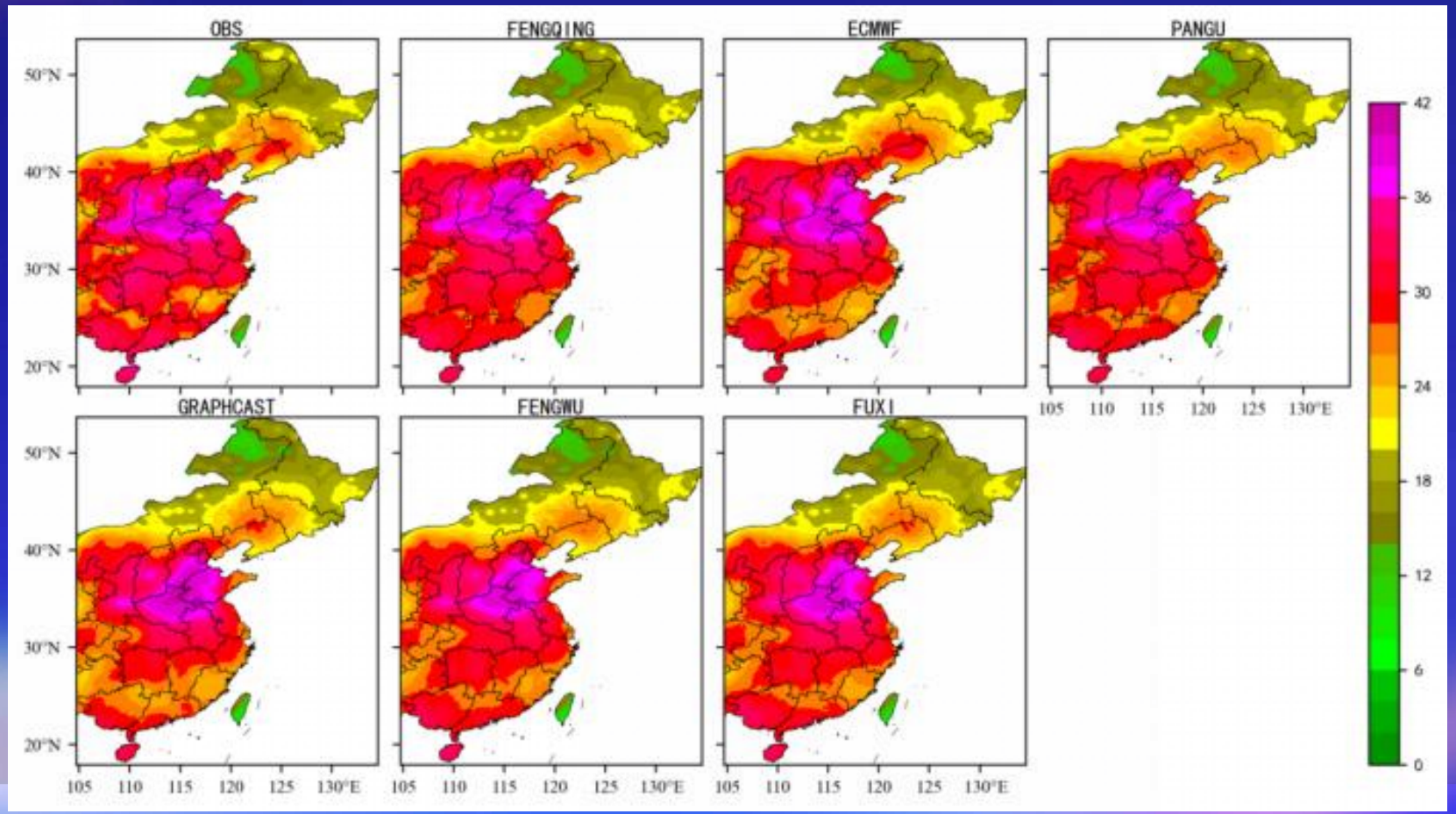


On July 7	Fengqing	ECMWF	PANGU	GRAPHCAST	FENGWU	FUXI
MAE	**1.79**	2.85	2.10	2.32	2.09	1.98
Hit rate	**0.68**	0.44	0.62	0.56	0.61	0.63

	Fengqing	ECMWF	PANGU	GRAPHCAST	FENGWU	FUXI
MAE	**1.62**	2.63	1.90	2.04	1.94	1.86
Hit rate	**0.71**	0.47	0.65	0.61	0.64	0.66

• Hazard Weather Events —— Heatwave

- In mid-June 2024 ,the North China region experienced a severe heatwave. The FENGQING model can accurately forecast the scope and intensity of high-temperature weather,and it also achieves the highest score in statistical verification with MAE about 0.57℃.

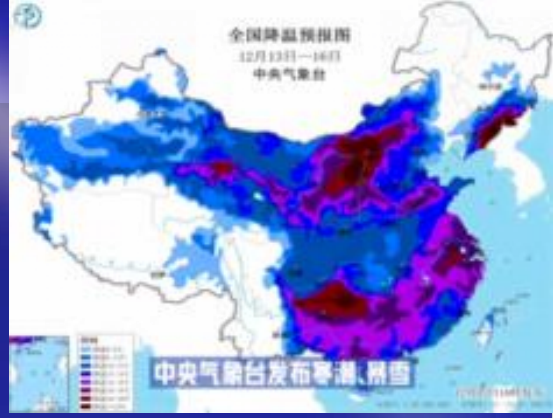


Forecast score

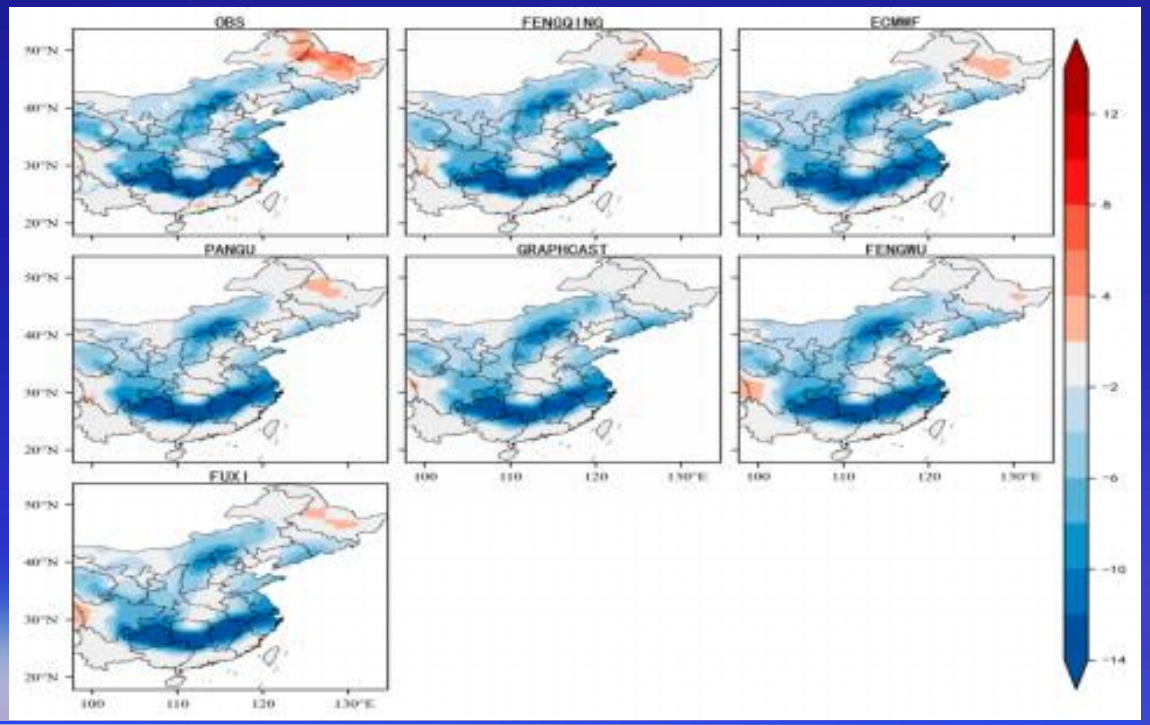
	Hit Rate	MAE
Fengqing	**0.57**	**2.01**
ECMWF	0.53	2.24
PANGU	0.55	2.12
GRAPHCAST	0.52	2.32
FENGWU	0.53	2.26
FUXI	0.53	2.27

Hazard Weather Events —— Coldwave

- China experienced the strongest nationwide cold wave in winter from December 13 to 16,2023, with five yellow, five orange and one blue warnings issued.
- For temperature decreasing range,forecasts of FENGQING is closest to the observations,and it also has the best in statistical verification.

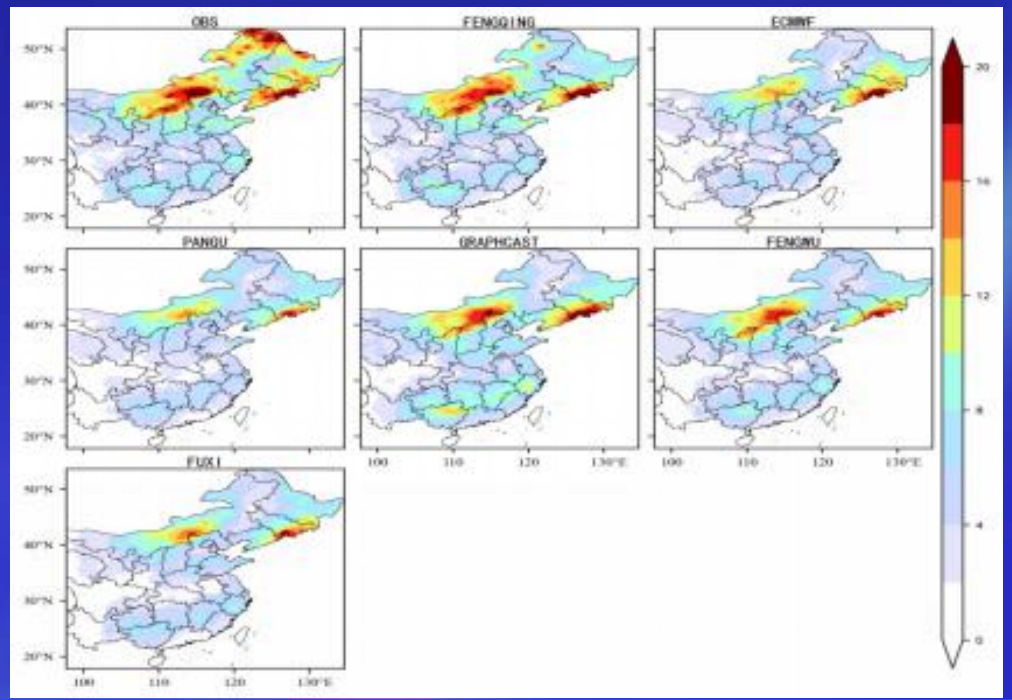


20:00-72h on December 15,2023



December 15th	Fengqing	ECMWF	PANGU	GRAPHCAST	FENGWU	FUXI
MAE	**1.59**	1.95	1.78	1.79	1.74	1.71

On 20-December, 0-72h was greater than-6℃

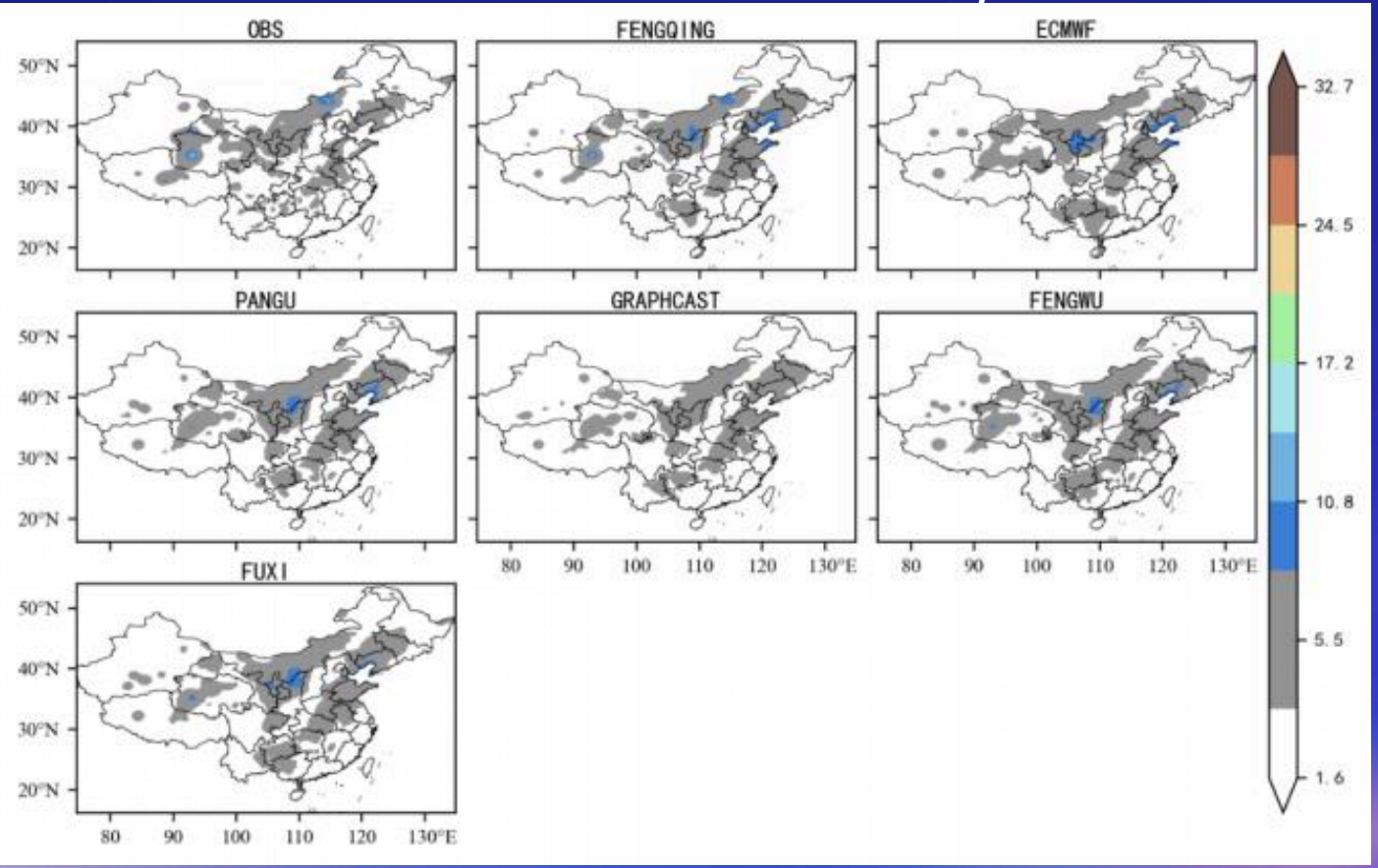


November-December	Fengqing	ECMWF	PANGU	GRAPHCAST	FENGWU	FUXI
MAE	**1.44**	1.65	1.51	1.70	1.47	1.49

• Hazard Weather Events —— Gust

Similarly, in the coldwave event from December 13-16,2023, the gusts accompanied by class 6~8 in most areas of the event.

At 20:00　0-48h on December 15,2023



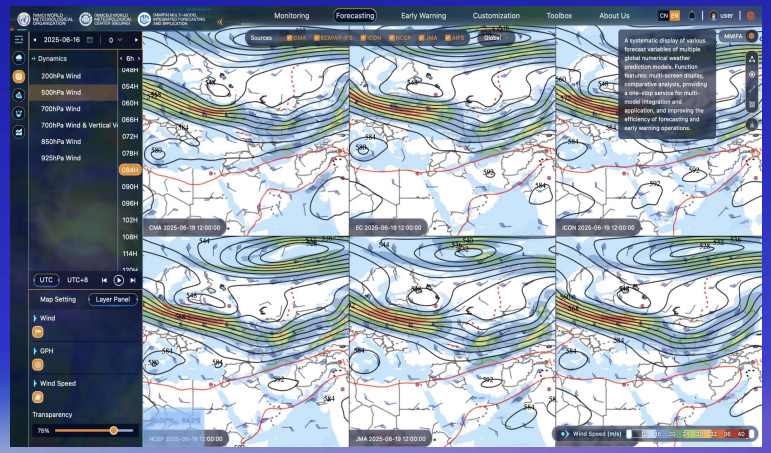
December 13-16 Forecast Scores

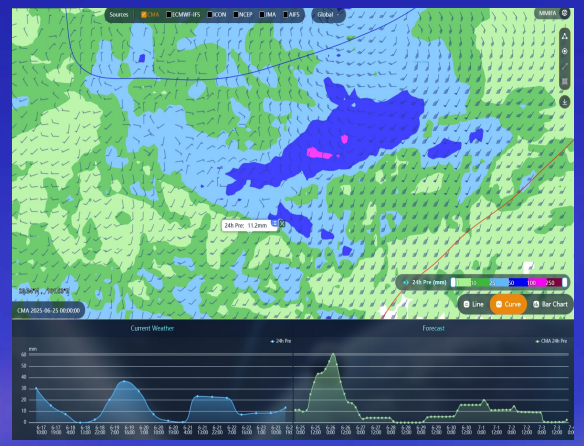
	Hit Rate	MAE
Fengqing	**0.41**	**1.40**
ECMWF	0.38	1.52
PANGU	0.41	1.39
GRAPHCAST	0.41	1.37
FENGWU	0.40	1.40
FUXI	0.40	1.41

Applications of Data-driven AI models

- At CMA, severial **data-driven weather forecasting models including Fengqing** have been implemented. These models are now real-timely providing forecasts and directly integrated into operational platform for use by forecasters.

- **High-resolution Monitoring: Utilizes satellite, surface station, and gridded analysis data to support global weather monitoring.**
- **MMIFA (Multi-Model Integrated Forecast Application) Support: This platform integrates outputs from multiple forecasting models, including 5 NWP models and 2 AI models, enabling a comprehensive application of both traditional and AI-based forecasts.**





The integration of diverse forecasting models into a single platform offers a unified and efficient solution for early warning operations, enabling users to access and compare multiple model outputs in one interface.

Content

Challenges and Perspective

Although data-driven AI models are developing rapidly, there are still gaps:

- How to endow AI models with the ability of quantifiying forecast uncertainty information, so as to **capture the extreme weather**.
- How to integrate physical constraints into AI models to **enhance the forecast reliability and continuation, dynamical/physical interpretability of forecast results**.
- ……

Recent plans:

- We will continue to follow the developing route of AI+Physics to enhance the ability to forecast processes on a smaller scale. Such as polishing the model structure, improving the spatiotemporal resolution, refining the forecast details of medium-long range， adding more forecast elements.
- Towards more different application senarios, based on the Fengqing outputs, we will utilize kinds of observation to bulid N small models for different special services, So as to provide more comprehensive services to all aspects of society.


Thanks!