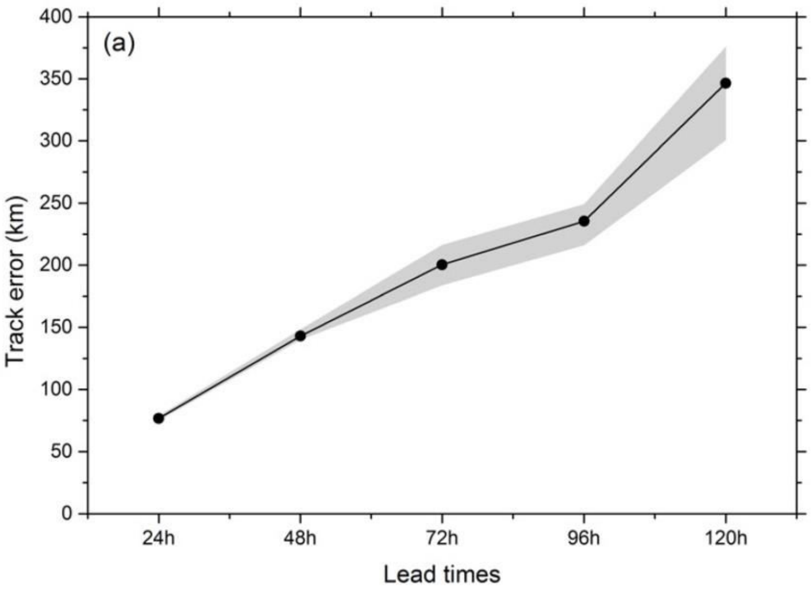
A Hybrid model of CMA-TRAMS and Pangu-Weather: framework and application

Guangzhou Institute of Tropical and Marine Meteorology/
Guangdong Provincial Key Laboratory of Regional Numerical Weather Prediction，CMA

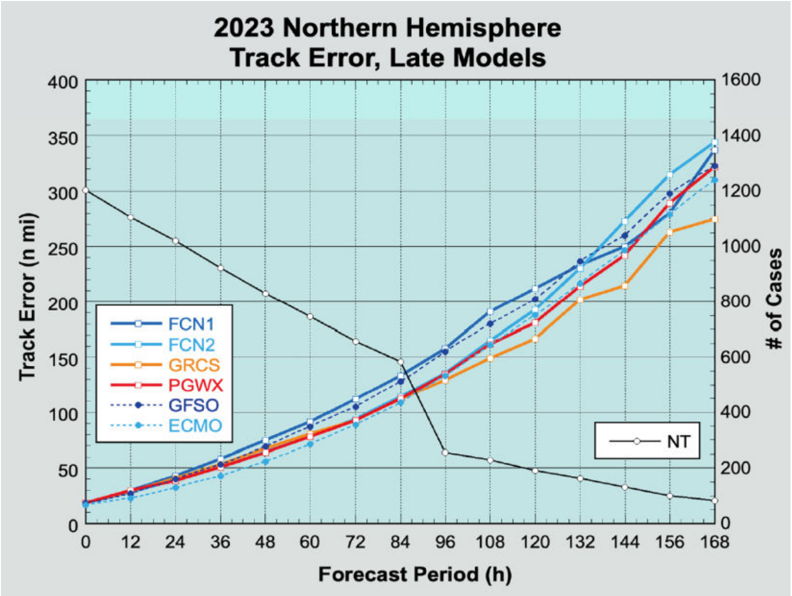
Outline

Introduction

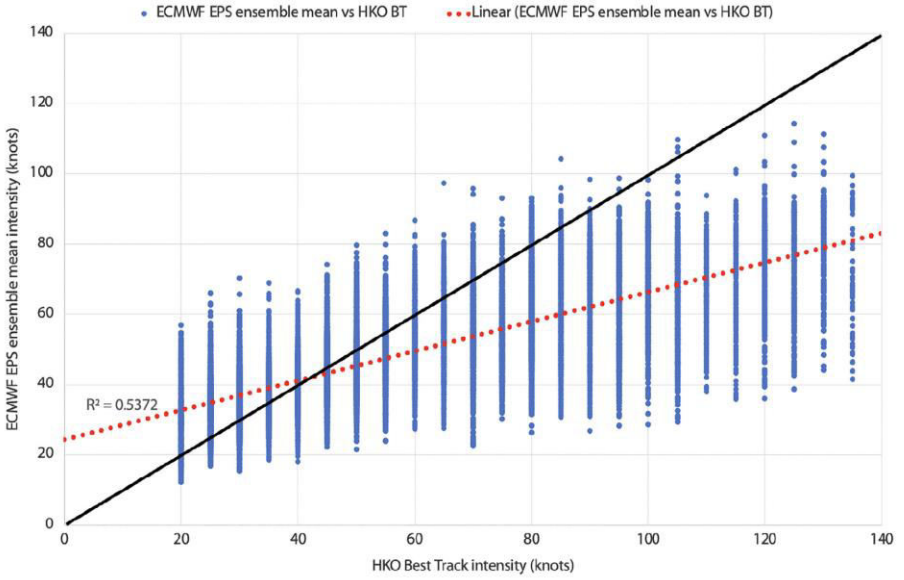
- Forecasting techniques based on numerical weather prediction (NWP) models have become the most important tools in weather forecasting.
- NWP models are still poor in the TC track forecasting at longer lead times and in the TC intensity forecasting for stronger cases (especially RI).



Annual mean PEs for track of the CMA official forecast guidance in 2022 (Yu et al. 2024)



Mean track errors for the late versions of the AIWP, GFS, and ECMWF models, for cases from May to November 2023 (DeMaria et al. 2025)



ECMWF EPS mean versus HKO BT intensity for TCs over the western North Pacific from 2016 to 2019 (Chan et al. 2021)

Introduction

CMA-TRAMS is a regional NWP model, which is developed by GITMM, CMA based on the GRAPES model.

Resolution: 0.09°, 65 vertical layers

Region: 70~161°E，0~51°N

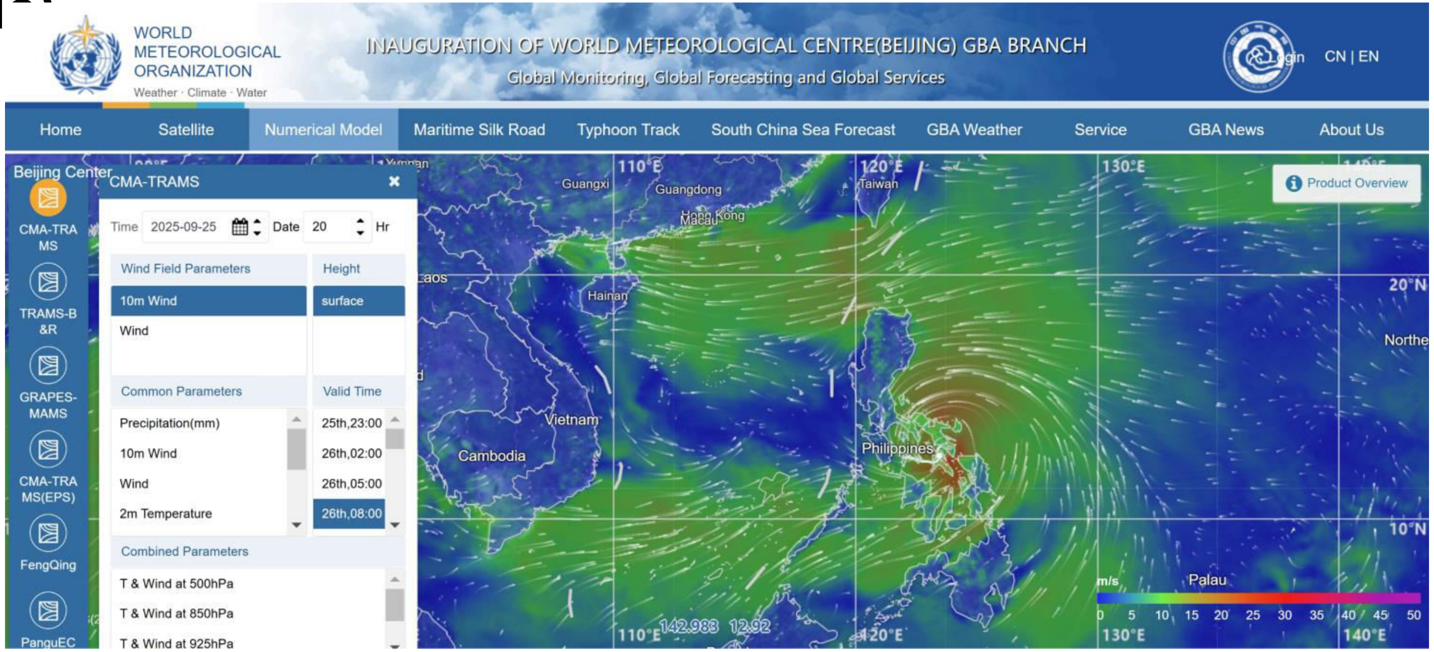
Initialization: (Cloud Analysis) Nudging + Land surface analysis

Init Time: 00/12z, T+168hrs FCS; 06/18z, T+72hrs FCS **(Deterministic)**

00/12z, T+120hrs FCS **(Ensembl**

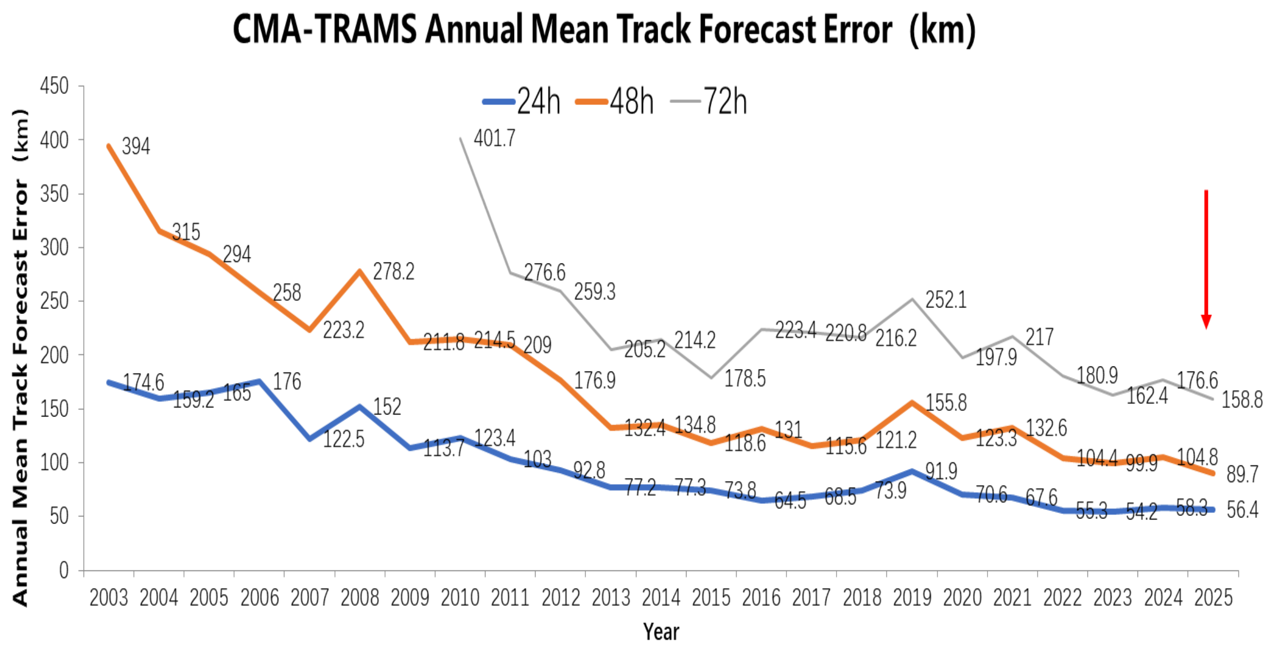
Products:

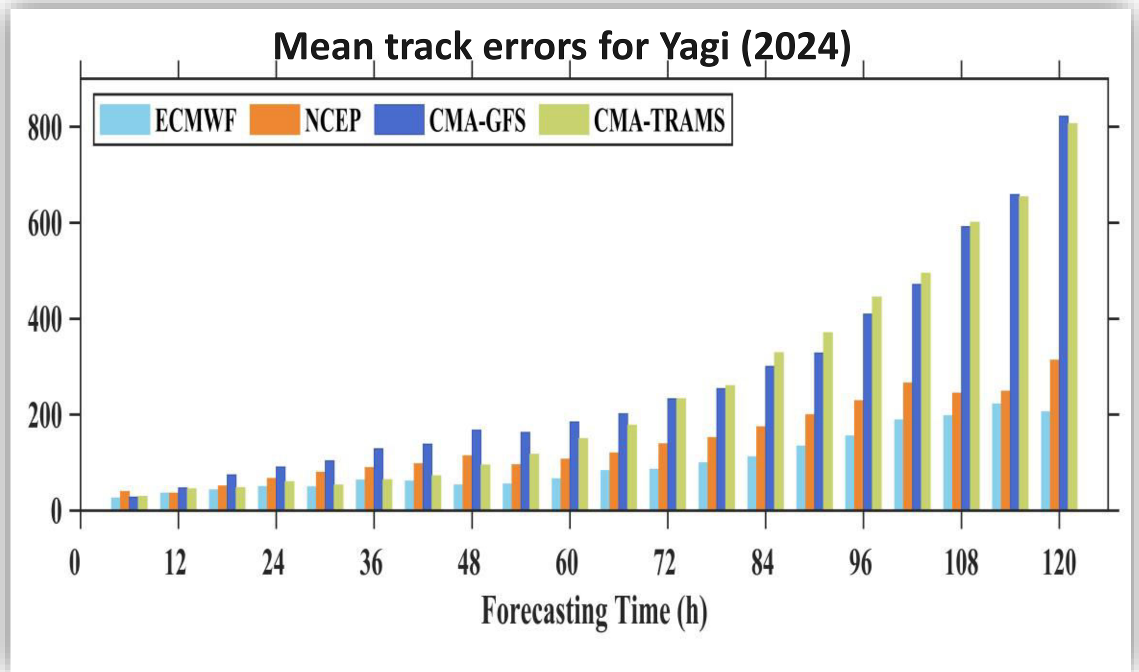
- TC track and intensity;
- Upper-air meteorological variables;
- Surface variables (e.g., precipitation)



Introduction

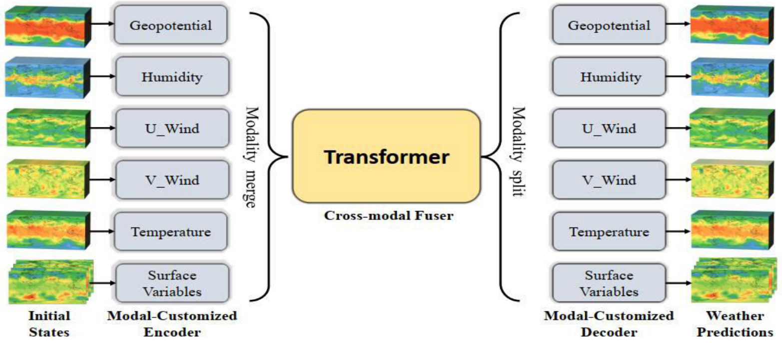
- Although the performance of CMA-TRAMS in TC track forecasting has generally been improved year by year, it is still poor in the longer-term forecasting of TC track for some TC cases.



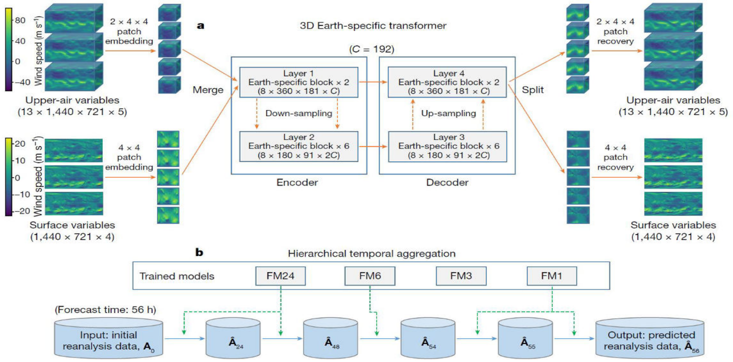


Introduction

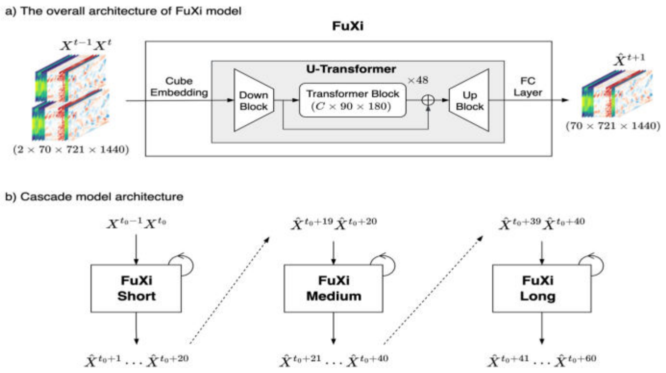
Artificial intelligence (AI) technology is rapidly advancing, with data-driven weather forecasting models (such as Pangu, Fuxi, Fengwu, AIFS, and GraphCast) gradually evolving



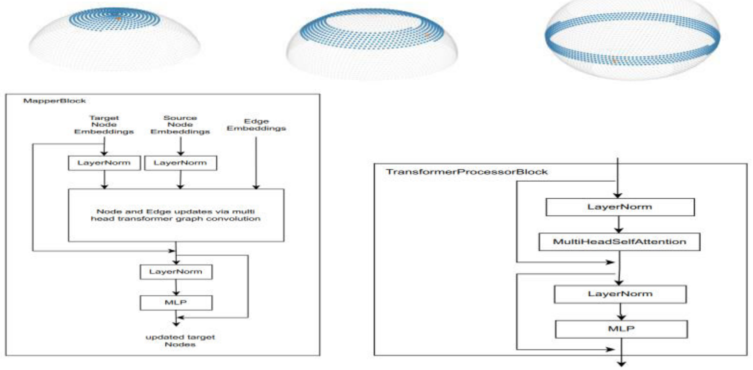
Fengwu (K. Chen et al., 2023)



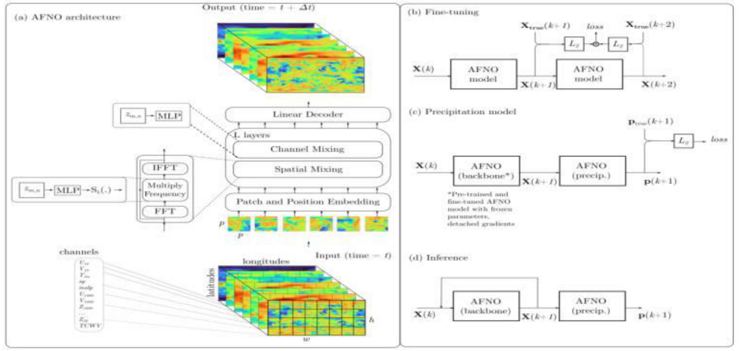
Pangu (Bi et al., 2023)



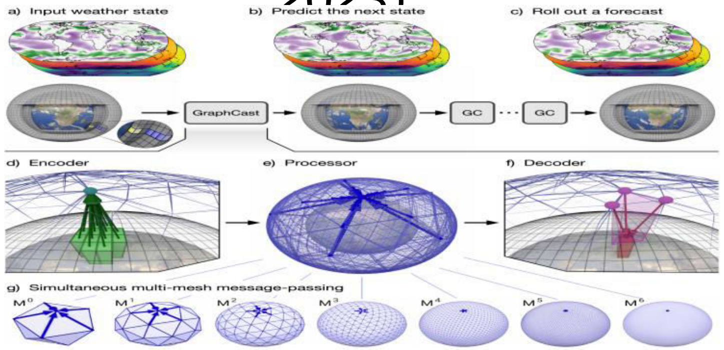
FuXi (L. Chen et al., 2023)



AIFS (Lang et al., 2024)



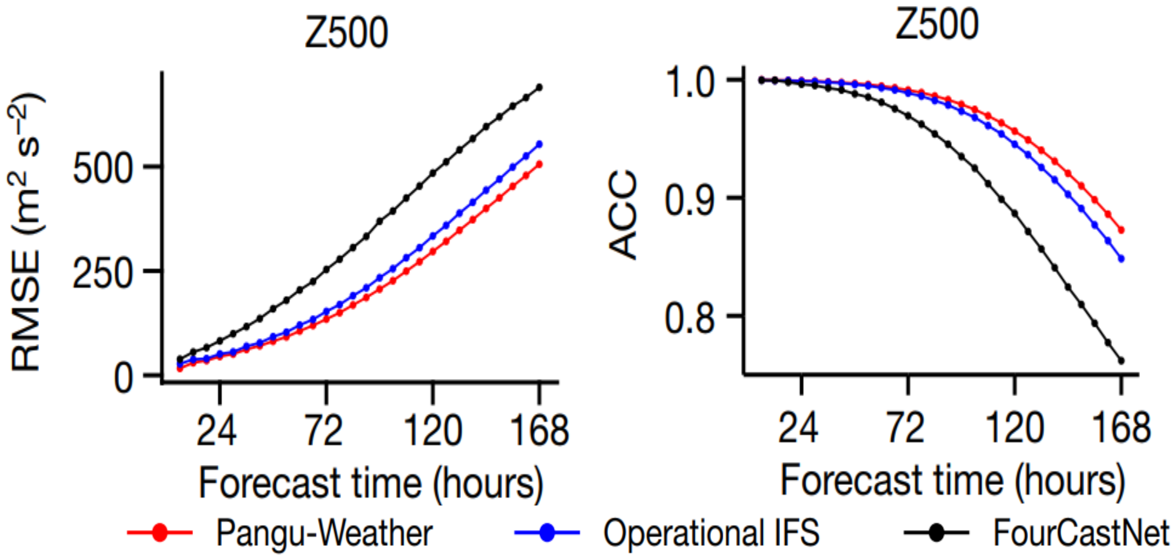
FourCastNet (Pathak et al., 2022)



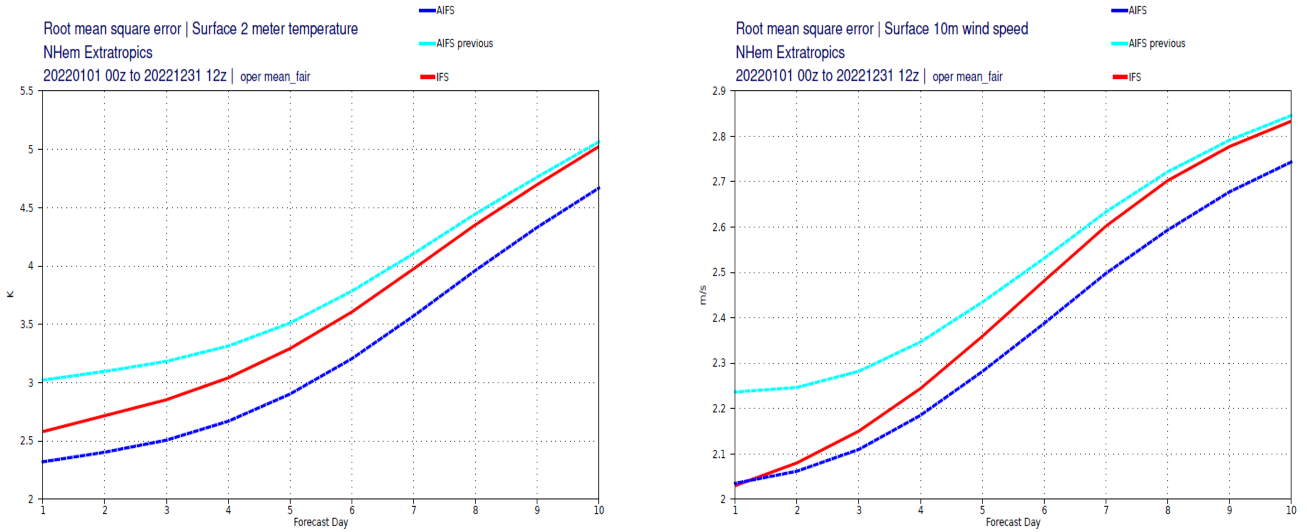
GraphCast (Lam et al., 2023)

Introduction

Compared with some operational global models (such as ECMWF IFS), AI-based weather models exhibit comparable or even superior forecasting skills in the spatial-temporal evolution of large-scale meteorological variables at higher levels.



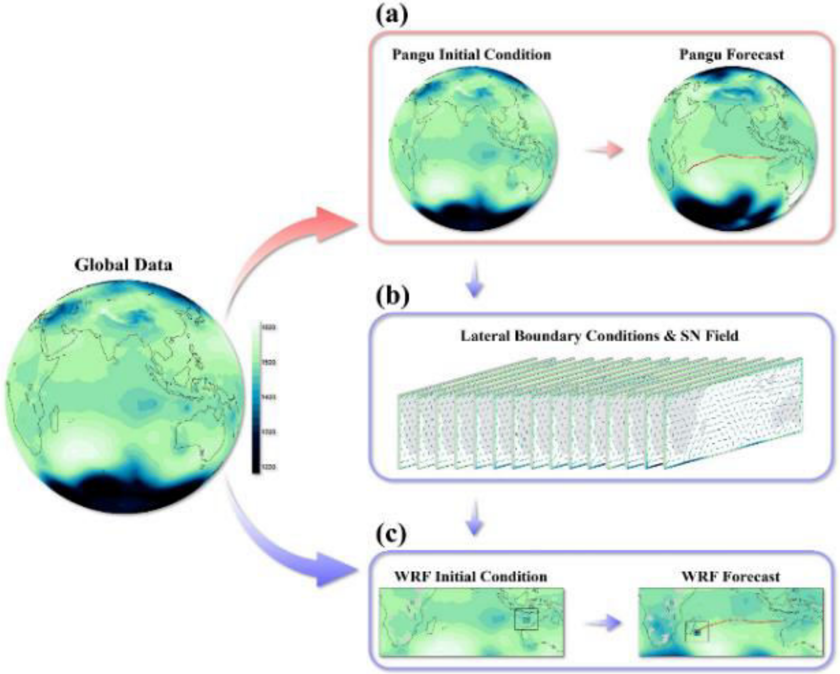
Pangu-Weather produces higher accuracy than the operational IFS and FourCastNet in deterministic forecasts on the ERA5 data (Bi et al. 2023).



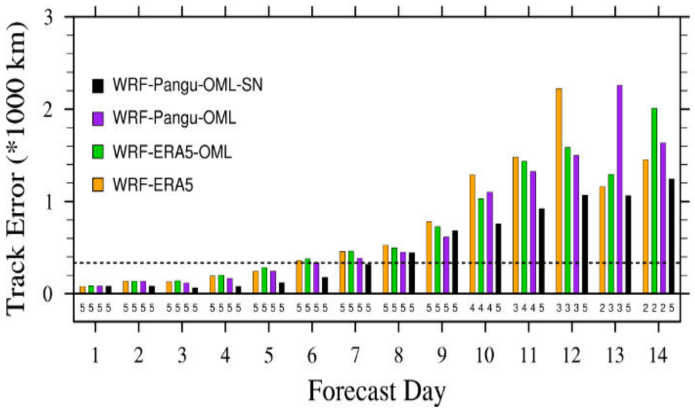
AIFS shows smaller RMSE than the operational IFS in deterministic forecasts (Lang et al. 2024).

Introduction

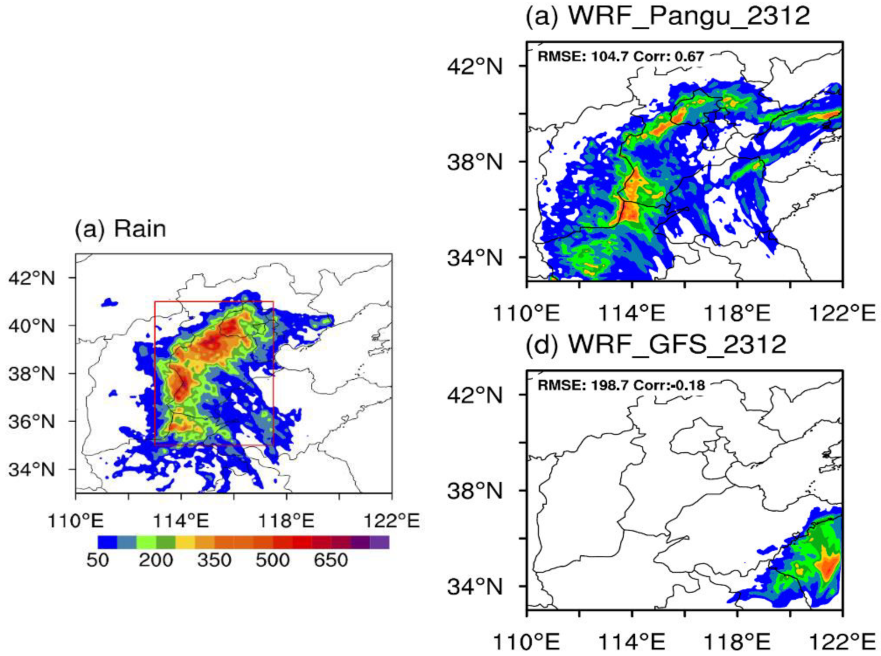
- The forecast performance of regional NWP models is closely related to the forecasts of large-scale synoptic fields from the global NWP models.
- Using AI-based weather models (e.g., Pangu) as the driving fields for the regional NWP models can leverage the advantages in forecasting large-scale synoptic fields.



Flowchart of the Integration of Pangu weather Model and regional NWP Model (Liu et al. 2024).



Downscaling and nudging improves TC track forecasting (Liu et al. 2024).



Using forecasts of Pangu weather Model as the driving fields of WRF improves the forecasts of heavy rainfall (Xu et al. 2024).

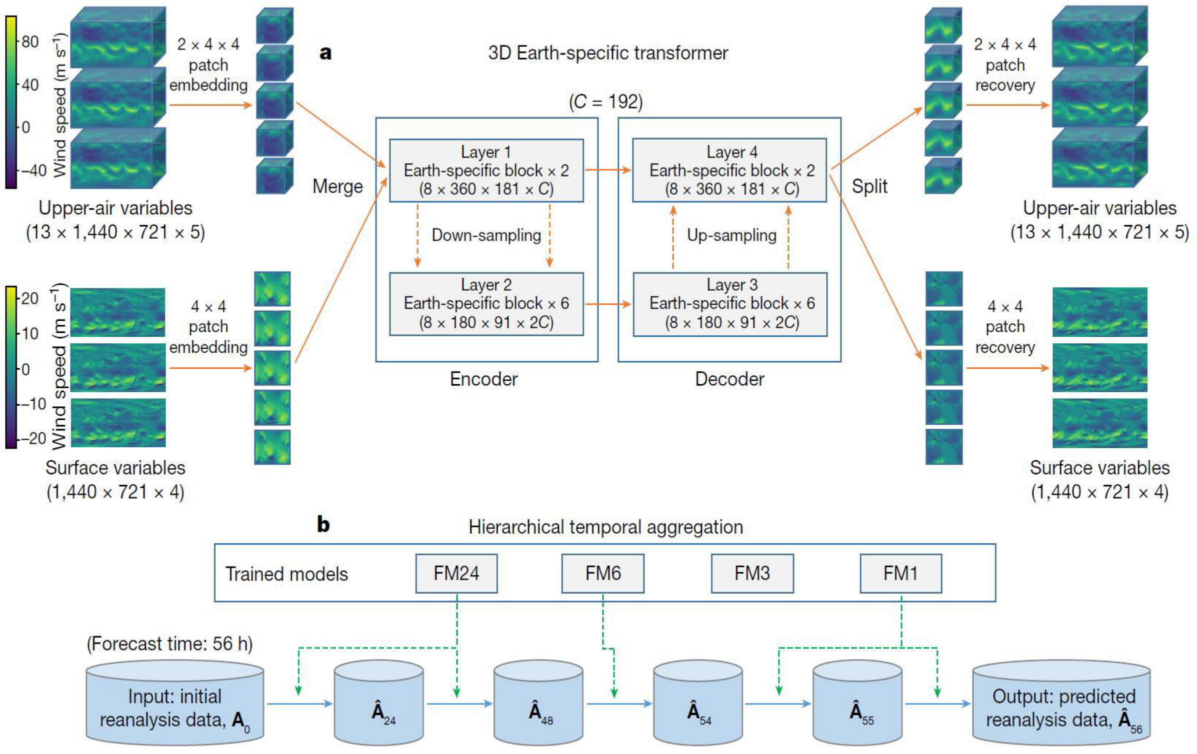
Outline

NWP and AI-based models

Regional **NWP** model: **CMA-TRAMS**
AI-based weather model: **Pangu**
IC/LBCs: The analyses and forecasts of ECMWF IFS with the horizontal resolutions of 0.1°*0.1° are used as the driving fields for Pangu and CMA-TRAMS.

CONFIG	CMA-TRAMS
Dyn frame	Fully Compressive, Non-hydrostatic, Predictor-Corrector Method For SISL, 3D Reference Atmosphere Scheme, Terrain Following Coordinate with Charney-philip Staggering, Lon-lat Grid with Arrakawa-C Stagerring
Microphysics	WSM6
PBL	MRF
LAND	SMS + CoLM
Cumulus	Deep convection: scale-aware NSAS; Shallow convection: CSC

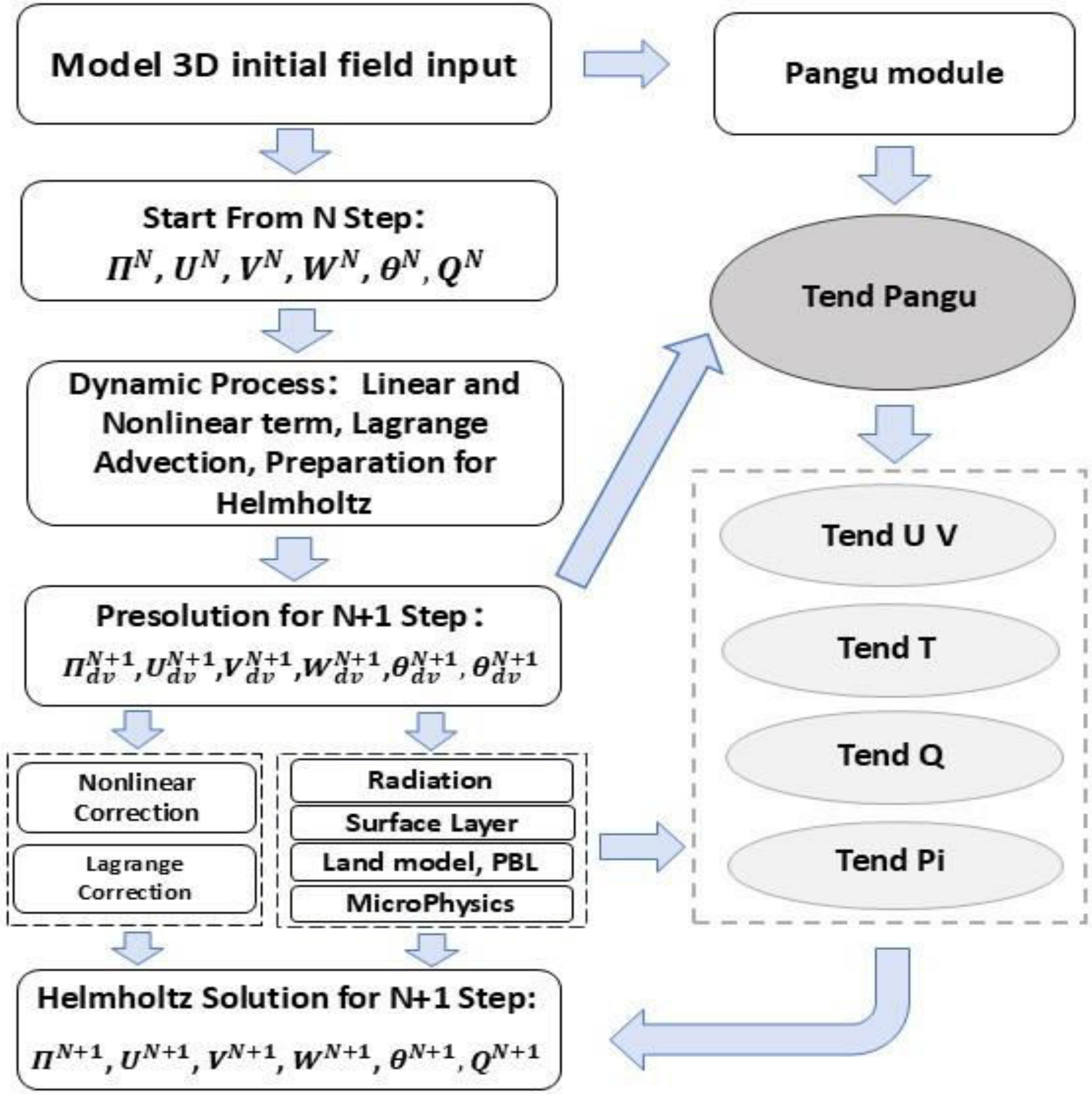
CMA-TRAMS (Chen et al., 2021)



Pangu (Bi et al., 2023)

Framework of the hybrid model

- During the integration process of CMA-TRAMS, **the forecast variables (e.g., U, V, T) with precision advantages from Pangu model** are used in **the online correction** to reduce the model errors of CMA-TRAMS.
- Similar to the parametrized tendency of physical processes, **Pangu model generates tendency of forecast variables**, which is used in the Helmholtz Solution.



Framework of the hybrid model

Time integral equation:

$$A^{n+1} = A_*^n + \Delta t[\alpha_\varepsilon (L_A + N_A)^{n+1} + \beta_\varepsilon (L_A + N_A)_*^n] + \Delta t\, \alpha_p\ S_A^{n+1} + \Delta t\, \beta_p\ S_*^n$$

Lagrange upstream point

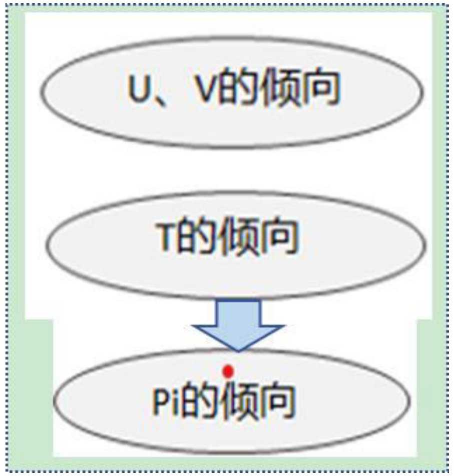
Linear term

Nonlinear term

Parametrized tendency of physical processes

=> Time integral equation:

$$\begin{cases} \vec{W}^{n+1} = \Delta t\left[\alpha_\varepsilon (L_{\vec{W}})^{n+1}\right] + \vec{W}_0 \\ \theta^{n+1} = \Delta t[\alpha_\varepsilon (L_\theta)^{n+1}] + \theta_0 \\ \pi^{n+1} = \Delta t[\alpha_\varepsilon (L_\pi)^{n+1}] + \pi_0 \end{cases}$$



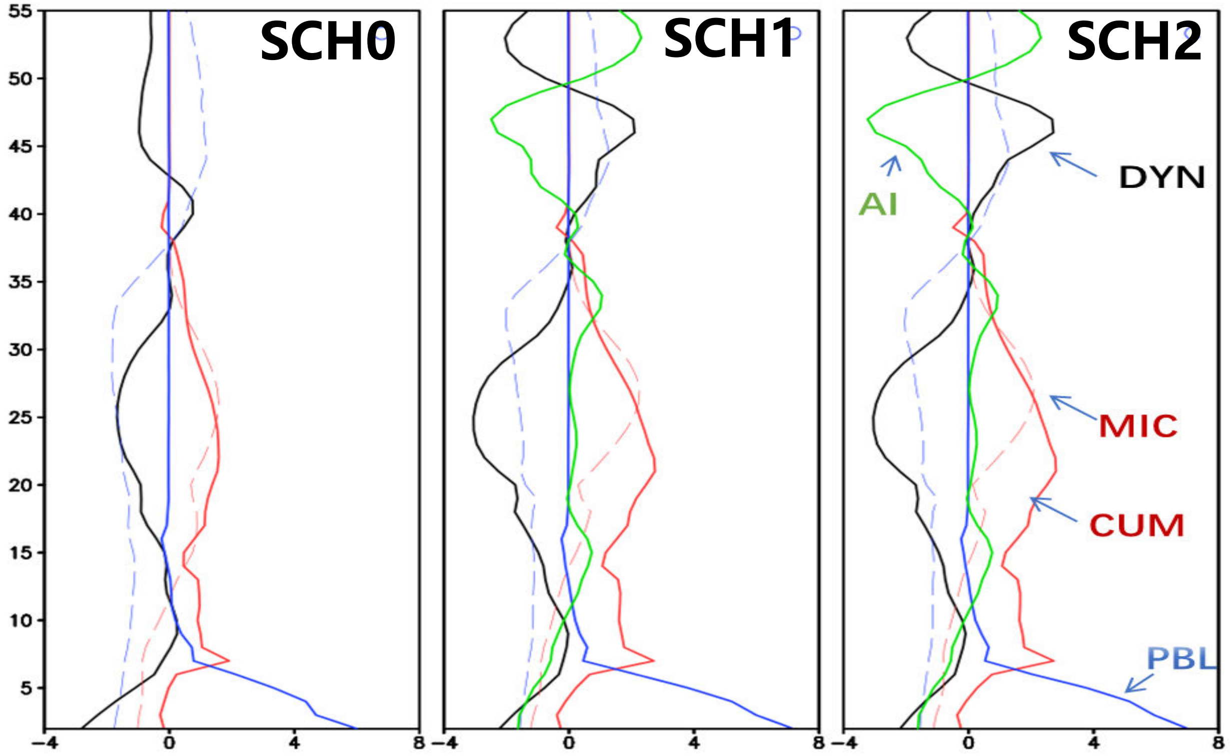
Tendency from Pangu model

Outline

Experimental results

- Comparative experiments (May-Oct 2025) show the impacts of introducing the tendency from Pangu on the tendencies from both the dynamic process and the parametrized physical processes (Cumulus, Microphysics, PBL).

Exp	Hybird scheme
SCH0	No hybrid
SCH1	Hybrid with T tendency from Pangu
SCH2	Hybrid with T, U, V tendencies from Pangu



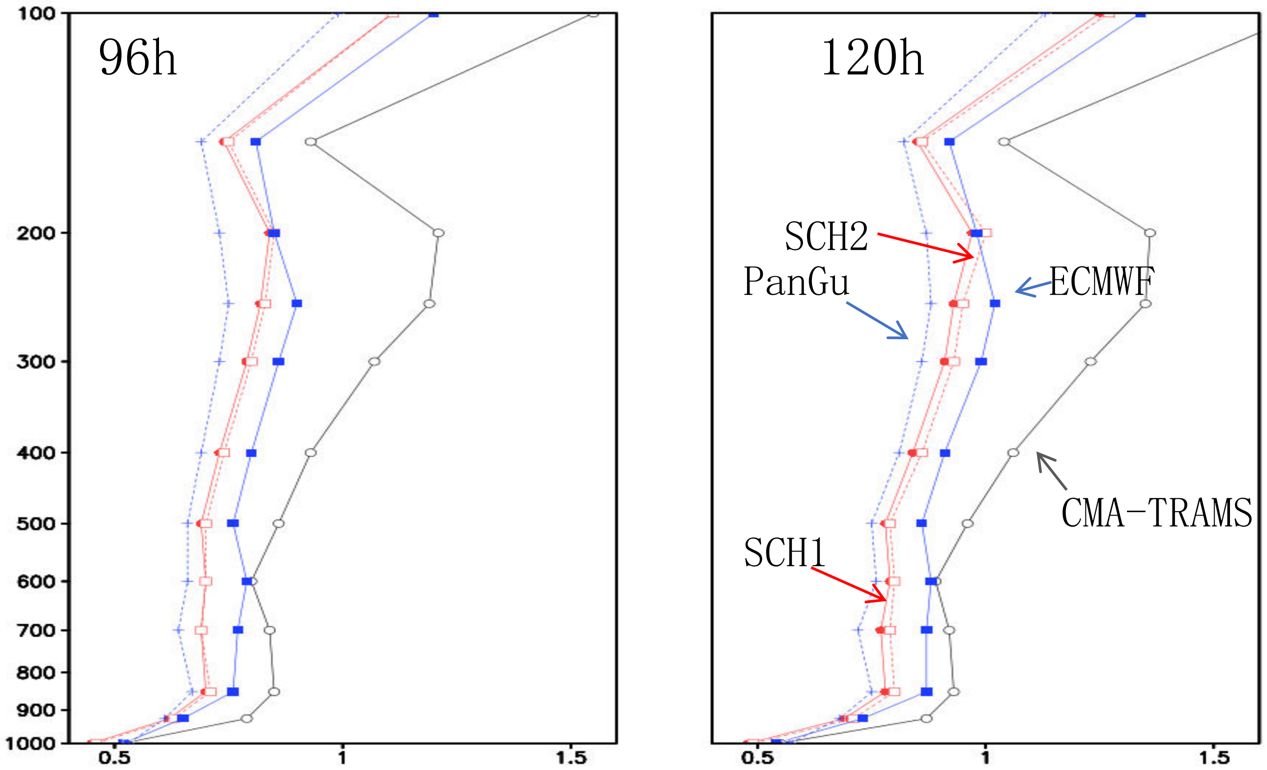
72-96-h Tendency of T from various processes for Podul (2025)

中国气象局
China Meteorological Administration

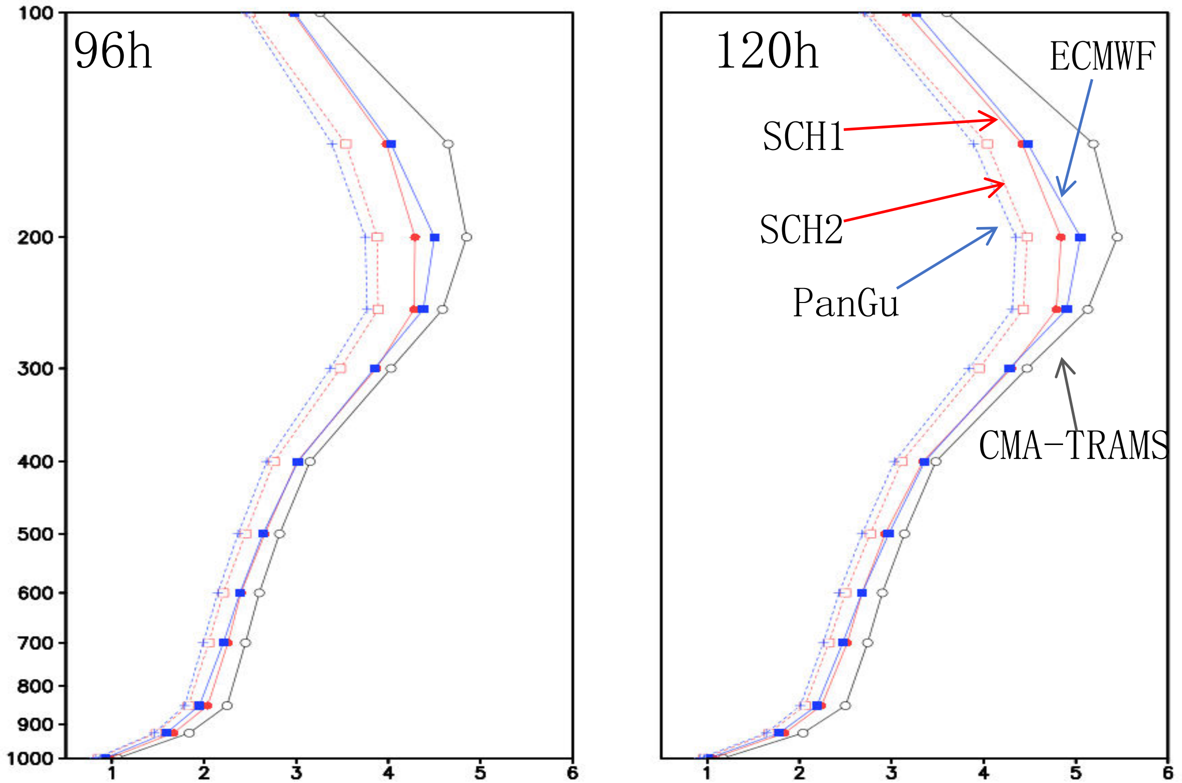
世界气象组织
World Meteorological Organization

Experimental results

- Introducing the tendency from Pangu (especially all of T, U, and V) reduces the forecast errors of T and wind beyond 72 h.



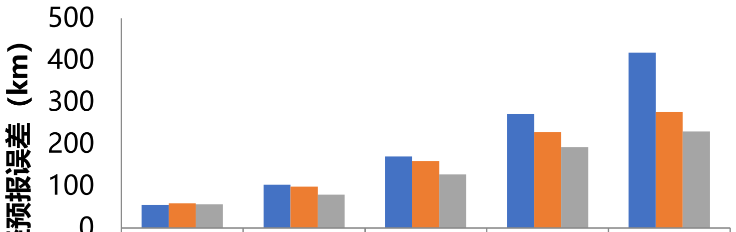
MAE of T from various models



MAE of Wind speed from various models

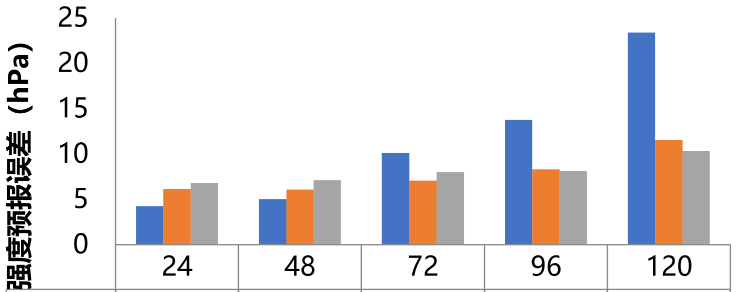
Experimental results

- Introducing the tendency from Pangu (especially all of T, U, and V) reduces the errors for both TC track and intensity forecasting beyond 72 h and improves the heavy rainfall forecasting beyond 48 h.



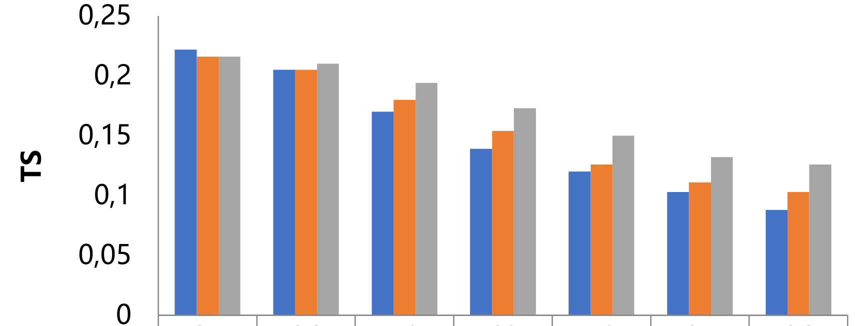
	24	48	72	96	120
SCH0	54,801	102,855	170,289	272,28	417,952
SCH1	58,833	98,764	159,532	228,589	276,651
SCH2	56,57	79,855	127,488	192,783	229,94

MAE of Track from various experiments



	24	48	72	96	120
SCH0	4,234	5,017	10,162	13,785	23,4
SCH1	6,157	6,082	7,061	8,303	11,523
SCH2	6,808	7,114	7,975	8,117	10,348

MAE of Intensity from various experiments

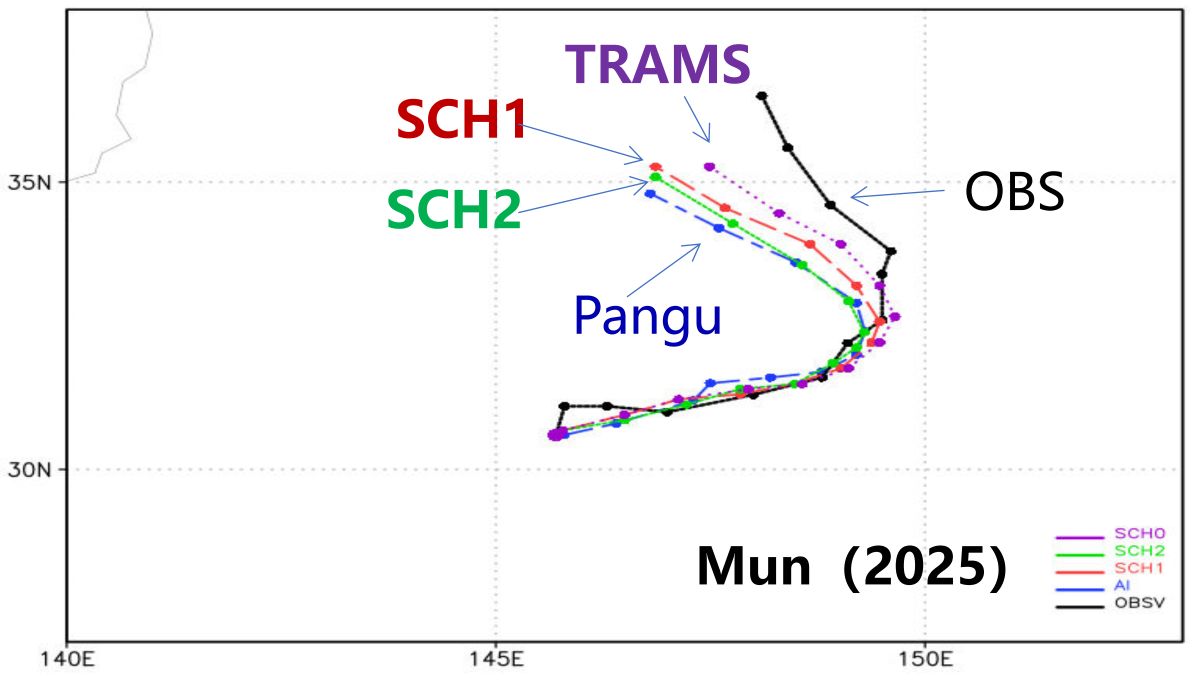


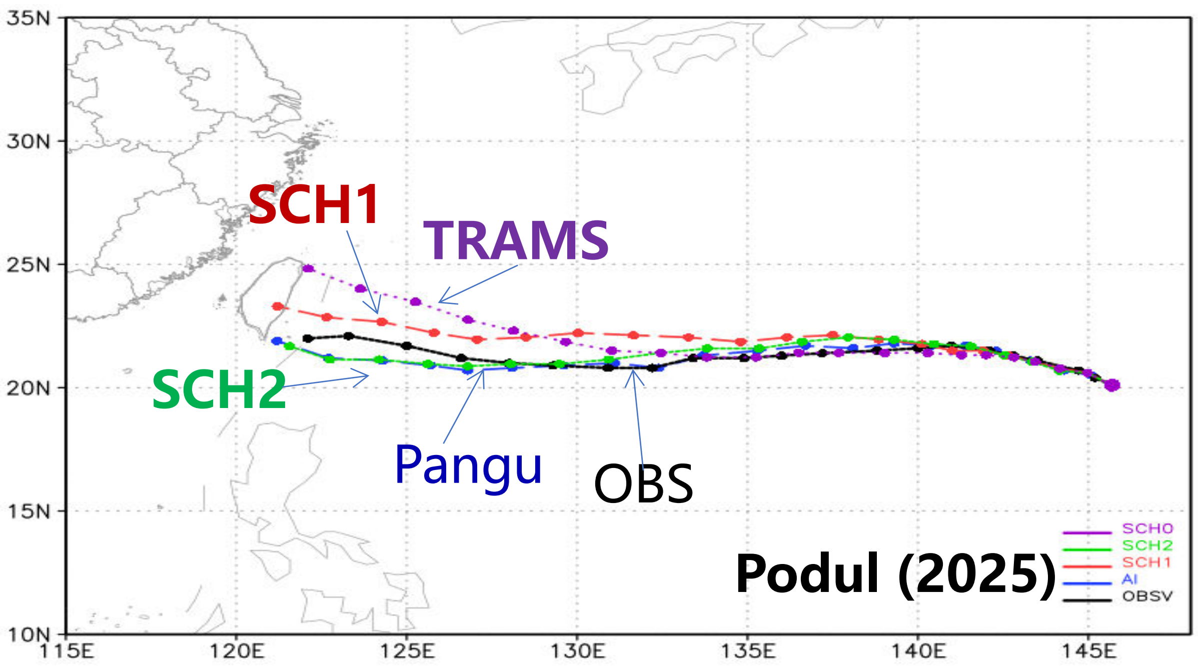
	24	36	48	60	72	84	96
SCH0	0,222	0,205	0,17	0,139	0,12	0,103	0,088
SCH1	0,216	0,205	0,18	0,154	0,126	0,111	0,103
SCH2	0,216	0,21	0,194	0,173	0,15	0,132	0,126

TS for 24-h accumulated rainfall above 50 mm from various experiments

Experimental results

- Introducing the tendency from Pangu (especially all of T, U, and V) can significantly improve TC track forecasting at longer valid times if Pangu model has better performance than CMA-TRAMS.





Outline

The pre-operational run

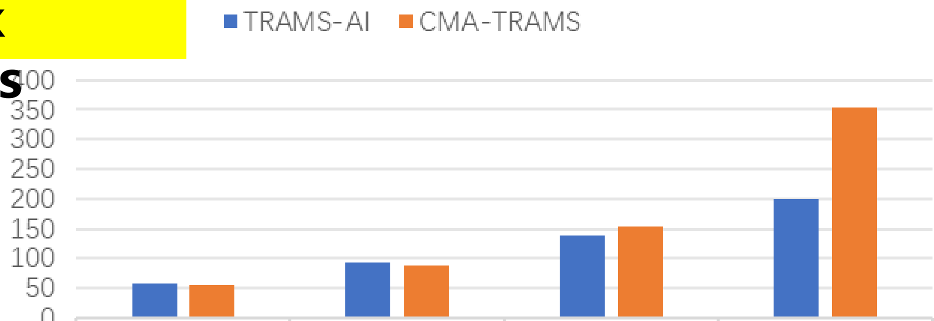
- The hybrid model (namely TRAMS-AI) of CMA-TRAMS and Pangu-weather has been in the pre-operational run since late May 2025.

Configuration: introducing the tendency of T from Pangu

Verification: TC cases in Jun-Sep 2025

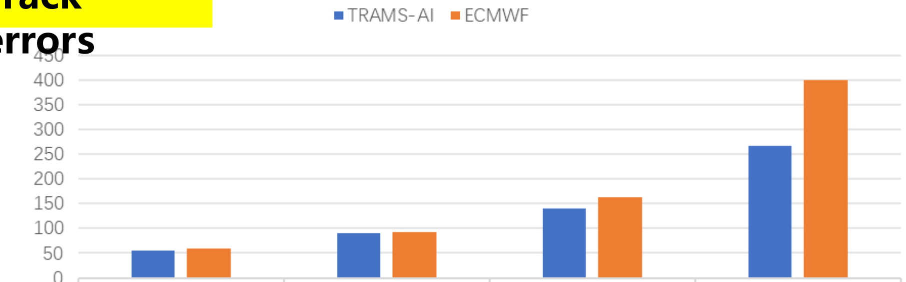
Advantages: **TC track and intensity forecasting beyond 72 h**

Track errors



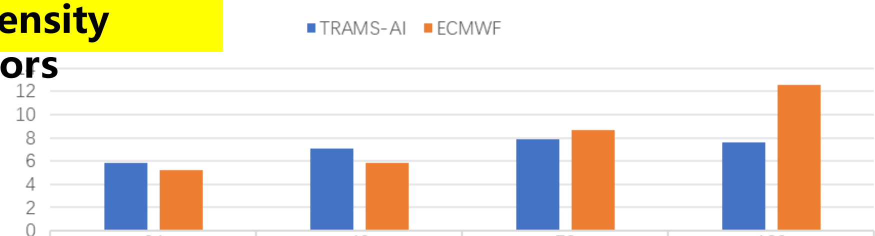
	24	48	72	120
TRAMS-AI	56.78429	92.15979	139.9625	200.1791
CMA-TRAMS	55.48243	88.17352	153.1469	354.4713

Track errors



	24	48	72	120
TRAMS-AI	55.81528	91.03405	140.4218	267.501
ECMWF	58.29528	93.01911	162.8055	398.841

intensity errors



	24	48	72	120
TRAMS-AI	5.866294	7.1	7.828577	7.614275
ECMWF	5.197752	5.844444	8.626192	12.58572

Issues need further works

- Although the hybrid model shows some **advantages** in the **long-term** forecasting, it may **degrade** the **short-term** forecasting (especially in **intensity**).
- The forecast performance of hybrid model is **closely related to the Pangu forecasting** (especially introducing all of T, U, V).

Future planning

I. Further experiments ***comparing SCH1 (only T tendency) with SCH2 (all of T, U, V tendency)*** in TC forecasting to select the better configuration of hybrid model.

II. Improving the ***framework of hybrid model*** for further improvements.

III. More experiments covering ***more TC cases***.

THANK YOU!