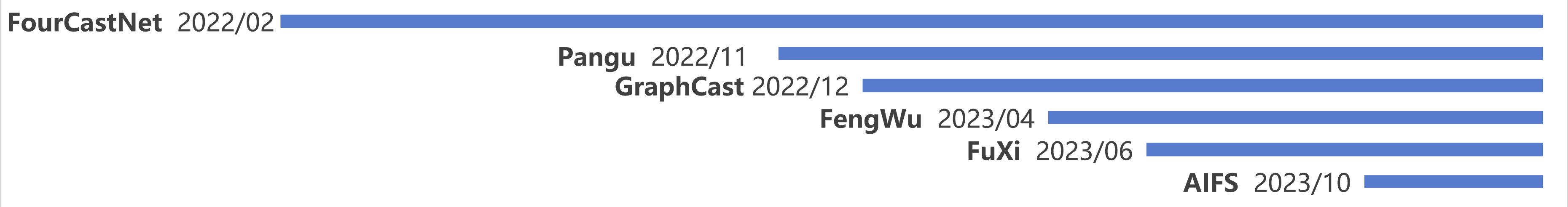
56th ESCAP/WMO Typhoon Committee，Malaysia

Preliminary Explorations on Data-driven AI-Models in Tropical Cyclone Prediction

27 February 2024

QIAN Qifeng, NMC/CMA

Background


FourCastNet 2022/02

Pangu 2022/11

GraphCast 2022/12

FengWu 2023/04

FuXi 2023/06

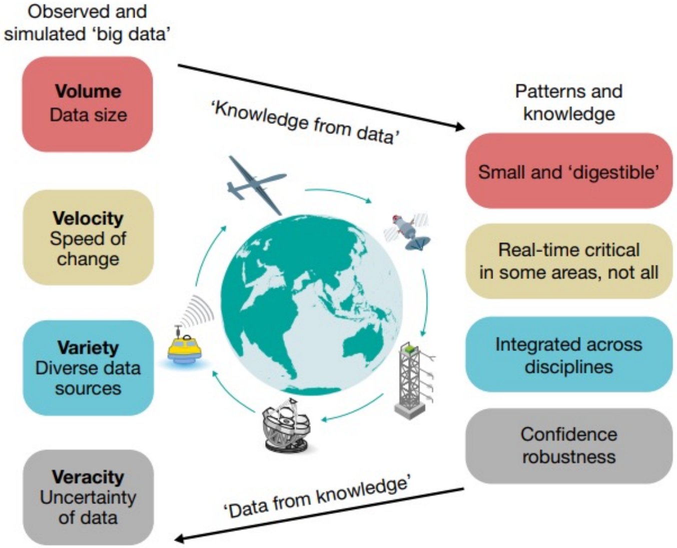
AIFS 2023/10

	FourCastNet	Pangu-Weather	GraphCast	FengWu	FuXi	AIFS
Developed by	NVIDIA	HUAWEI	Google DeepMind	Shanghai Artificial Intelligence Laboratory	Fudan University	ECMWF
Architecture	Transformer	Transformer	GNN	Transformer	Transformer	GNN
Horizontal Resolution	0.25°	0.25°	0.25°	0.25°	0.25°	1/0.5/0.25°
Levels	4+1	13+1	37+1	19+1	34+1	13+1
Time Resolution	6h	1/3/6/24h	6h	6h	6h	6h
Variables	high: 4 variables surface: 5 variables (with precipitation)	high: 5 variables surface: 4 variables	high: 6 variables surface: 5 variables (with precipitation)	high: 5 variables surface: 4 variables	high: 5 variables surface: 5 variables (with precipitation)	high: 6 variables surface: 6 variables
Features	Frist Transformer based weather model	Better than ECMWF-IFS in	90% of the variables outperform ECMWF-IFS	Effective forecast period: 10.75 days	Superior to ECMWF-IFS; Comparable to the EC-	Superior to ECMWF-IFS and

Necessity of Data-driven AI Models

Advantages in handling big data (Speed)

- Running time : less than 1 min
- Demand computing power： single GPU



Observed and simulated ‘big data’

Volume
Data size

Velocity
Speed of change

Variety
Diverse data sources

Veracity
Uncertainty of data

‘Knowledge from data’

‘Data from knowledge’

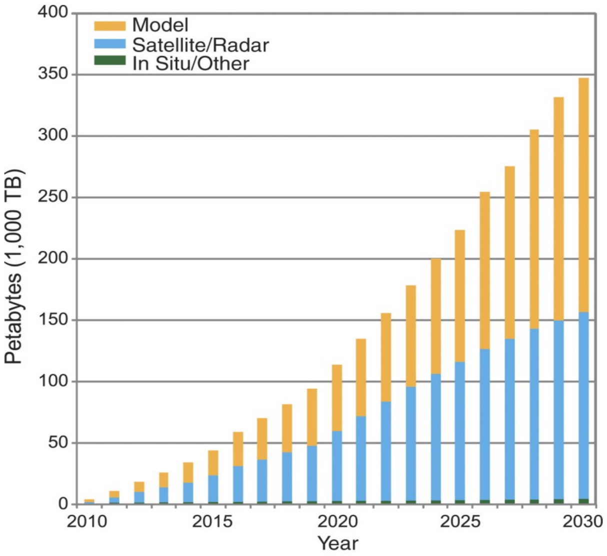
Patterns and knowledge

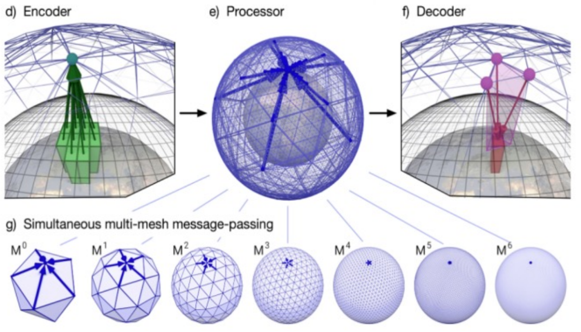
Small and ‘digestible’

Real-time critical in some areas, not all

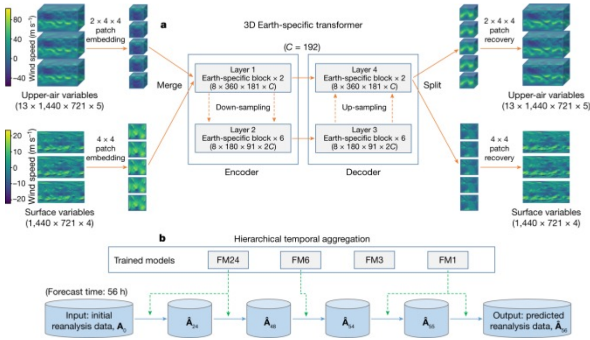
Integrated across disciplines

Confidence robustness





d) Encoder
e) Processor
f) Decoder
g) Simultaneous multi-mesh message-passing
M^0
M^1
M^2
M^3
M^4
M^5
M^6

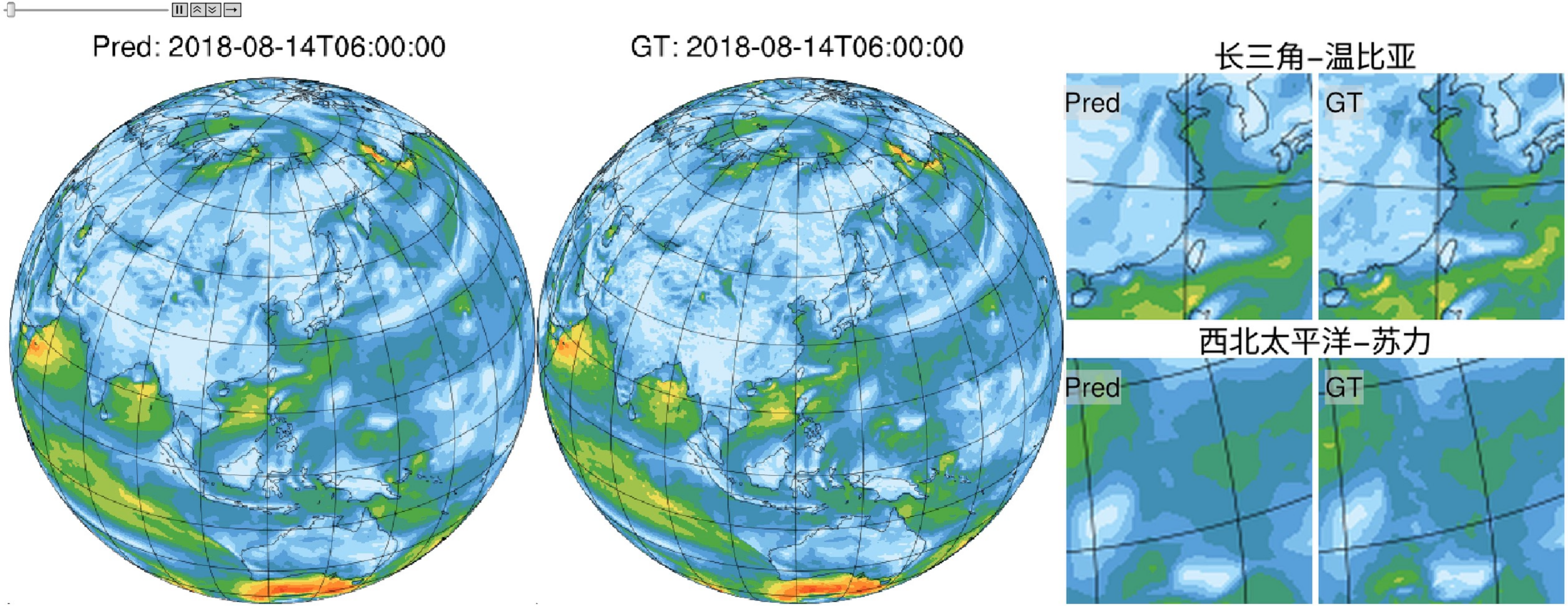


a
3D Earth-specific transformer
80
40
0
−40
Wind speed (m s⁻¹)
2 × 4 × 4 patch embedding
Upper-air variables (13 × 1,440 × 721 × 5)
20
10
0
−10
−20
Wind speed (m s⁻¹)
4 × 4 patch embedding
Surface variables (1,440 × 721 × 4)
Merge
(C = 192)
Layer 1 Earth-specific block × 2 (8 × 360 × 181 × C)
Down-sampling
Layer 2 Earth-specific block × 6 (8 × 180 × 91 × 2C)
Encoder
Layer 4 Earth-specific block × 2 (8 × 360 × 181 × C)
Up-sampling
Layer 3 Earth-specific block × 6 (8 × 180 × 91 × 2C)
Decoder
Split
2 × 4 × 4 patch recovery
Upper-air variables (13 × 1,440 × 721 × 5)
4 × 4 patch recovery
Surface variables (1,440 × 721 × 4)
b
Hierarchical temporal aggregation
Trained models
FM24
FM6
FM3
FM1
(Forecast time: 56 h)
Input: initial reanalysis data, $\mathbf{A}_0$
$\hat{\mathbf{A}}_{24}$
$\hat{\mathbf{A}}_{48}$
$\hat{\mathbf{A}}_{54}$
$\hat{\mathbf{A}}_{55}$
Output: predicted reanalysis data, $\hat{\mathbf{A}}_{56}$

《Climate Data Challenges in the 21st Century》,

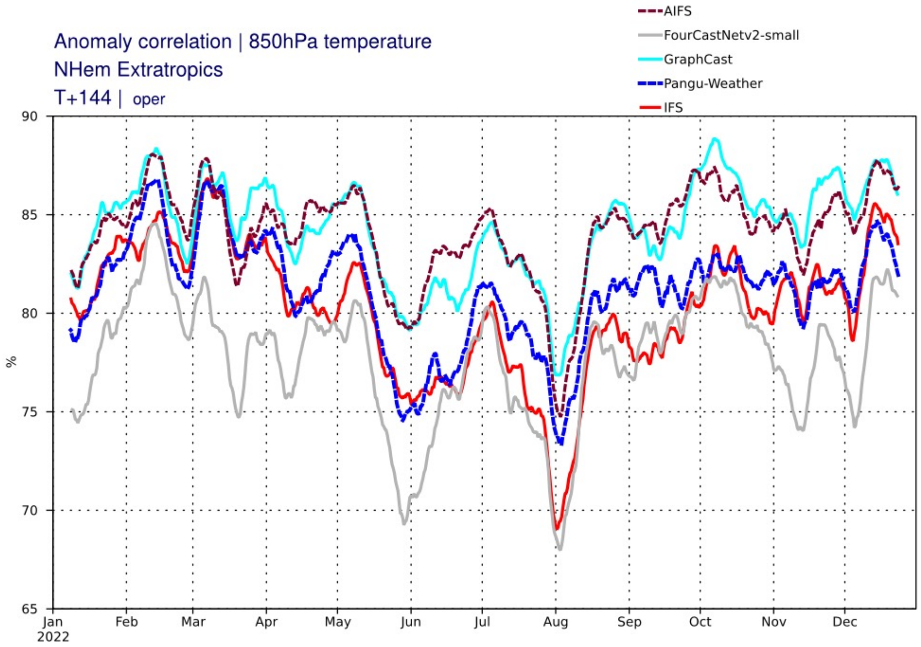
Overpeck et al., Science , 331 (6018): 700-702. 2011

Global Medium Range Meteorological Forecasting in AI-Model

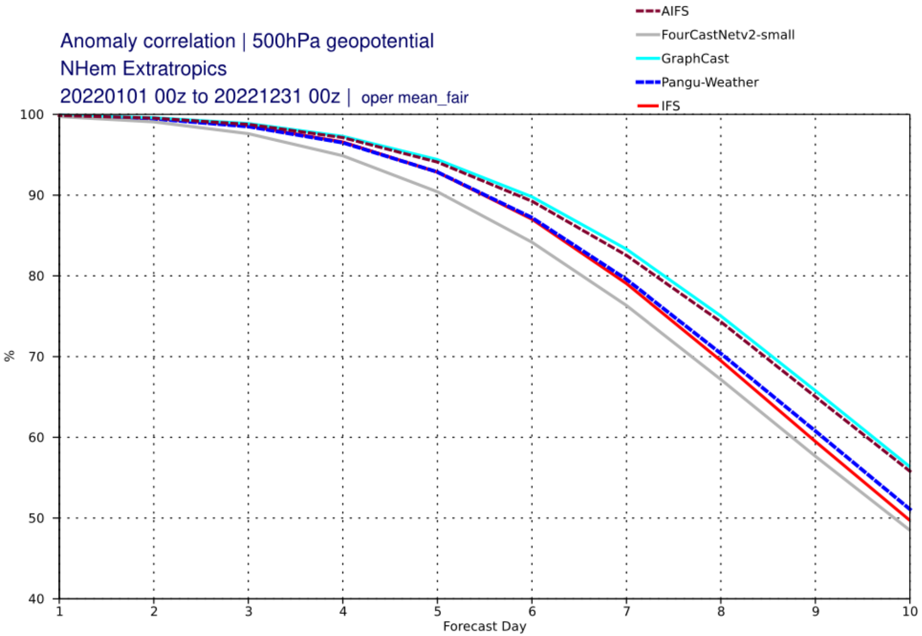

Pred: 2018-08-14T06:00:00
GT: 2018-08-14T06:00:00
长三角–温比亚
Pred
GT
西北太平洋–苏力
Pred
GT

Makes predictions for wind, temperature, humidity, geopotential as well as TCs

Global Medium Range Meteorological Forecasting in AI-Model



Anomaly correlation of 144th hour weather forecasts for T850 from AI models and ECMWF's operational model(IFS) in 2022.



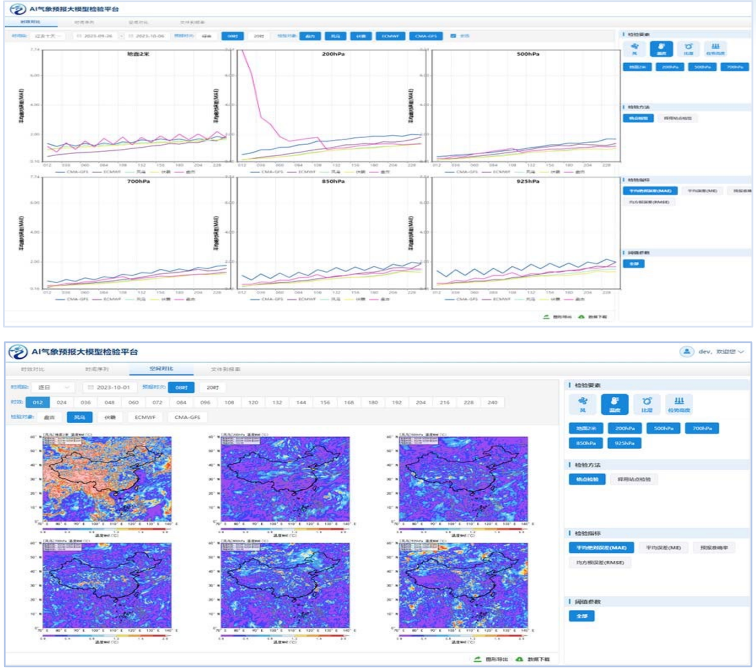
Anomaly correlation for next 10 days weather forecasts for H500 from AI models and ECMWF's operational model(IFS) in 2022.

Prediction Ability and the available forcast time Exceed ECMWF(IFS)

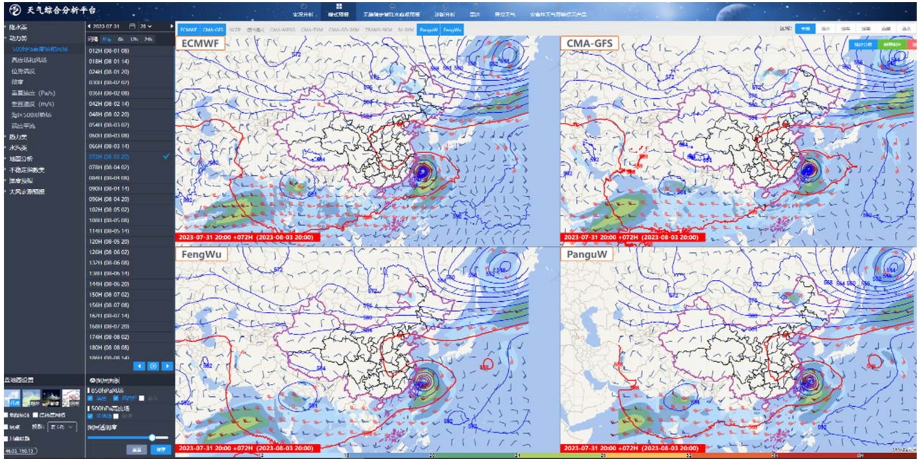
Data-driven AI Models in NMC/CMA

Three data-driven weather forecasting models are real time running in CMA

- **Pangu-Weather (Huawei)**
  CMA National Meteorological Centre from Dec 2022
- **Fengwu (Shanghai Artificial Intelligence Laboratory)**
  CMA National Meteorological Centre-from July 2023
  Shanghai Meteorological Bureau-from July 2023
- **Fuxi (Fudan University)**
  CMA National Meteorological Centre-from July 2023


AI气象预报大模型检验平台
地面2米
200hPa
500hPa
700hPa
850hPa
925hPa
AI气象预报大模型检验平台

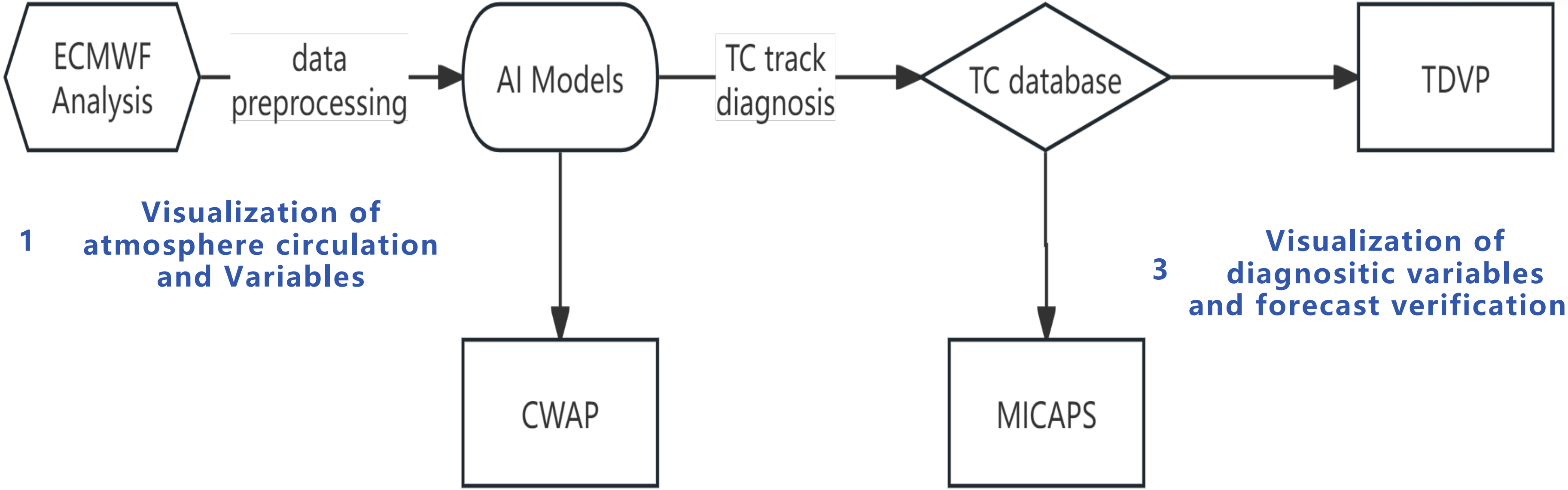
Realtime evaluation platform for Data-driven AI models


天气综合分析平台
ECMWF
CMA-GFS
FengWu
PanguW
2023-07-31 20:00 +072H (2023-08-03 20:00)

Real-time diagnosis and analysis application platform for data-driven AI models

Courtesy of National meteorological Center of CMA

Data-driven AI Models in NMC/CMA

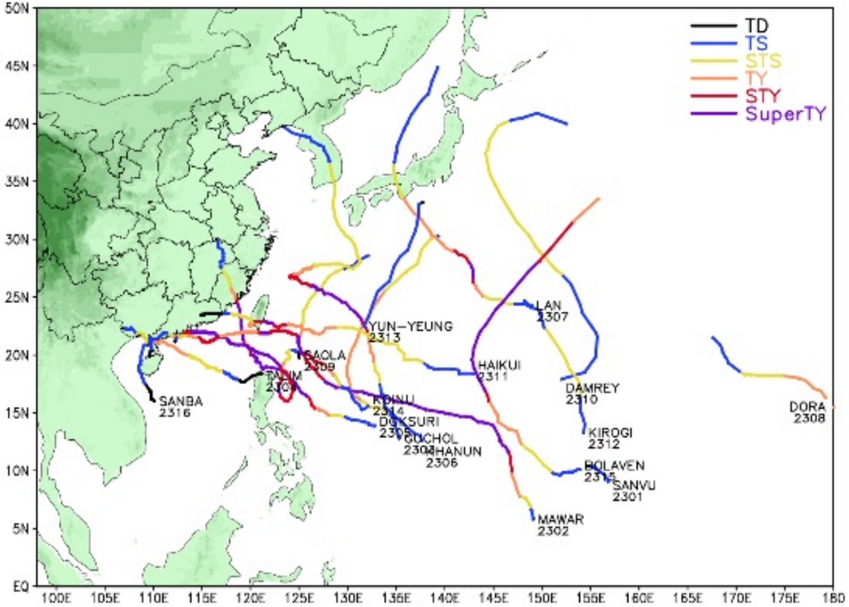

ECMWF Analysis
data preprocessing
AI Models
TC track diagnosis
TC database
TDVP
CWAP
MICAPS

1 Visualization of atmosphere circulation and Variables

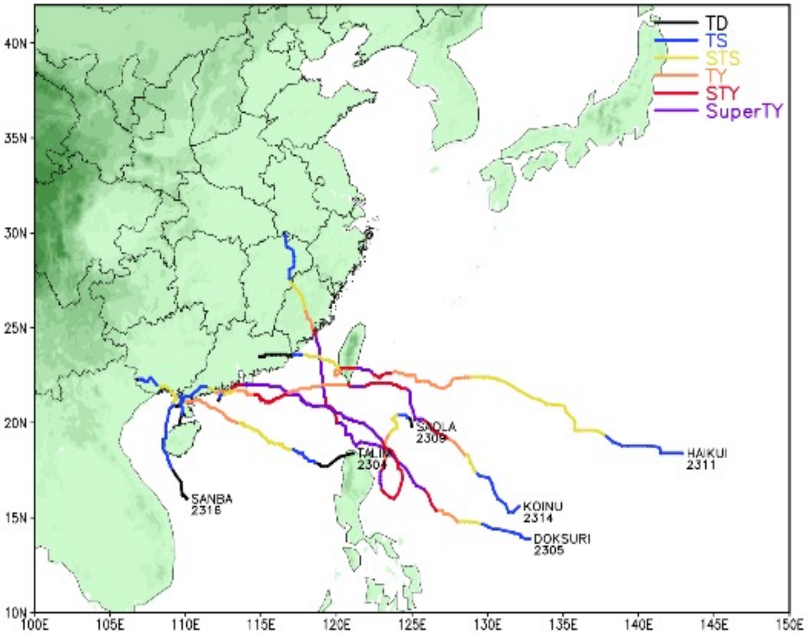
3 Visualization of diagnositic variables and forecast verifications

2 Make operational products using MICAPS

Data-driven AI Models in NMC/CMA


TD
TS
STS
TY
STY
SuperTY
LAN
2307
YUN−YEUNG
2313
SAOLA
2309
TALIM
2304
SANBA
2316
HAIKUI
2311
DAMREY
2310
KOINU
2314
DOKSURI
2305
GUCHOL
2303
KHANUN
2306
KIROGI
2312
BOLAVEN
2315
SANVU
2301
MAWAR
2302
DORA
2308
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
100E
105E
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
160E
165E
170E
175E
180

Tracks of TCs over the WNP and the South China Sea from 1st January to 31th October 2023.


TD
TS
STS
TY
STY
SuperTY
SAOLA
2309
TALIM
2304
SANBA
2316
HAIKUI
2311
KOINU
2314
DOKSURI
2305
40N
35N
30N
25N
20N
15N
10N
100E
105E
110E
115E
120E
125E
130E
135E
140E
145E
150E

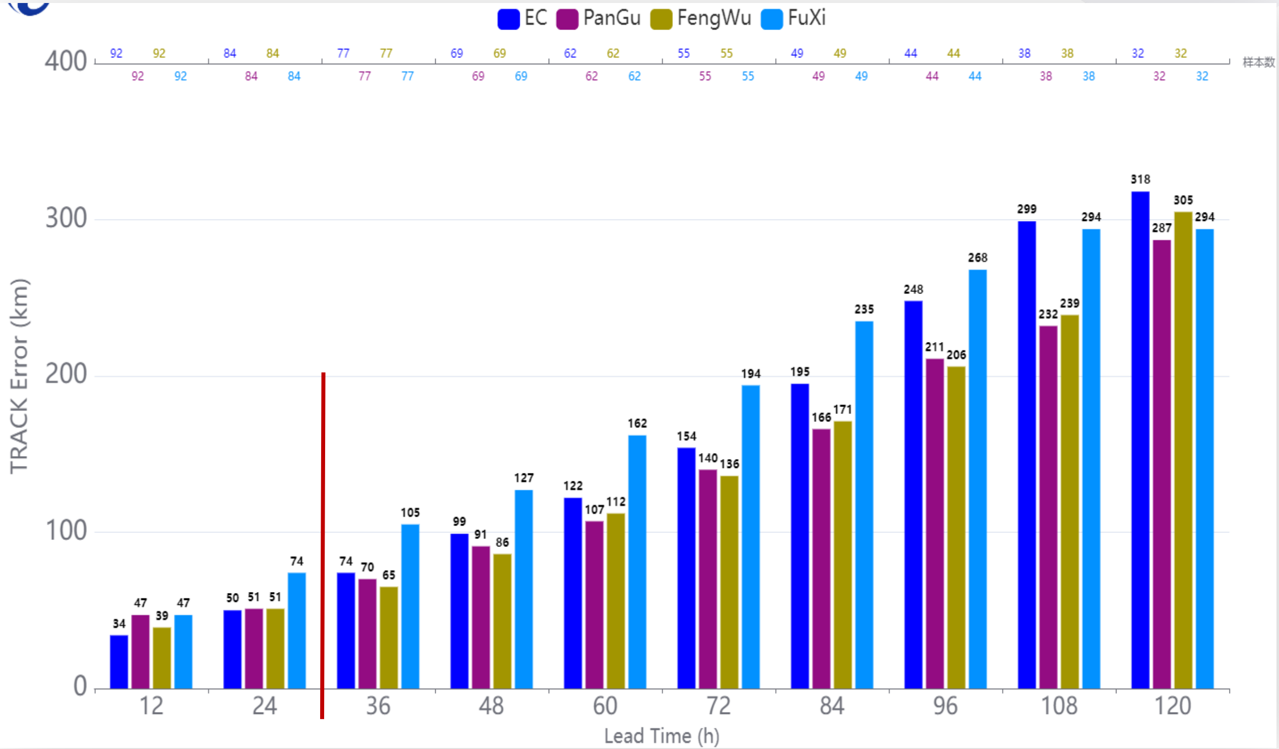
landfall TCs

预报检验

Track Error:

- Within a 24-hour forecast period, Pangu-Weather and FengWu are comparable to or slightly worse than the European deterministic level.
- For forecast periods of 36 hours and beyond, Pangu-Weather and FengWu have errors smaller than the ECMWF-IFS.
- Overall, Pangu-Weather has the best path forecasting ability, while FuXi has the largest forecast error.

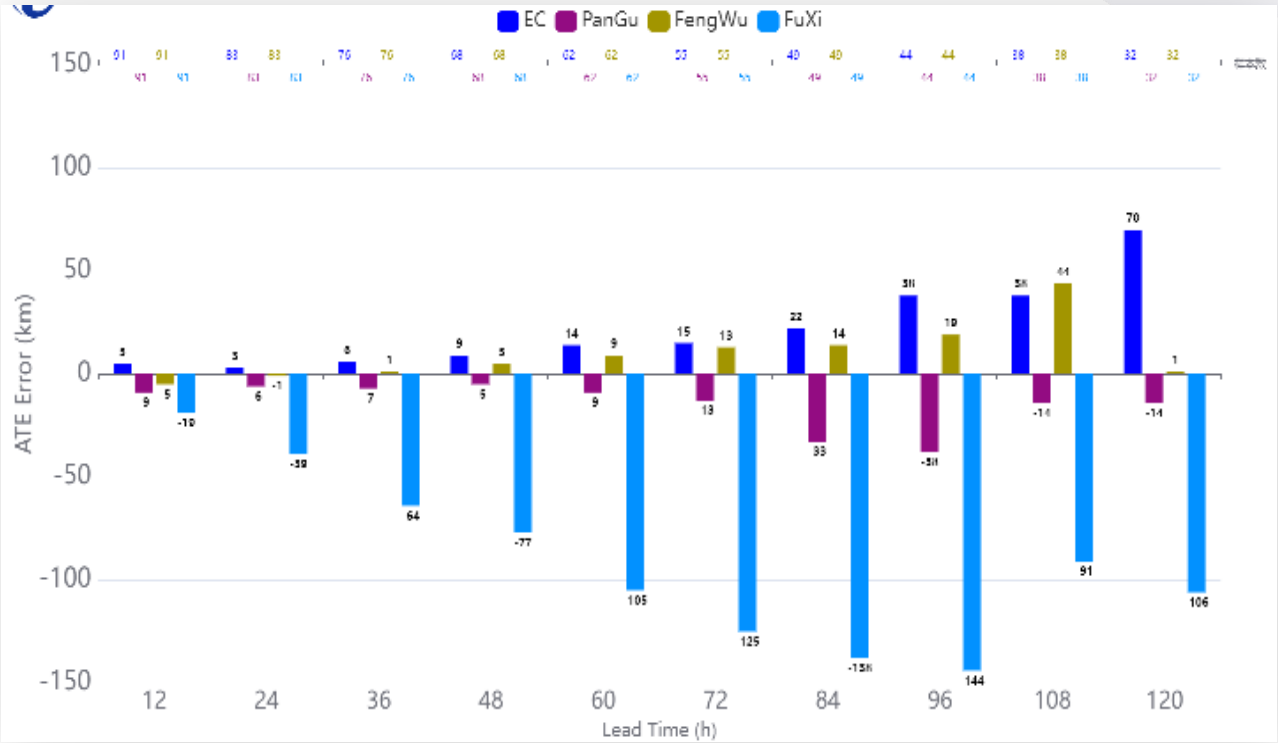
2023 Typhoon Track Forecast Error



移速偏差：

Along Track Error（ATE）：

- Pangu-Weather and FuXi underestimate the typhoon's speed, while the ECMWF-IFS and FengWu exhibit the opposite.
- Pangu-Weather reflects the speed of movement the best, while FuXi shows a larger deviation in speed.



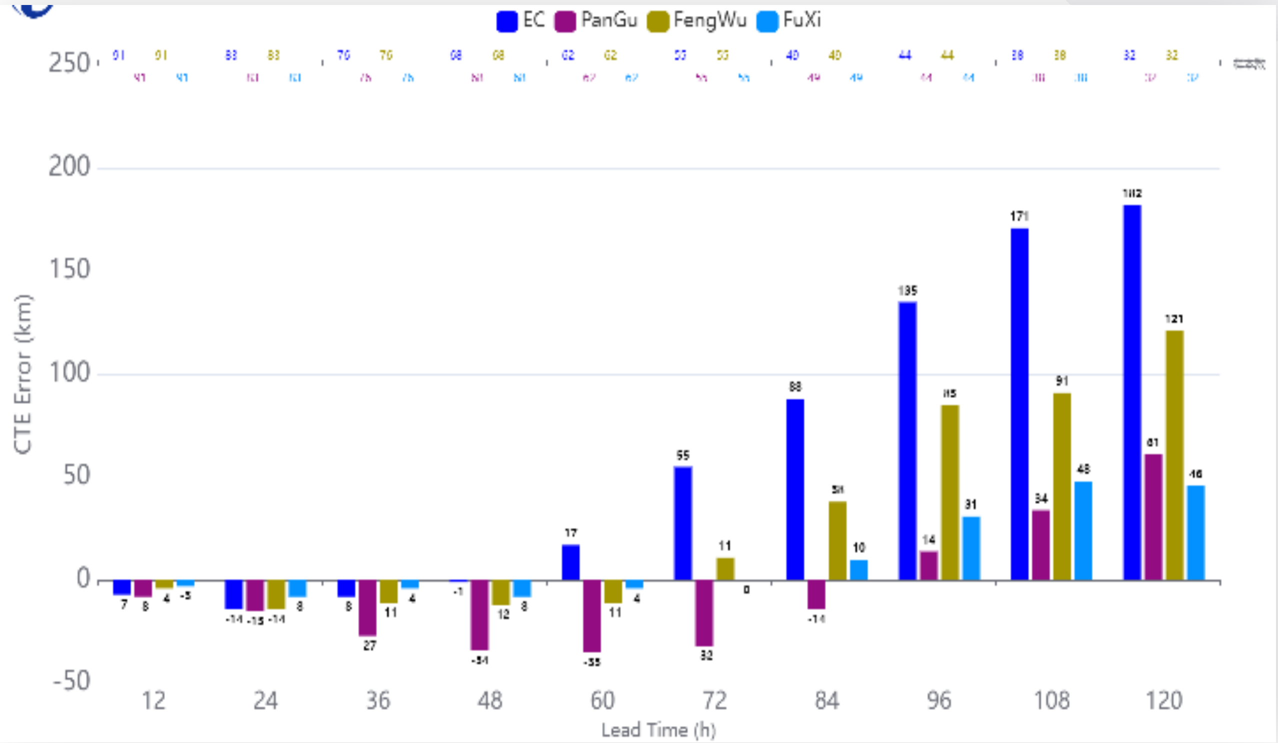
Along Track Error

移向偏差：

Cross Track Error（CTE）：

- Before 60 hours lead times, the track forecast tends to veer left; after 84 hours, the track forecast consistently veers right.
- For 72 hours and longer lead times, the track forecasts of the three large models are superior to those of the ECMWF-IFS.
- Fuxi's track forecast has the smallest deviation in direction on both sides of the typhoon's track.

Cross Track Error



2023 Typhoon Track Forecast Mean Absolute Error （Average of all Lead Times）

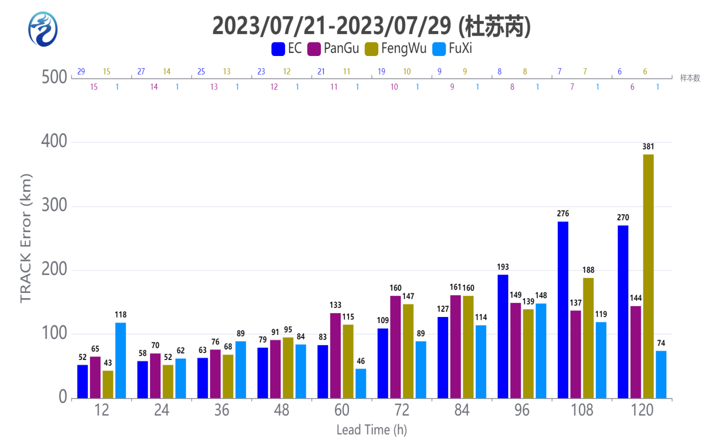
TCID	NAME	MAX INTENSITY (m/s)	LIFE TIME (day)	ECMWF	Pangu-Weather	FengWu	FuXi
2301	Sanvu	23	2				
2302	**Mawar**	68	13	165	137	**93**	
2303	**Guchol**	40	7	254	124	**114**	
2304	Talim	40	3				
2305	**Doksuri**	62	8	125	**119**	139	94
2306	**Khanun**	52	15	152	183	**103**	123
2307	**Lan**	55	9	**101**	143	183	163
2308	Dora	40	3	67	9	104	
2309	**Saola**	62	10	198	**132**	200	392
2310	Damrey	30	4	83	118	160	51
2311	**Haikui**	52	9	474	278	**226**	243
2312	Kirogi	30	3	203	197	159	192
2313	Yun-Yeung	20	3	124	168	187	191
2314	**Koinu**	55	9	119	**102**	137	128
2315	**Bolaven**	68	7	183	134	**118**	190
2316	Sanba	25	2				
2317	Jelawat	18	1				
average				**169.7**	**140.8**	**141.1**	**176.7**

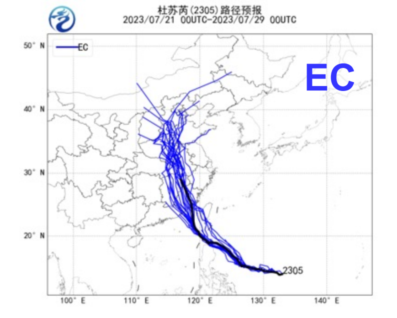
red：Pangu outperform

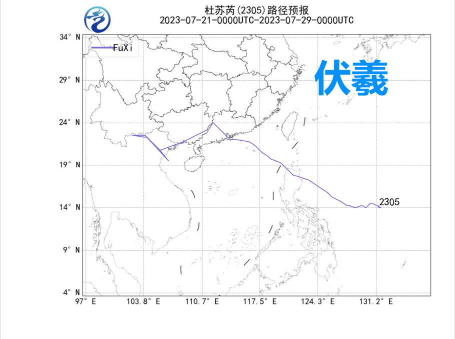
blue：ECMWF outperform

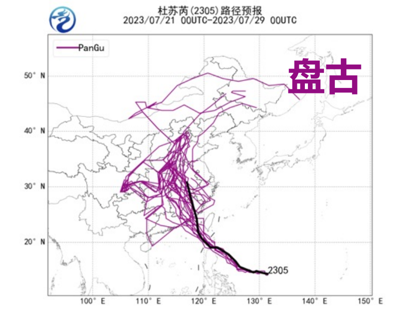
台风编号	台风名称	最大强度（米/秒）	生命史（天）	ECMWF	盘古	风乌	伏羲
2305	杜苏芮	62	8	125	**119**	139	94

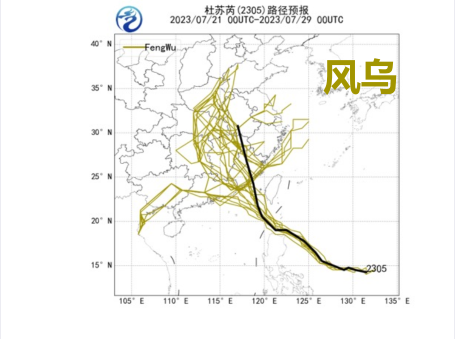
杜苏芮




杜苏芮(2305)路径预报
2023/07/21 00UTC-2023/07/29 00UTC
EC
EC
2305
50° N
40° N
30° N
20° N
100° E
110° E
120° E
130° E
140° E

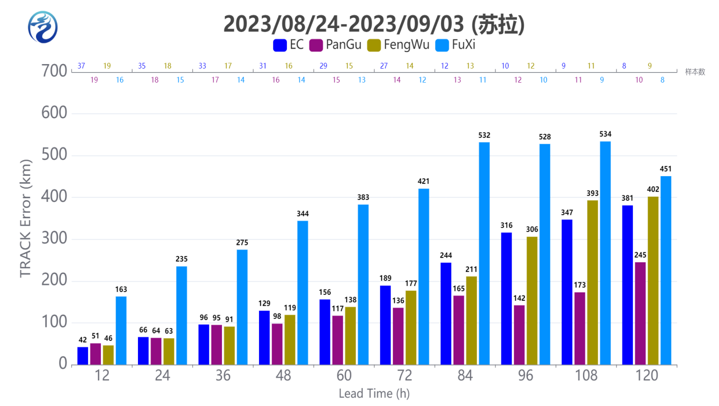

杜苏芮(2305)路径预报
2023-07-21-0000UTC-2023-07-29-0000UTC
FuXi
伏羲
2305
34° N
29° N
24° N
19° N
14° N
9° N
4° N
97° E
103.8° E
110.7° E
117.5° E
124.3° E
131.2° E

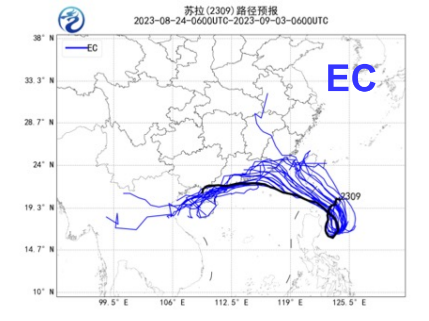

杜苏芮(2305)路径预报
2023/07/21 00UTC-2023/07/29 00UTC
PanGu
盘古
2305
50° N
40° N
30° N
20° N
100° E
110° E
120° E
130° E
140° E
150° E

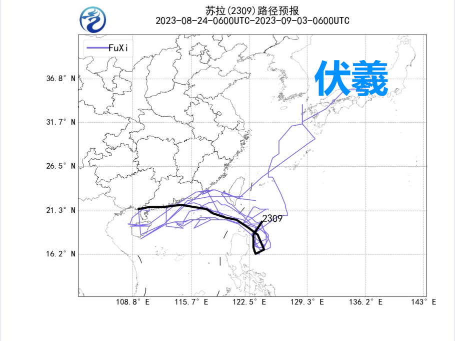

杜苏芮(2305)路径预报
2023/07/21 00UTC-2023/07/29 00UTC
FengWu
风乌
2305
40° N
35° N
30° N
25° N
20° N
15° N
105° E
110° E
115° E
120° E
125° E
130° E
135° E

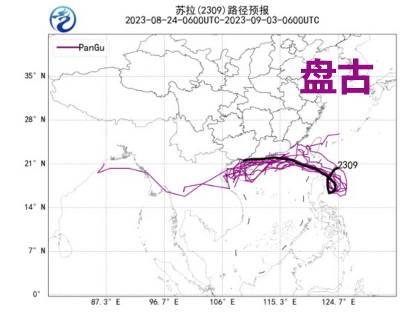
台风编号	台风名称	最大强度（米/秒）	生命史（天）	ECMWF	盘古	风乌	伏羲
2309	苏拉	62	10	198	**132**	200	392

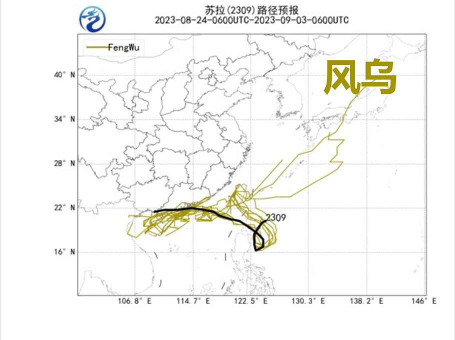
苏拉




苏拉(2309)路径预报
2023-08-24-0600UTC-2023-09-03-0600UTC
EC
2309
38° N
33.3° N
28.7° N
24° N
19.3° N
14.7° N
10° N
99.5° E
106° E
112.5° E
119° E
125.5° E

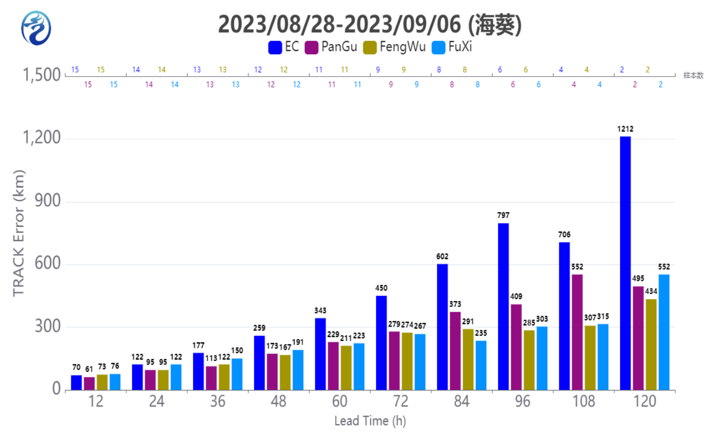

苏拉(2309)路径预报
2023-08-24-0600UTC-2023-09-03-0600UTC
FuXi
伏羲
2309
36.8° N
31.7° N
26.5° N
21.3° N
16.2° N
108.8° E
115.7° E
122.5° E
129.3° E
136.2° E
143° E

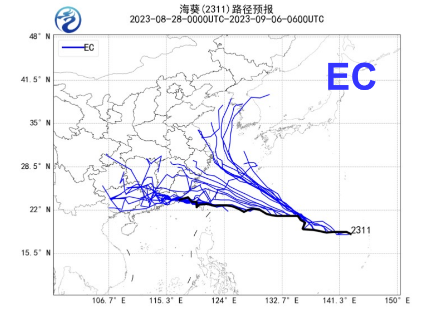

苏拉(2309)路径预报
2023-08-24-0600UTC-2023-09-03-0600UTC
PanGu
盘古
2309
35° N
28° N
21° N
14° N
7° N
0°
87.3° E
96.7° E
106° E
115.3° E
124.7° E

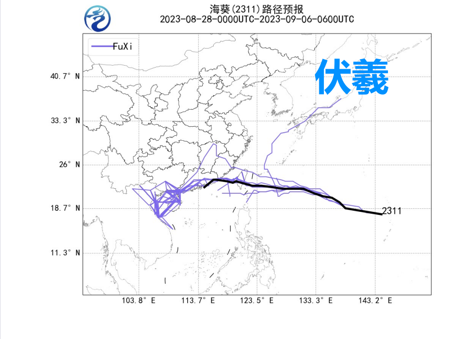

苏拉(2309)路径预报
2023-08-24-0600UTC-2023-09-03-0600UTC
FengWu
风乌
2309
40° N
34° N
28° N
22° N
16° N
106.8° E
114.7° E
122.5° E
130.3° E
138.2° E
146° E

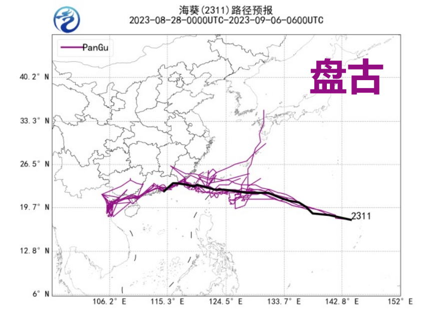
台风编号	台风名称	最大强度（米/秒）	生命史（天）	ECMWF	盘古	风乌	伏羲
2311	海葵	52	9	474	278	**226**	243

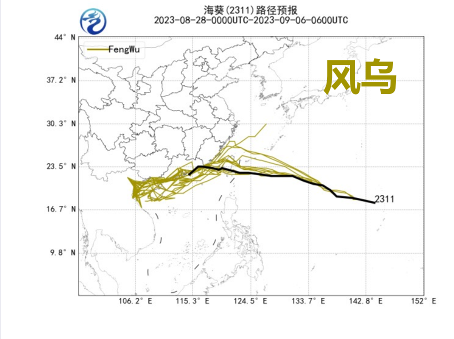
海葵



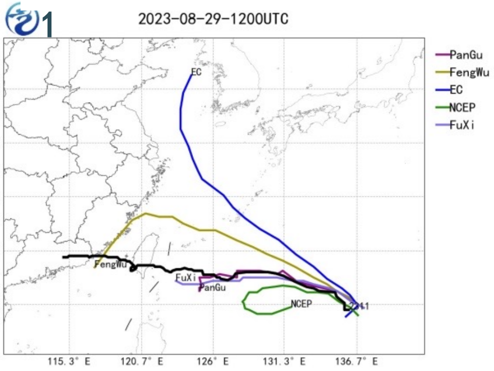

海葵(2311)路径预报
2023-08-28-0000UTC-2023-09-06-0600UTC
EC
EC
2311
48° N
41.5° N
35° N
28.5° N
22° N
15.5° N
106.7° E
115.3° E
124° E
132.7° E
141.3° E
150° E

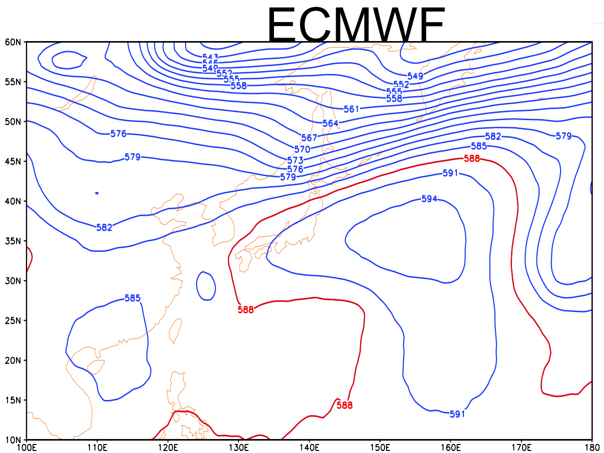

海葵(2311)路径预报
2023-08-28-0000UTC-2023-09-06-0600UTC
FuXi
伏羲
2311
40.7° N
33.3° N
26° N
18.7° N
11.3° N
103.8° E
113.7° E
123.5° E
133.3° E
143.2° E

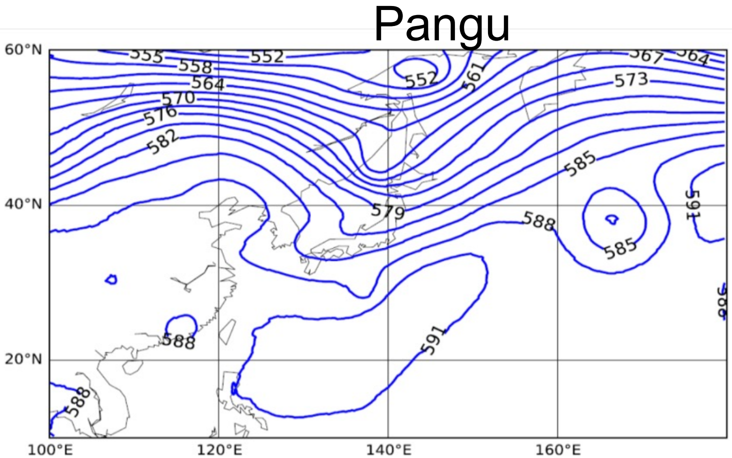

海葵(2311)路径预报
2023-08-28-0000UTC-2023-09-06-0600UTC
PanGu
盘古
2311
40.2° N
33.3° N
26.5° N
19.7° N
12.8° N
6° N
106.2° E
115.3° E
124.5° E
133.7° E
142.8° E
152° E

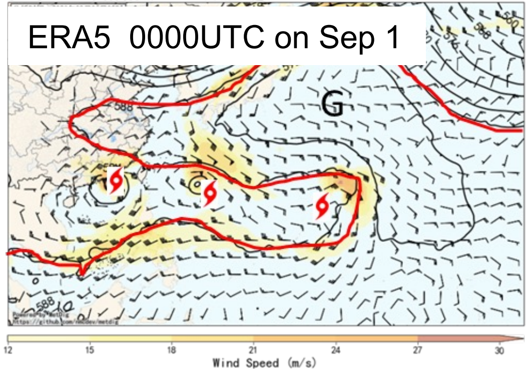

海葵(2311)路径预报
2023-08-28-0000UTC-2023-09-06-0600UTC
FengWu
风乌
2311
44° N
37.2° N
30.3° N
23.5° N
16.7° N
9.8° N
106.2° E
115.3° E
124.5° E
133.7° E
142.8° E
152° E

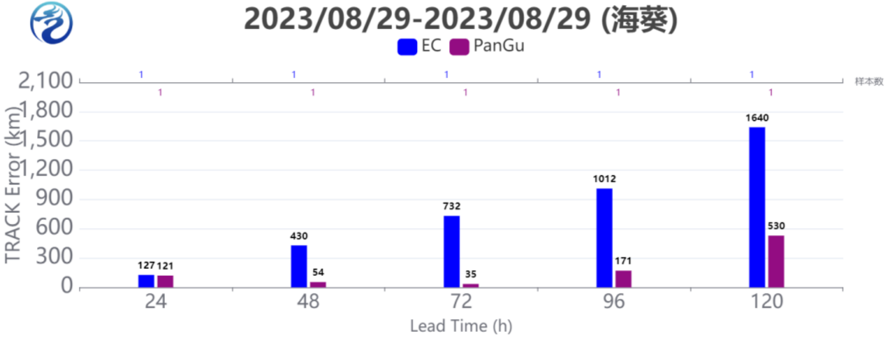
At 1200UTC on Aug 29, ECMWF and Pangu predicted the 500hPa Height field for 0000UTC on Sep 1


2023-08-29-1200UTC
PanGu
FengWu
EC
NCEP
FuXi
36° N
32° N
28° N
24° N
20° N
115.3° E
120.7° E
126° E
131.3° E
136.7° E
EC
FengWu
FuXi
PanGu
NCEP


ECMWF
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
100E
110E
120E
130E
140E
150E
160E
170E
180
576
579
582
585
588
591
594
561
564
567
570
573
549
552
555
558


Pangu
60°N
40°N
20°N
100°E
120°E
140°E
160°E
555
558
552
564
570
576
582
561
567
564
573
585
579
588
585
591
588
588

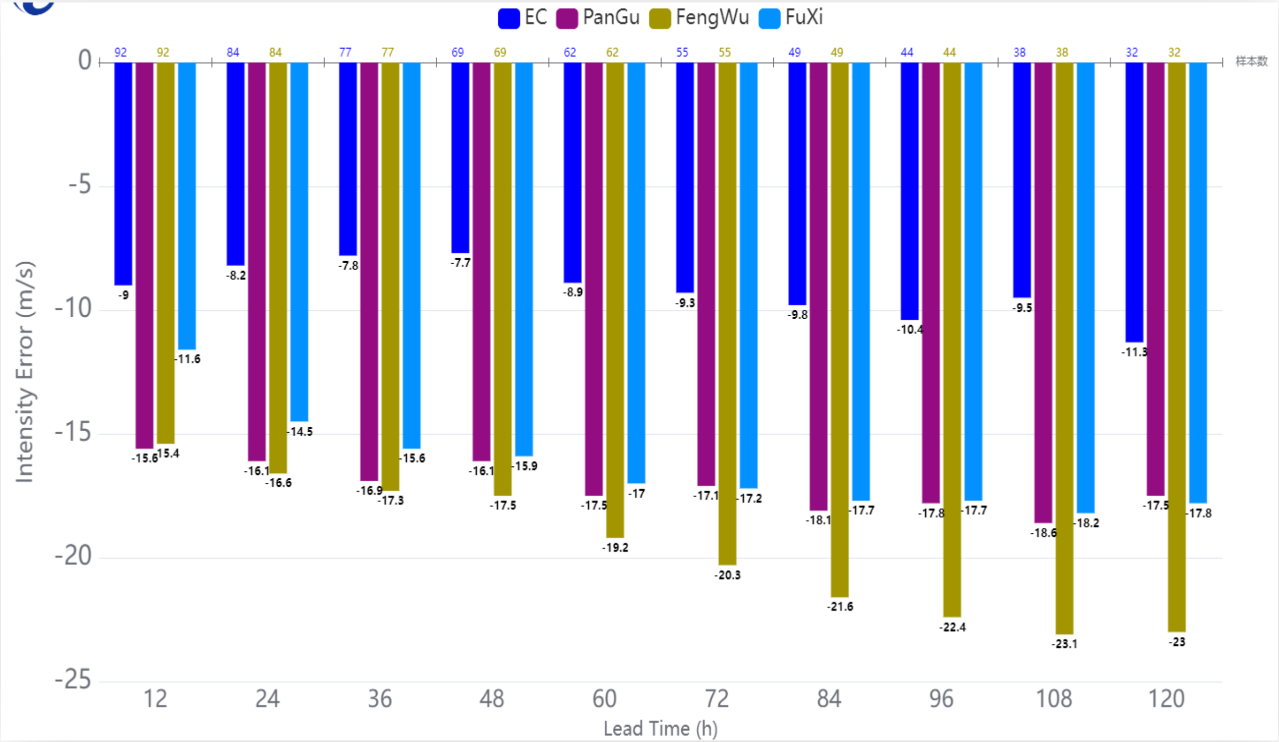

ERA5 0000UTC on Sep 1
G
588
12
15
18
21
24
27
30
Wind Speed (m/s)



EC model predicted the subtropical high much than weak then ERA5, but Pangu model predicted much stonger. The track error is large than Pangu. EC predicted HAIKUI move northwestward, Pangu predicted better for the moving direction, but the moving speed is much slower, and has less track errors.

Shortage

2023 Typhoon Intensity Forecast Error



Intensity Error:

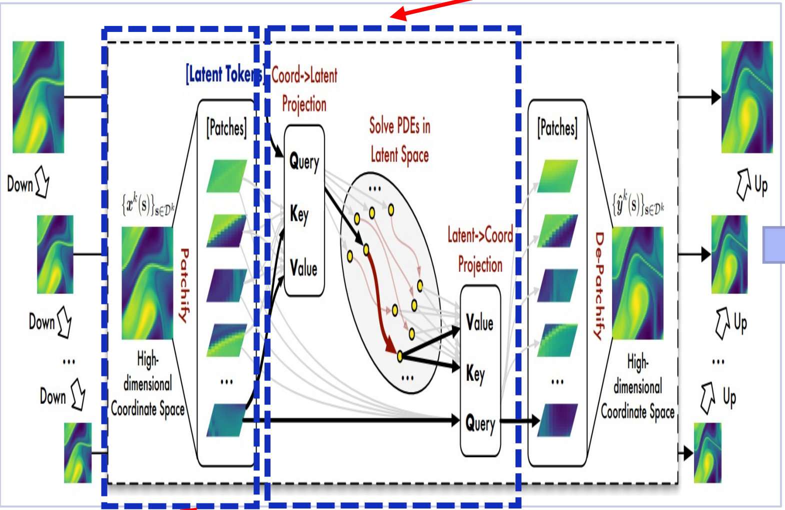
- ○ Pangu-Weather, FengWu, and FuXi are all significantly inferior to the major mainstream models such as ECMWF-IFS, showing a clear systematic underestimation in typhoon intensity forecasting.

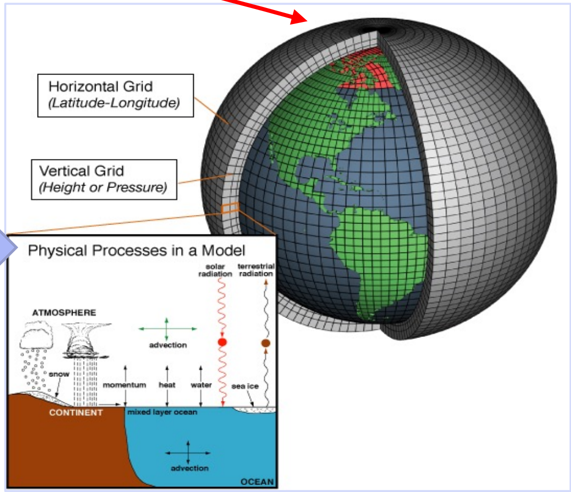
Next generation of AI-model development

Based on the meteorological model, the development of fine-tuning models based on CRA40 and can improve the forecast performance for 1-5 days

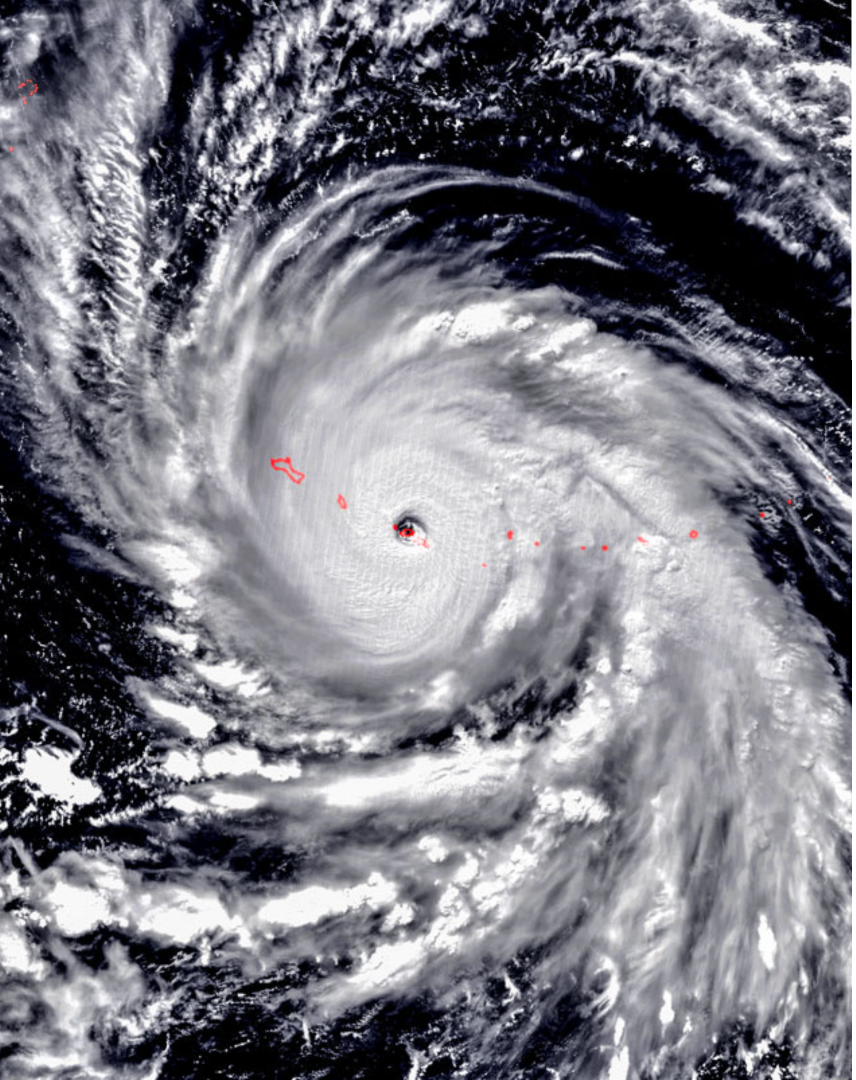
Maximum available time up to 10.0 days.

Spectral mode multiscale decomposition


[Latent Tokens]
Coord->Latent Projection
[Patches]
Query
Key
Value
Solve PDEs in Latent Space
Latent->Coord Projection
Value
Key
Query
[Patches]
Down
Down
...
Down
$\{x^k(s)\}_{s\in D^k}$
Patchify
High-dimensional Coordinate Space
$\{\hat{y}^k(s)\}_{s\in D^k}$
De-Patchify
High-dimensional Coordinate Space
Up
Up
...
Up


Horizontal Grid
(Latitude-Longitude)
Vertical Grid
(Height or Pressure)
Physical Processes in a Model
solar radiation
terrestrial radiation
ATMOSPHERE
advection
snow
momentum
heat
water
sea ice
CONTINENT
mixed layer ocean
advection
OCEAN

Improving Strength Prediction through Physical Process Mechanisms



Continuous plan for AI for typhoon forecast Application

- **Goals**
  - Improve the typhoon forecasting with AI to support the EW4ALL Initiative
  - Comprehensively Evaluate AI's potential for typhoon forecasting
  - Provide operational AI-driven Typhoon Forecasting Tools
- **Expected Outcomes**
  - AI-enhanced typhoon Prediction Tools and Products, including ensemble and deterministic typhoon forecast products
  - Comprehensive Report on AI for typhoon prediction

Thanks a lot for your listening!