The typhoon model of Tropical Region Atmospheric Model System (CMA-TRAMS): development and evaluation

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Outline

1. Overview of TRAMS model
2. Technical development
3. Operational performance
4. Future plan

Operational performance

1. Performance evaluation
2. Cases demonstration
3. Model application

Operational performance–Typhoon track error

- The prediction accuracy of TRAMS model has been improved year by year.
- In 2022, the typhoon track error of TRAMS by 24h, 48h and 72h forecast was 50.6km, 91.9km and 146.7km.
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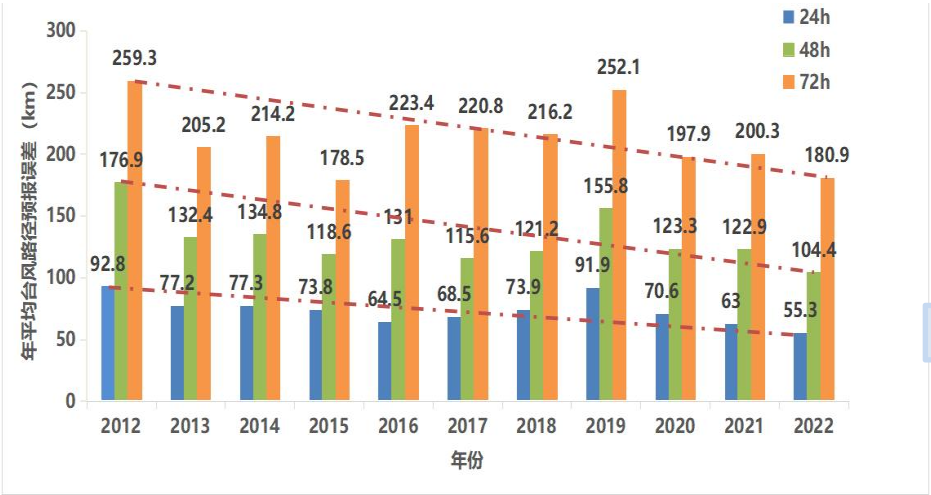


Annual Typhoon track error by TRAMS

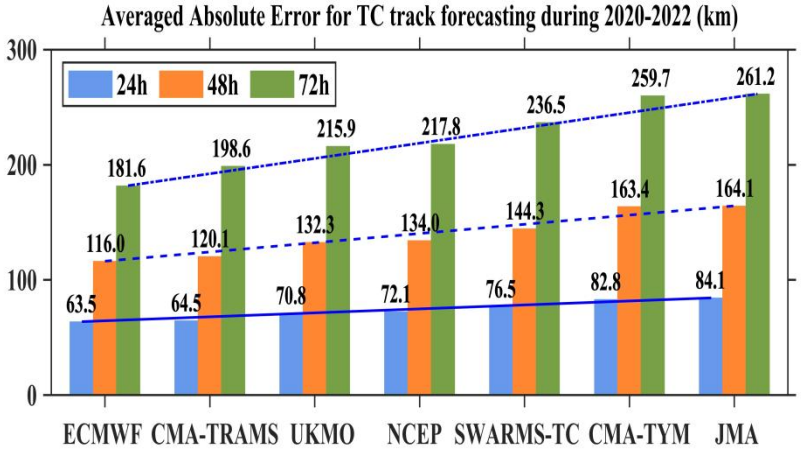
	MODELS	24 h samples	24 h Error(km)	48 h samples	48 h Error(km)	72 h samples	72 h Error(km)
GFS	CMA-GFS	77	90.3	60	161.2	43	243.0
	NCEP-GFS		65.1		134.5		210.4
	ECMWF-IFS		60.8		113.3		184.8
	METOFFICE		65.5		136.3		213.7
	JAPAN		64.6		132.5		228.7
	SHANGHAI		78.0		162.3		213.3
Regional models	CMA-TRAMS	60	50.6	48	91.9	36	146.7
	CMA-TYM		76.3		163.0		230.1
	GRAPES-TCM		94.7		178.4		248.3
	HWRF		66.4		146.0		194.0

Comparison of Typhoon track error by NWP models

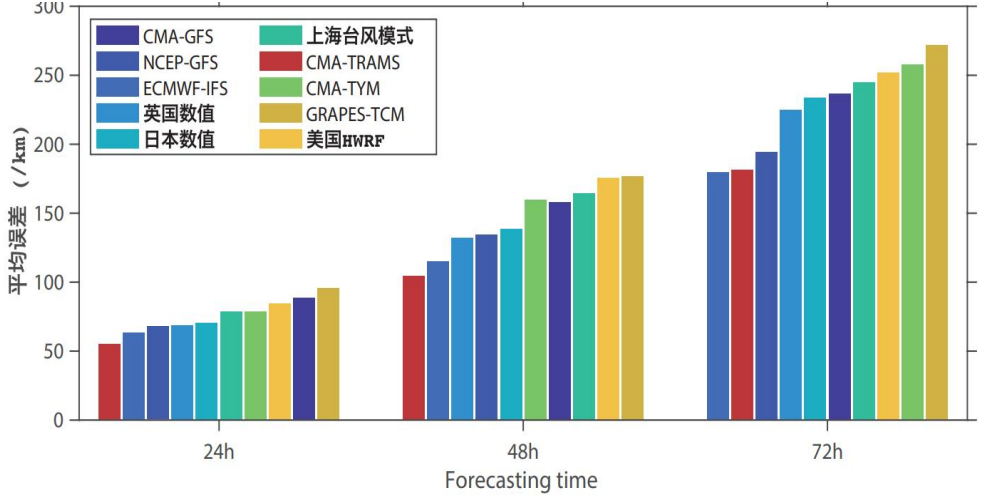
(Official Evaluation by CMA typhoon committee)

Operational performance–Typhoon track error

- TRAMS showed competitive forecasting ability with ECMWF in 2020-2022.
- In 2022, TRAMS showed generally better performances(smaller track error) than ECMWF.



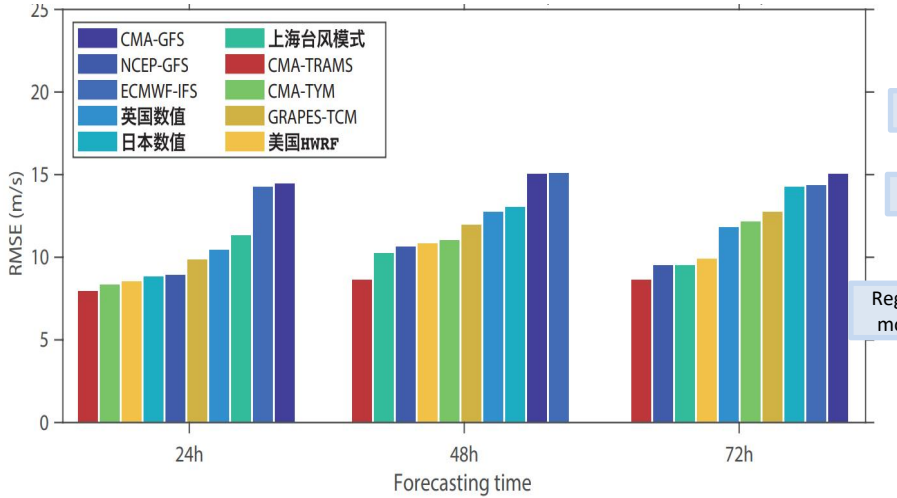
Comparison of typhoon track error by NWP models between 2020-2022



Comparison of typhoon track error by NWP models in 2022

Operational performance–Typhoon track error

- In addition, TRAMS showed generally better performances on typhoon intensity forecasting than the other NWP model in 2022.
- In 2022, the typhoon track error by 24h, 48h and 72h forecast was 55.3km, 104.4km and 180.9km.



Typhoon intensity error by NWP models

（MAE 和 RMSE 单位：$m \cdot s^{-1}$）

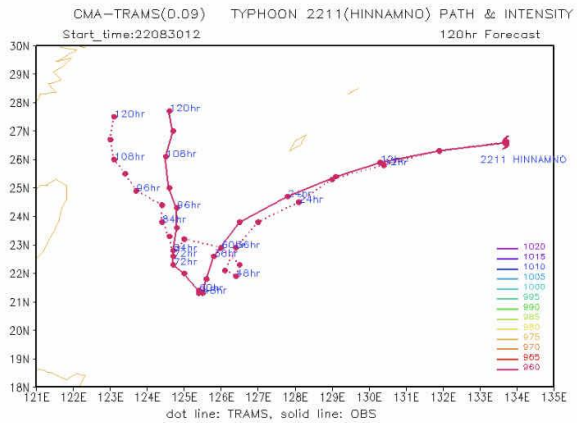
MODELS		24 h				48 h				72 h				96 h				120 h			
		MAE	RCT (%)	RMSE	样本数	MAE	RCT (%)	RMSE	样本数	MAE	RCT (%)	RMSE	样本数	MAE	RCT (%)	RMSE	样本数	MAE	RCT (%)	RMSE	样本数
GFS	CMA-GFS	10.6	63.1	14.4	260	11.1	66.3	15.0	193	11.1	65.2	15.0	132	10.7	56.5	14.1	85	9.1	60.7	12.1	56
	NCEP-GFS	6.7	67.0	8.9	218	7.7	76.3	10.6	169	7.0	74.8	9.5	127	5.3	75.6	7.1	90	6.8	73.0	8.7	63
	ECMWF-IFS	11.0	72.7	14.2	234	11.6	75.0	15.1	176	10.9	76.6	14.3	128	10.3	66.7	13.1	45	11.8	65.5	14.4	29
	英国数值	7.8	34.4	10.4	125	9.2	46.2	12.7	91	8.7	56.7	11.8	67	9.3	62.8	11.7	43	7.8	64.3	9.4	28
	日本数值	6.5	70.0	8.8	227	9.7	73.3	13.0	165	10.7	67.8	14.2	115	13.7	59.2	16.8	76	13.5	66.0	16.4	50
Regional models	上海台风模式	8.4	75.2	11.3	129	8.0	78.5	10.2	93	7.5	80.3	9.5	61	/	/	/	/	/	/	/	/
	CMA-TRAMS	5.8	68.9	7.9	119	6.9	76.4	8.6	89	7.1	80.7	8.6	62	/	/	/	/	/	/	/	/
	CMA-TYM	6.4	72.6	8.3	266	8.4	80.8	11.0	198	9.3	80.5	12.1	133	9.1	75.9	12.4	87	9.2	79.0	11.3	57
	GRAPES-TCM	7.2	69.2	9.8	94	9.7	76.1	11.9	71	10.2	80.0	12.7	50	/	/	/	/	/	/	/	/
	HWRF	6.2	72.3	8.5	195	7.9	82.0	10.8	150	7.6	87.8	9.9	115	7.6	85.5	10.2	83	7.3	85.0	8.7	60

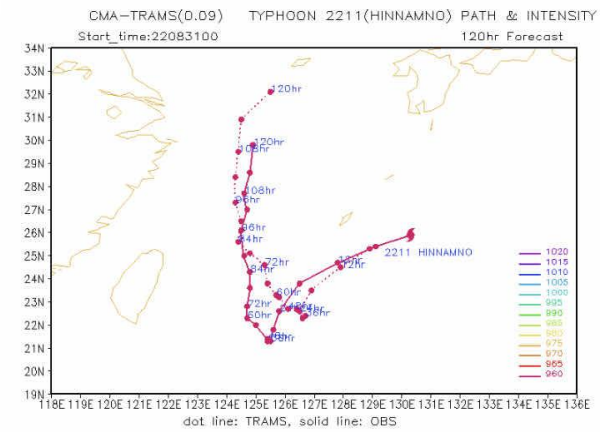
Typhoon Intensity error in 2022

Operational performance–Typhoon track forecast

- TRAMS model showed a robust ability to forecast the complicated typhoon path in operation.

Two days in advance forecast the northward turning of Super Typhoon Hinnamnor in 2022

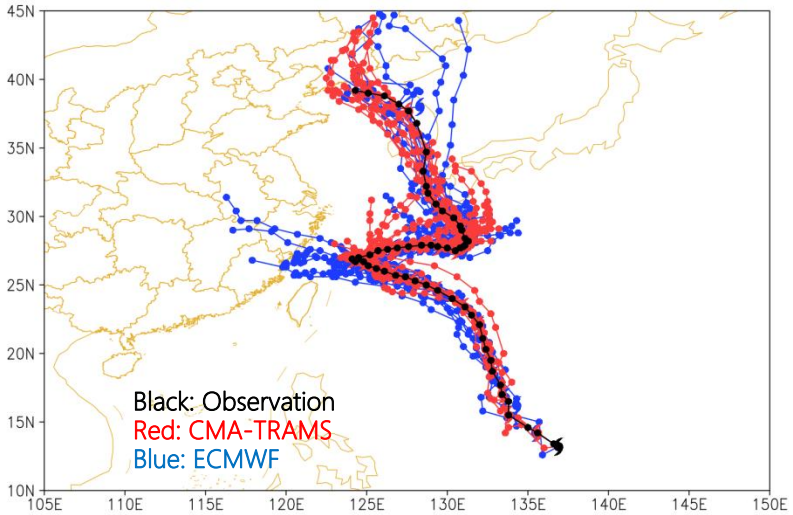




Three days in advance forecast the southward turning of Super Typhoon Atsani in 2020

Operational performance–Typhoon track forecast

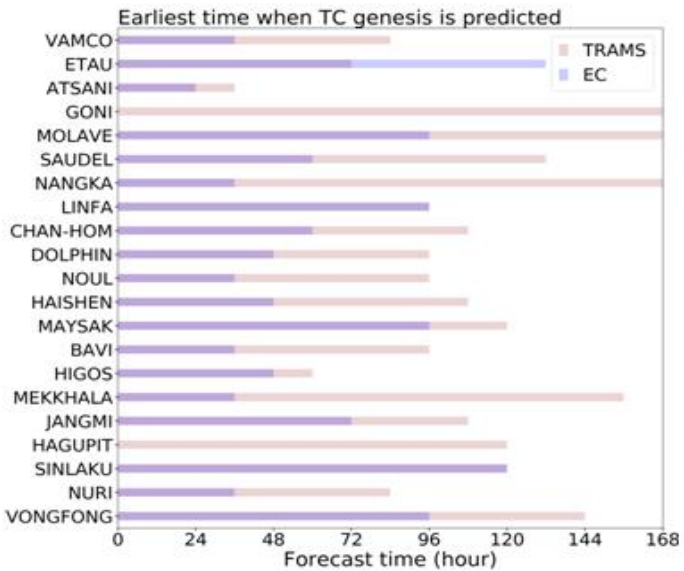
- TRAMS successfully predicted the first recurving of typhoon KHANUN 6 days in advance and accurately predicted the second recurving processes.



Typhoon track of KHANUN(卡努，2306)

Operational performance–Typhoon generation forecast

➢ **CMA-TRAMS 9km can predict 90% of typhoon generation 3 days in advance.**

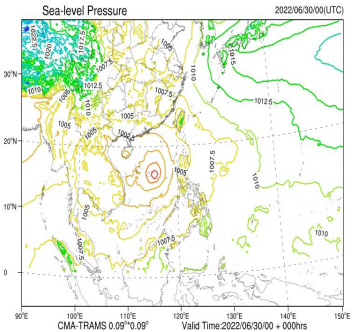


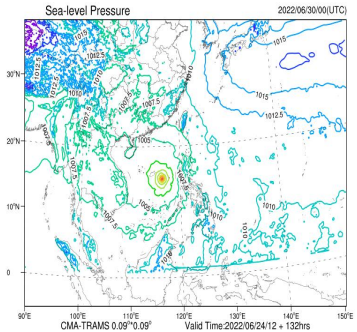
	TRAMS	EC
VONGFONG	6-day	4-day
NURI	3-day	1-day
SINLAKU	5-day	5-day
HAGUPIT	5-day	
JANGMI	4-day	3-day
MEKKHALA	6-day	1-day
HIGOS	2-day	2-day
BAVI	4-day	1-day
MAYSAK	5-day	4-day
HAISHEN	4-day	1-day
NOUL	4-day	1-day
DOLPHIN	4-day	1-day
CHAN-HOM	4-day	2-day
LINFA	4-day	4-day
NANGKA	7-day	1-day
SAUDEL	5-day	2-day
MOLAVE	7-day	4-day
GONI	7-day	
ATSANI	1-day	1-day
ETAU	3-day	5-day
VAMCO	3-day	1-day

Typhoon generation by CMA-TRAMS in 2020

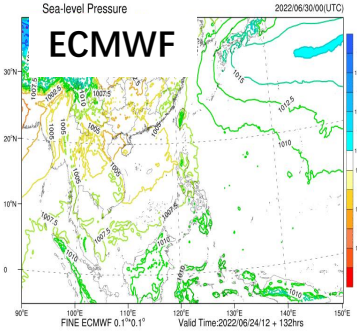
Reanalysis

CMA-TRAMS

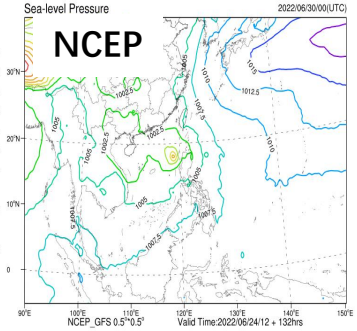




ECMWF



NCEP

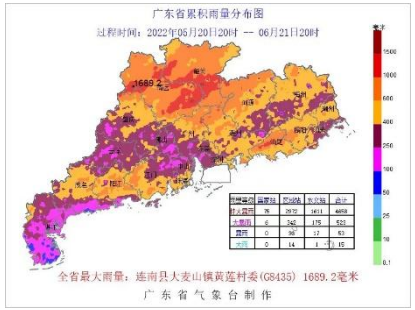


CMA-TRAMS predicts the generation of "Chaba" 132 hours in advance

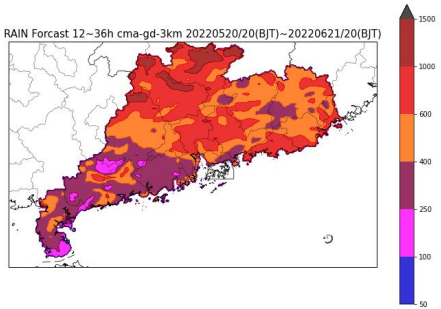
Operational performance–heavy rainfall forecast

- The TRAMS model has shown higher performances on predicting the "**dragon boat rainfall**"(from May 21 to June 21) in 2022. The ECMWF and NCEP models underestimated the precipitation.
- for 24-48 hour and 48-72 hour forecasts, the TRAMS shows a higher TS score of rainstorm and heavy rainstorm than the GFS models (ECMWF and NCEP).

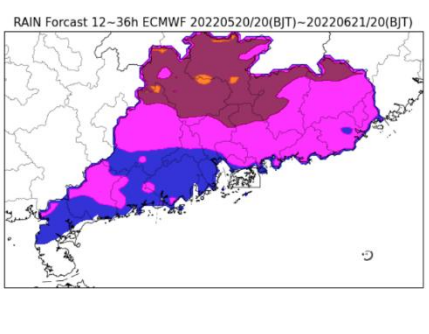
OBS



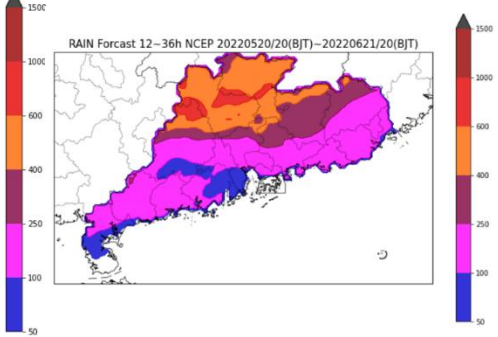
TRAMS



ECMWF



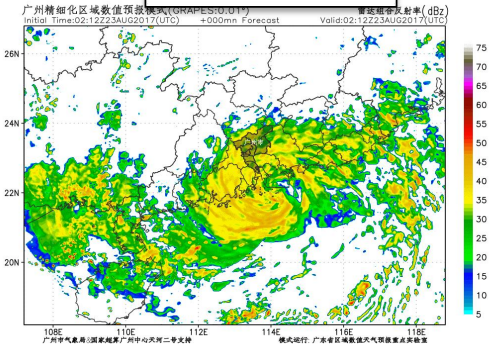
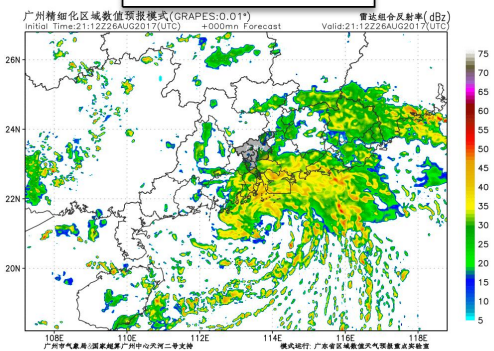
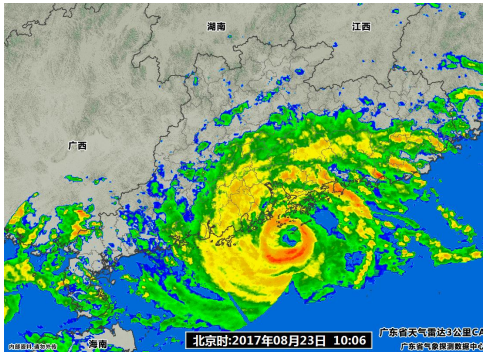
NCEP



	≥10mm				≥25mm				≥50mm				≥100mm			
预报时段	ECMWF	CMA-TRAMS	CMA-GD	NCEP	ECMWF	CMA-TRAMS	CMA-GD	NCEP	ECMWF	CMA-TRAMS	CMA-GD	NCEP	ECMWF	CMA-TRAMS	CMA-GD	NCEP
24-48h	0.488	0.440	0.439	0.455	0.299	0.285	0.270	0.232	0.103	0.122	0.124	0.059	0.002	0.020	0.048	0.001
48-72h	0.471	0.436	0.408	0.442	0.302	0.276	0.263	0.259	0.113	0.134	0.141	0.072	0.009	0.039	0.041	0.003

Operational performance–Typhoon forecast

- In 2017, Super Typhoon Hato caused huge devastation over the coastal regions of Guangdong.
- The TRAMS(1km) model provided realistic forecast of the typhoon landing.

	Super Typhoon Hato	Typhoon Pakhar
TRAMS		
OBS		

Operational performance–Typhoon forecast

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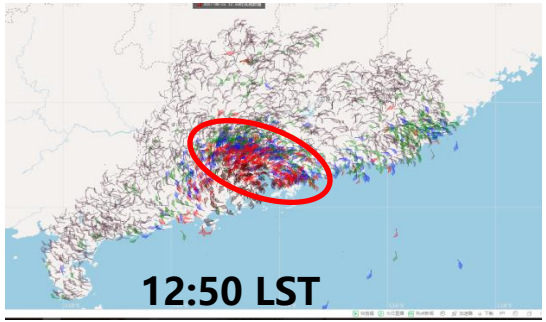
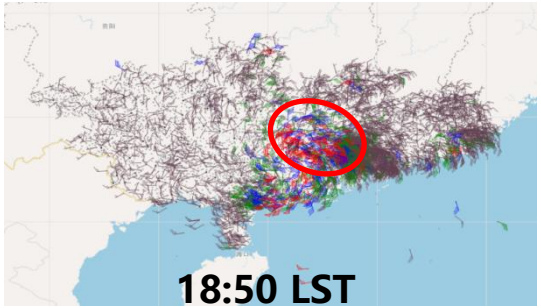
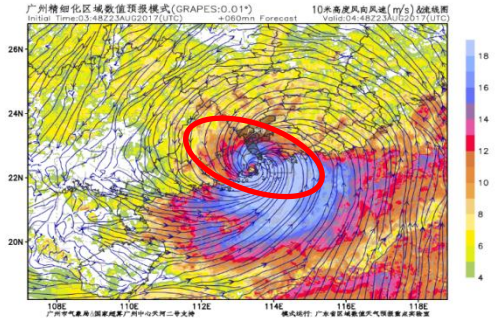
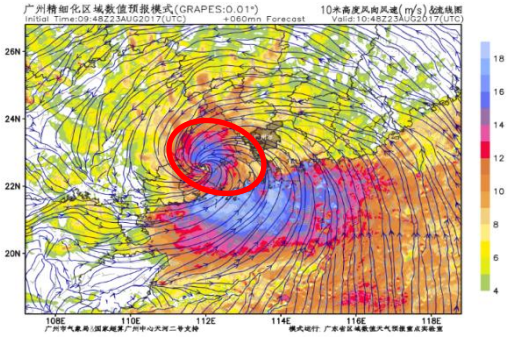








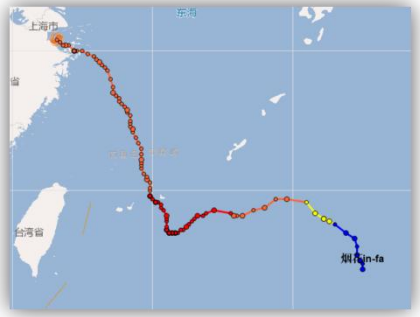
The strong winds caused by super typhoon Hato (1hr forecast)

Operational performance

1. Performance evaluation
2. Cases demonstration
3. Model application

Operational performance–Cases demonstration

- The operational performances of the CMA-TRAMS on six Typhoons will be given.



Typhoon IN-FA-2106

Typhoon Chaba-2203

Typhoon Doksuri-2305

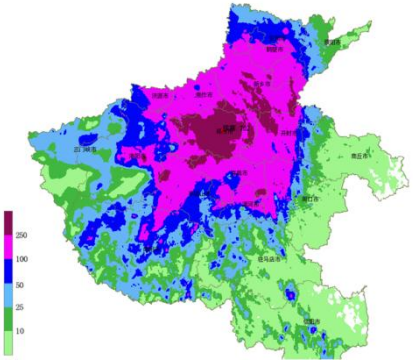
Typhoon SAOLA-2309

Typhoon HAIKUI-2311

Typhoon SANBA-2316

Operational performance–Typhoon IN-FA（2106）

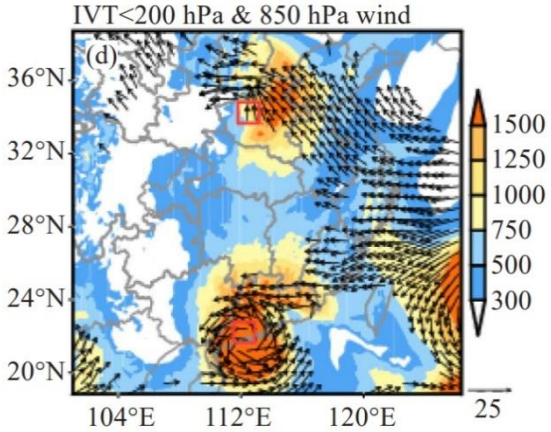
- From July 17 to 23, 2021, Henan Province experienced a rare extremely heavy rainstorm. The disaster caused 398 deaths and missing with direct economic loss is $20 billion.
- The extreme precipitation was caused by the co-effects by Typhoon IN-FA and local effects (orographic lifting, urban effects, etc).



24h Acc-Pre by 20th-21th July 2021
(maximum 24hr accumulative rainfall: 702 mm)

flooding subway

flooding car



Comparisons of the vertically integrated water vapor transport (IVT, units: $kgm^{-1}s^{-1}$) and wind (> 8m s^{-1}) of the layers below 200 hPa (wind vectors at 850 hPa) on 0600 UTC 20 July.

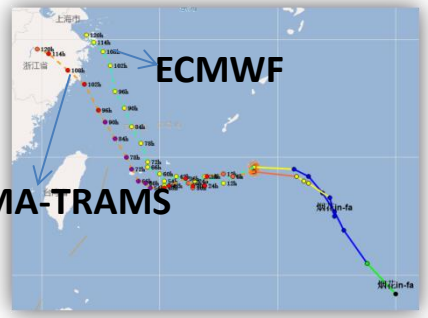
Operational performance–Typhoon IN-FA（2106）

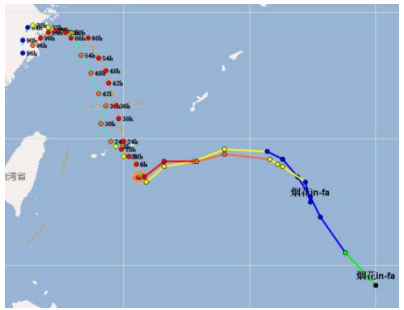
- Both ECMWF and CMA-TRAMS can predict the typhoon path of IN-FA.
- For the typhoon landing forecasting, both EC and TRAMS model can predict the perfect landing location and time. EC had better landing forecasting with 5 days in advance.

CMA-TRAMS

ECMWF

Comparisons of Typhoon path forecasts

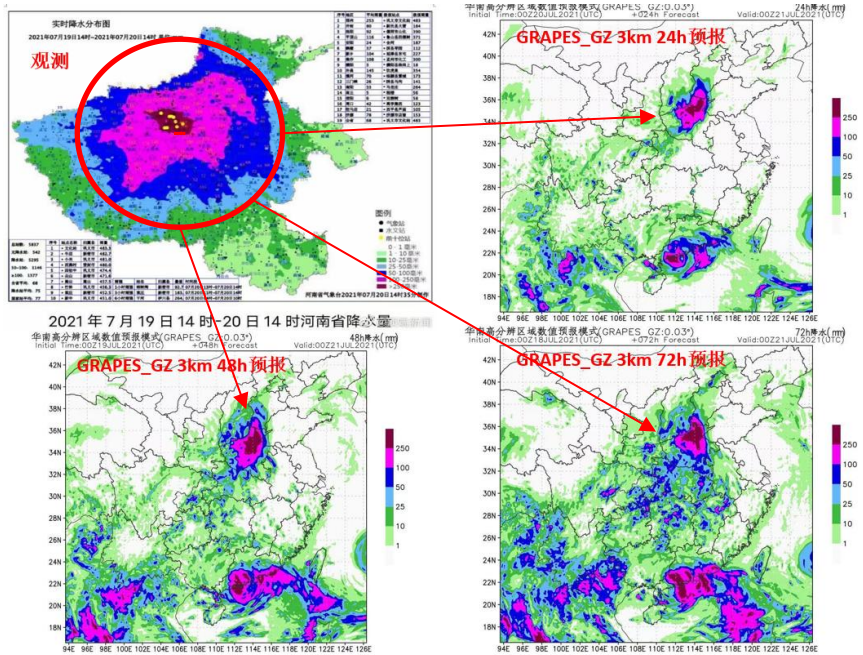




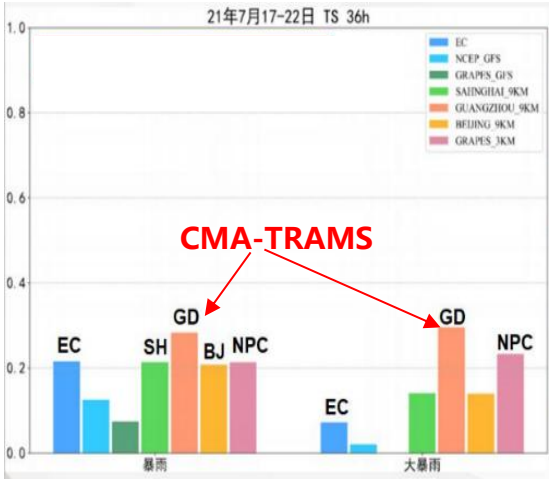
Typhoon landing forecasts

Operational performance–Typhoon IN-FA（2106）

- **CMA-TRAMS can predict the extremely heavy rainfall in Zhengzhou on July 17-22, 2021 by 3 days in advance.**
- **The model predicted the 24h accumulative precipitation of 556mm (627mm by observation) on July 20.**



The extreme rainfall over Zhenzhou: observation and 3 days forecast

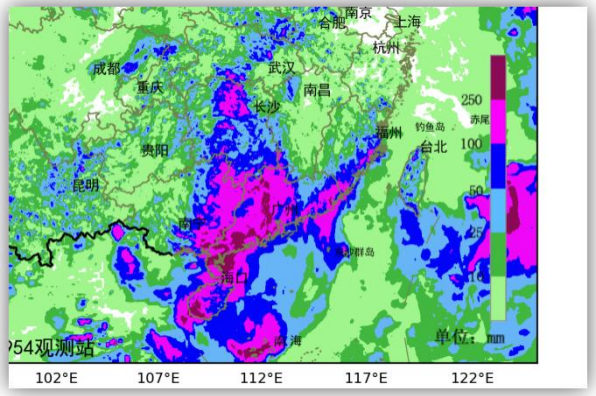


TS of the heavy rainfall by 36h forecast

Operational performance–Typhoon Chaba（2203）

- Typhoon “chaba" strengthened to a storm level in the central South China Sea on June 30th.
- It made landfall along the coast of Dianbai in Maoming, Guangdong Province at on July 2 with a typhoon level.
- At the time of landfall, the maximum wind speed was 35 meters/second (12 levels).

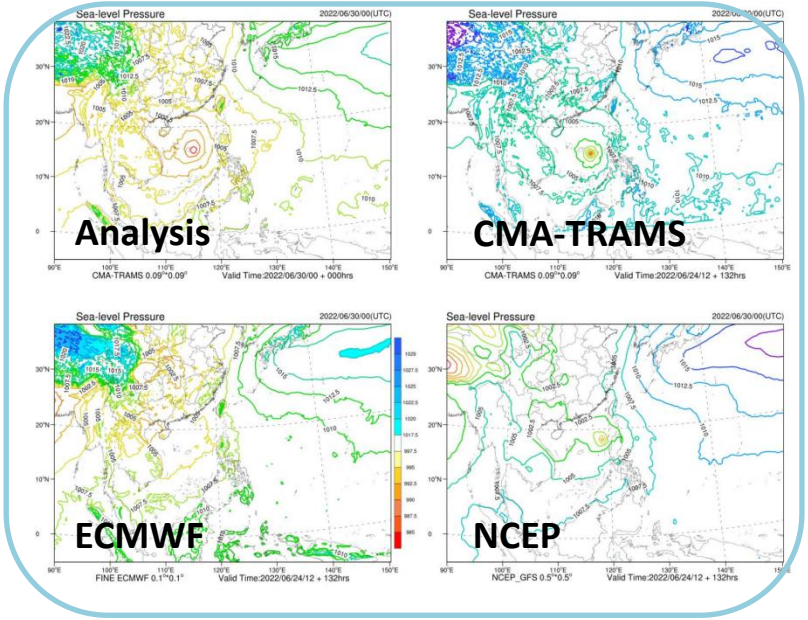
Typhoon path of Chaba



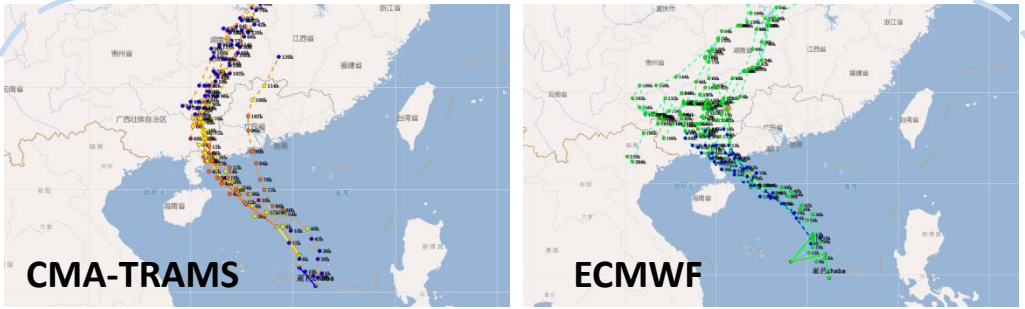
72h Acc-Pre by 1st-4th July 2022
(maximum 24hr accumulative rainfall: 593 mm)

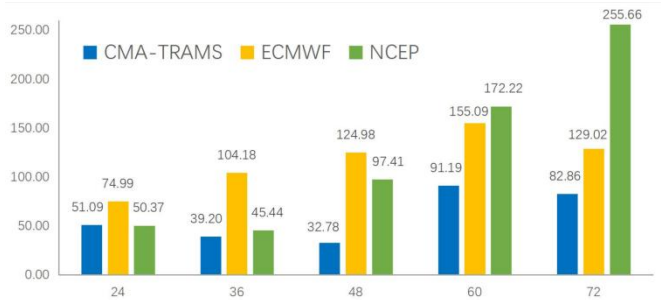
Operational performance–Typhoon Chaba（2203）

- Both TRAMS and NCEP model can predict the typhoon genesis of Chaba with 132 hr in advance.
- TRAMS showed smaller typhoon track error against ECMWF and NCEP model.



Comparisons of Typhoon genesis forecasts

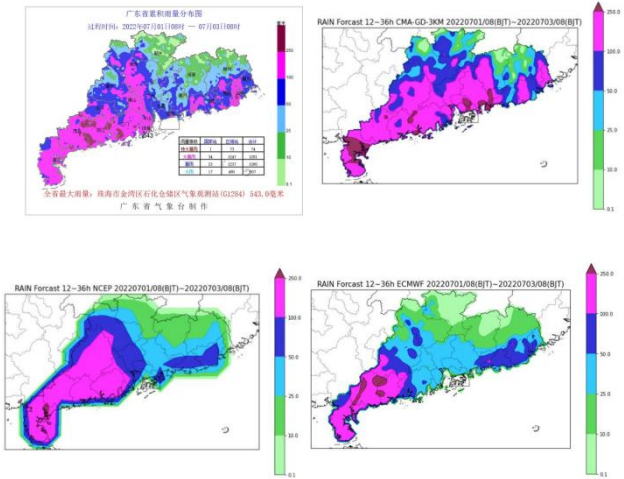




Typhoon track error

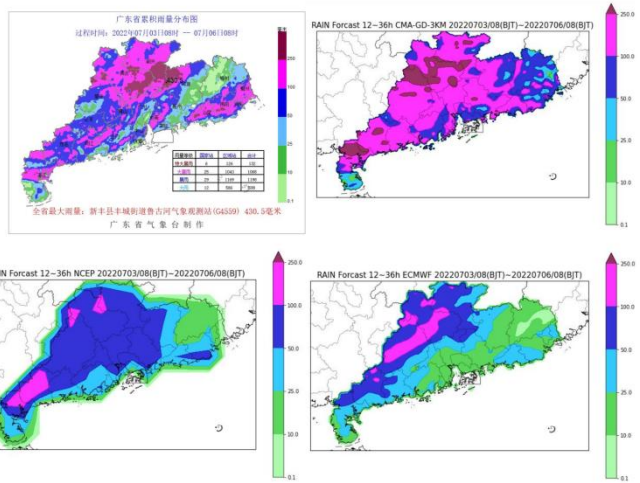
Operational performance–Typhoon Chaba（2203）

- Stage 1 - typhoon landing: all NWP models generally captured the heavy rainfall caused by typhoon Chaba within 36 hr forecasting.
- Stage 2 - typhoon weakening impacts: TRAMS showed better intensity forecast of the rainfall, especially the forecast with the TRAMS-3KM system.



48h Acc-Pre by 1th-3th July 2023

Stage 1 - typhoon landing



72h Acc-Pre by 3th-6th July 2023

Stage 2 - typhoon weakening impacts

Operational performance–Typhoon Chaba（2203）

- The evaluation of the forecasting capabilities of the NWP models showed that TRAMS had higher TS score for the rainfall forecasting of typhoon Chaba, especially for the forecast with the TRAMS-3KM system.

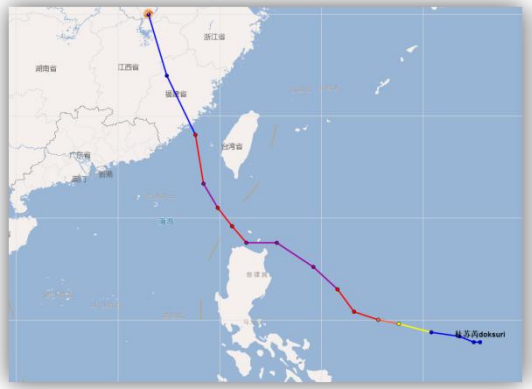
	≥10mm				≥25mm			
	Ecmwf	CMA-TRAMS	CMA-GD	NCEP	Ecmwf	CMA-TRAMS	CMA-GD	NCEP
24-48h	0.558	0.586	0.607	0.601	0.423	0.465	0.450	0.463
48-72h	0.509	0.532	0.545	0.524	0.315	0.427	0.442	0.351

≥50mm				≥100mm			
Ecmwf	CMA-TRAMS	CMA-GD	NCEP	Ecmwf	CMA-TRAMS	CMA-GD	NCEP
0.206	0.306	0.319	0.284	0.070	0.121	0.095	0.111
0.115	0.258	0.268	0.194	0.000	0.110	0.120	0.056

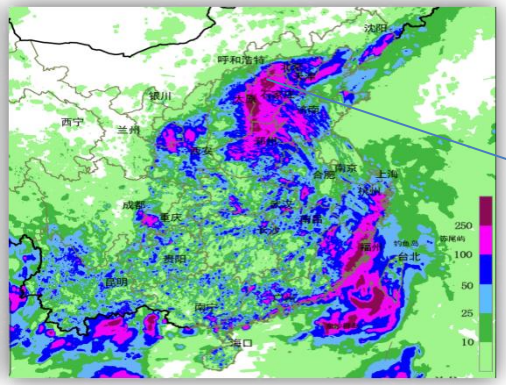
Comparison of the 24h precipitation forecast from July 1 to 6, 2022

Operational performance–Typhoon Doksuri（2305）

- Typhoon "Duksuri" was generated in the east of the Philippines on July 21 and strengthened to a super typhoon on July 24. And at 09:55 on July 28th, it made landfall in the coastal area of Fujian with a strong typhoon (15, 50 m/s, 945 hPa).
- The northward moving of Typhoon "Doksuri" after the landfall caused the local extremely heavy rainstorm in Beijing Tianjin Hebei region.



Typhoon path of Doksuri



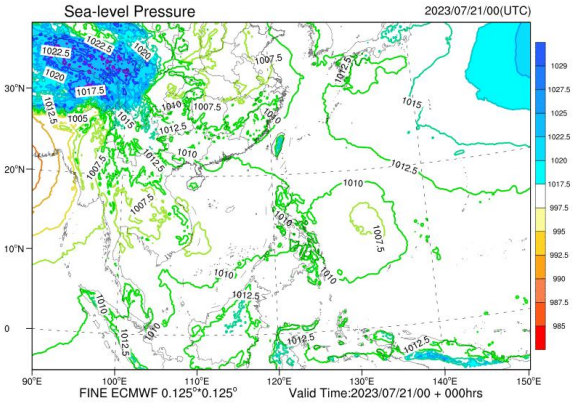
72h Acc-Pre by 27th-30th July 2023
(maximum 24hr accumulative rainfall: 895 mm)

before

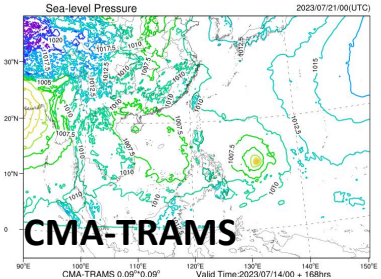
after

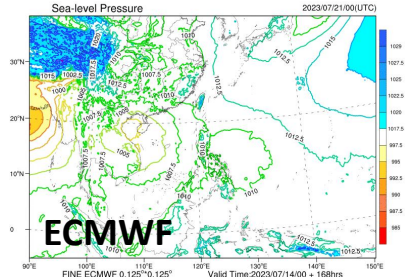
Operational performance–Typhoon Doksuri（2305）

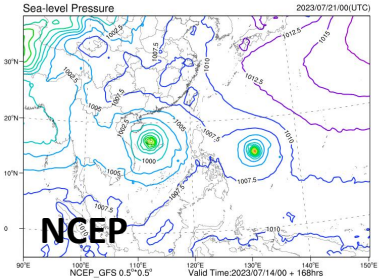
- Both TRAMS and NCEP model can predict the typhoon genesis of Doksuri with 168 hr in advance.
- NCEP model showed a false typhoon genesis over the South China Sea.

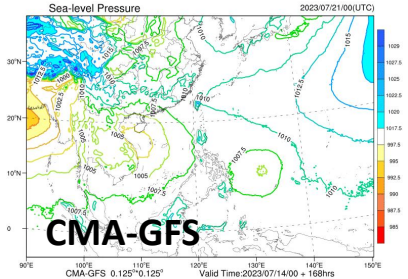


Analysis



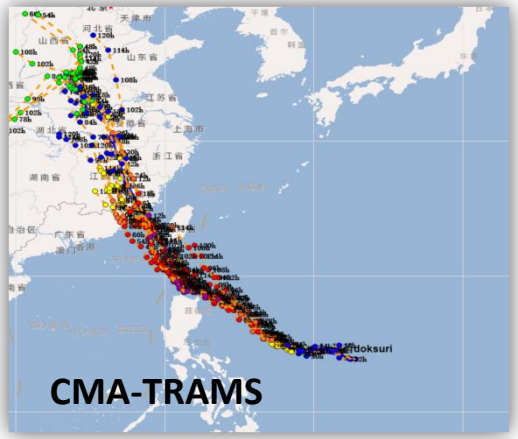


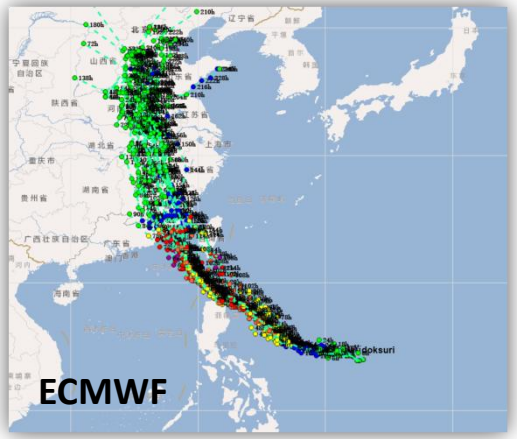




Operational performance–Typhoon Doksuri（2305）

- Both TRAMS and ECMWF can predict the typhoon path of Doksuri.
- TRAMS and NCEP showed smaller typhoon track error against ECMWF and CMA-GFS model.





Typhoon track forecasts

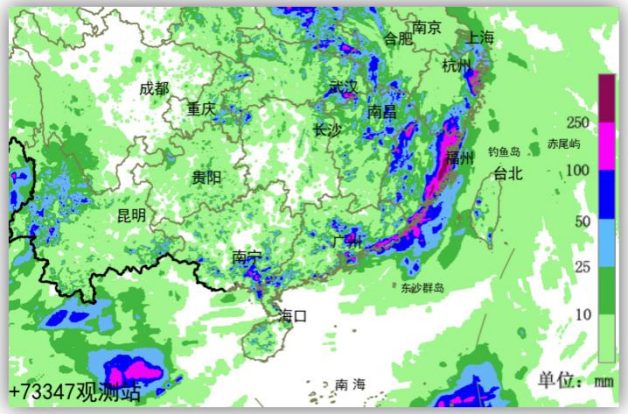
	6hr	12hr	18hr	24hr	30hr	36hr	42hr	48hr	54hr	60hr	66hr	72hr
EC	40	51.8	35.6	45.1	43.7	48.3	49	55.9	64.4	60.7	67.3	59.8
CMA-GFS	64	68.5	71.9	79	66.8	83.6	80.7	75.8	83.2	100.1	96.9	115
NCEP	41.4	51.2	52	58.9	72.4	94.4	114.4	124.6	172.4	186.7	226.7	267.5
CMA-TRAMS	40.1	43.1	45.4	58.6	47.2	59.4	55.8	50.3	76.1	72.6	100.9	110.7

	6hr	12hr	18hr	24hr	30hr	36hr	42hr	48hr	54hr	60hr	66hr	72hr
EC	4.2	8.8	11.8	14.9	15.8	18.1	21	23.5	23.3	26.7	26.2	28.6
CMA-GFS	4.5	7.9	10	12.5	12.9	16.3	17.5	18.8	19.2	22.2	24	24.8
NCEP	5.7	5.9	7.7	8.9	9.4	11.2	13.7	16.9	16.9	22.6	21.7	26.3
CMA-TRAMS	3.9	8.1	10.8	12.6	13	15.3	16.1	18.7	17.3	19.5	21.8	22.9

Typhoon track error

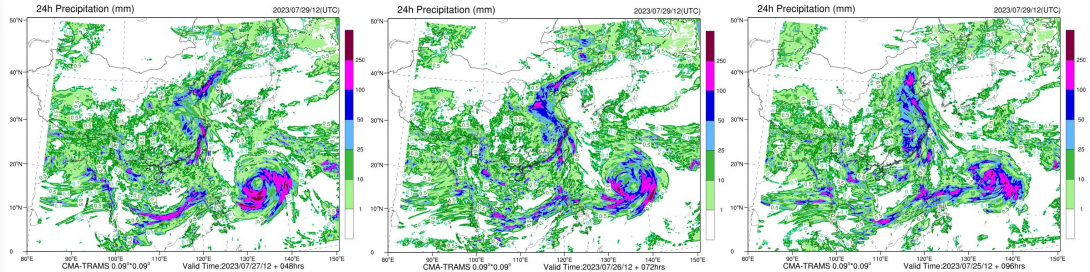
Operational performance–Typhoon Doksuri（2305）

- CMA-TRAMS can predict the heavy rainfall over Fujian Province (maximum 24hr accumulative rainfall: 706 mm) by 4 days in advance.

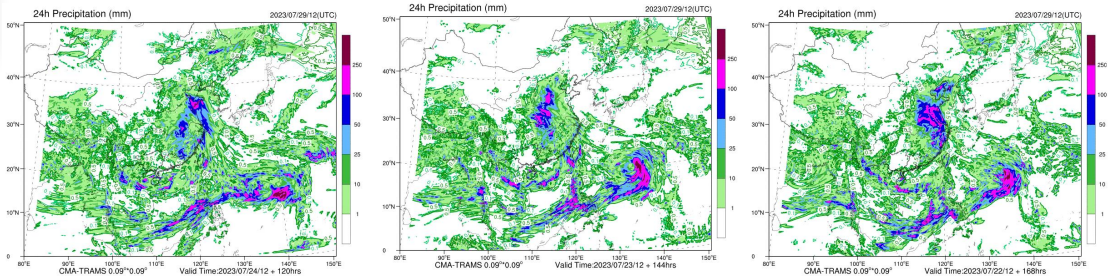


24 Acc-Pre by 28th-29th July

Stage 1 - typhoon landing



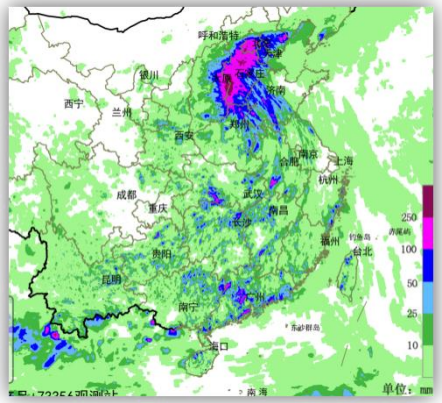
48h 72h 96h



120h 144h 168h

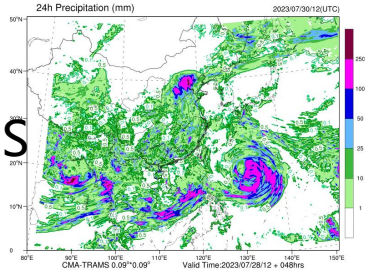
Operational performance–Typhoon Doksuri（2305）

- Both the ECMWF and CMA-TRAMS can predict the extreme heavy rainfall (maximum 24hr accumulative rainfall: 659 mm) over the north China by 4 days in advance.

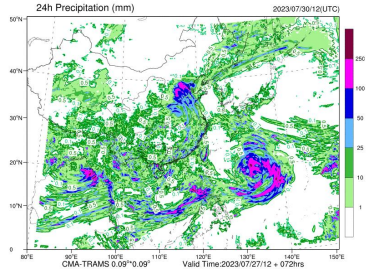


24 Acc-Pre by 29th-30th July

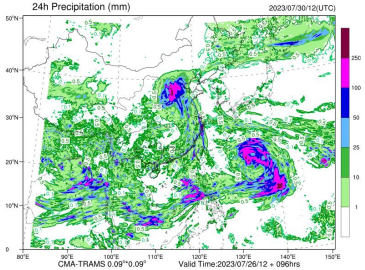
TRAMS



48h

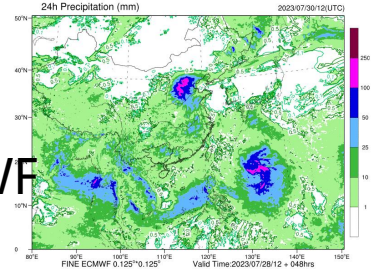


72h

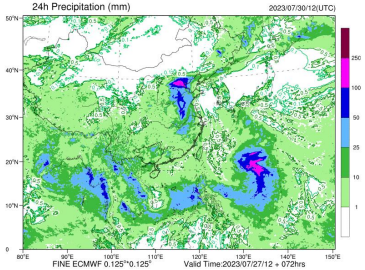


96h

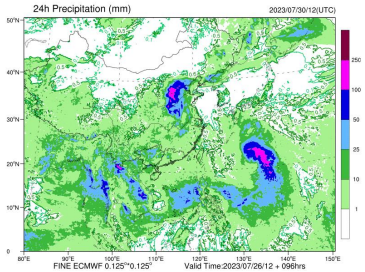
ECMWF



48h



72h

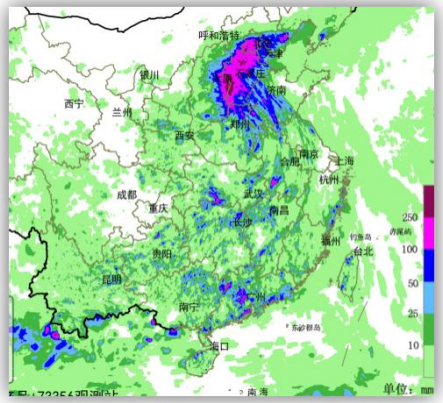


96h

Stage 2 - Typhoon northward moving (inland)

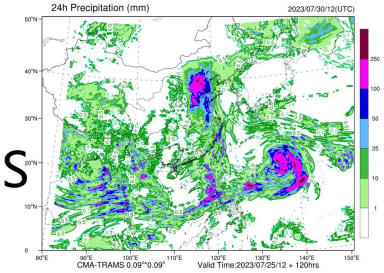
Operational performance–Typhoon Doksuri（2305）

- CMA-TRAMS can predict the extreme heavy rainfall (maximum 24hr accumulative rainfall: 659 mm) over the north China by 7 days in advance.

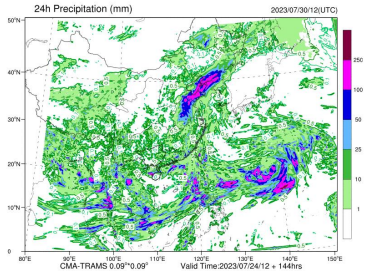


24 Acc-Pre by 29th-30th July

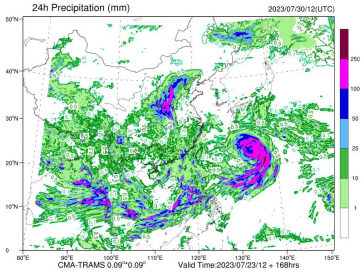
TRAMS



120h

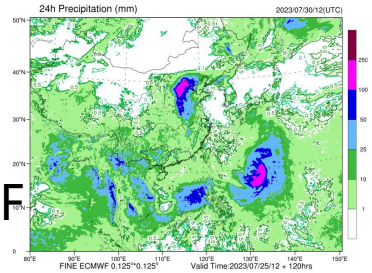


144h

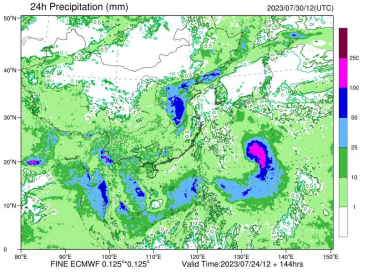


168h

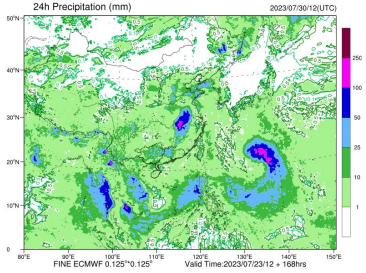
ECMWF



120h



144h

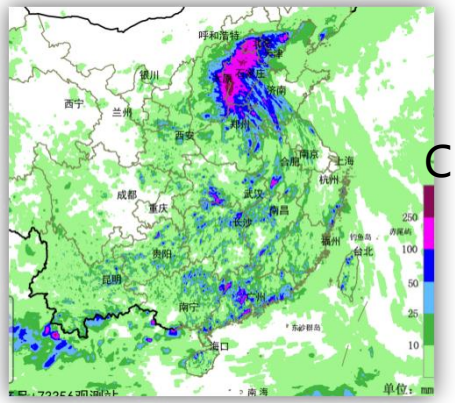


168h

Stage 2 - Typhoon northward moving (inland)

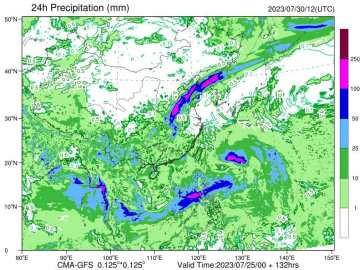
Operational performance–Typhoon Doksuri（2305）

- CMA-TRAMS can predict the extreme heavy rainfall (maximum 24hr accumulative rainfall: 659 mm) over the north China by 7 days in advance.

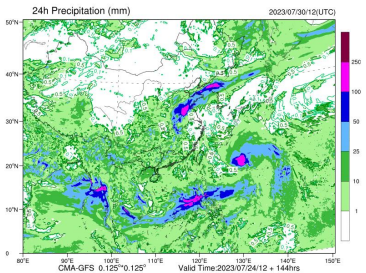


24 Acc-Pre by 29th-30th July

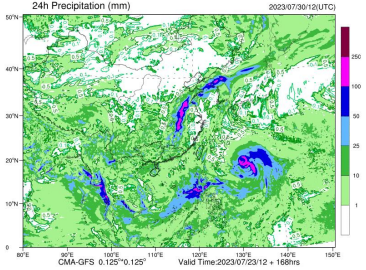
CMA-GFS



132h



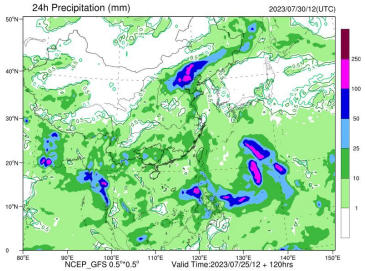
144h



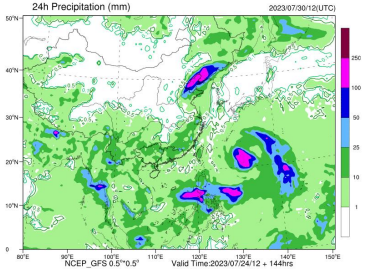
168h

NCEP

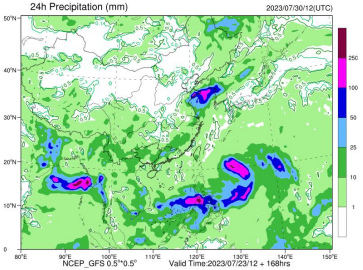
Stage 2 - Typhoon northward moving (inland)



120h



144h

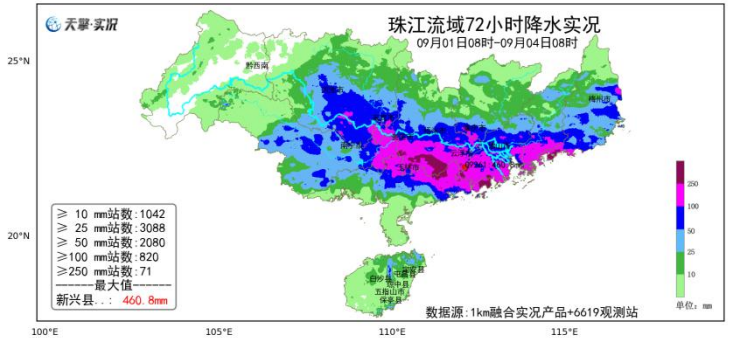


168h

Operational performance–Typhoon Saola（2309）

- Typhoon Saola was generated on the northeast sea surface of Luzon Island, Philippines on **August 24th**.
- It strengthened to a super typhoon on 26th, and made landfall along the southern coast of Zhuhai with a strong typhoon level (45 m/s) on September 2nd .
- It **made landfall again in Hailing Island, Yangjiang City** with a strong tropical storm level (28 m/s), and weakened to a strong tropical storm level at 14:00.

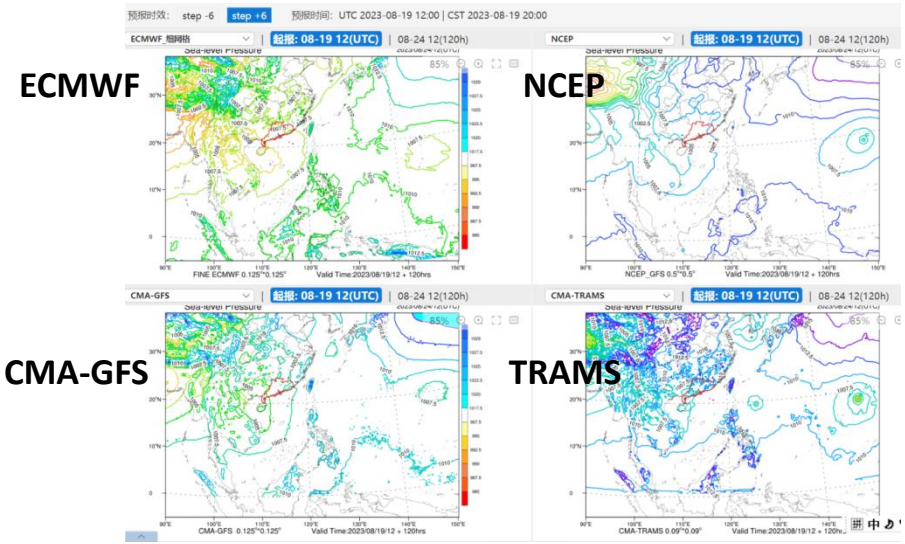
Typhoon path of SAOLA



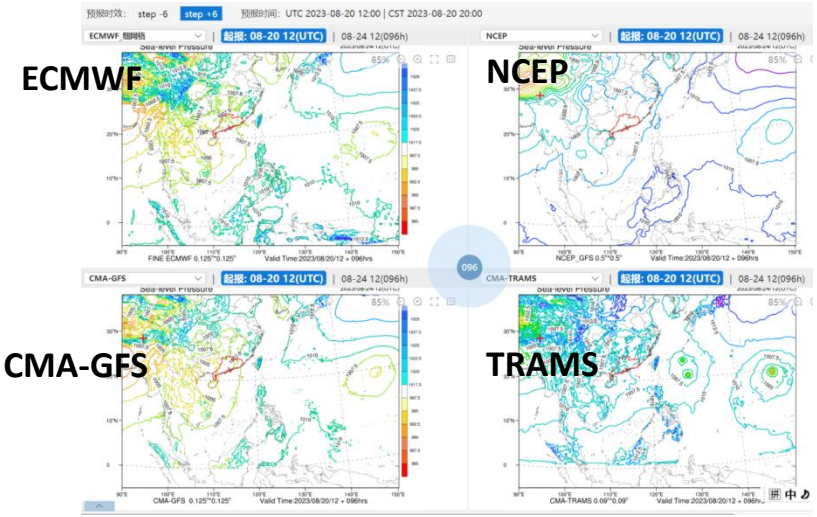
72h accumulative precipitation

Operational performance–Typhoon Saola（2309）

- CMA-TRAMS can predict the typhoon genesis of Saola with 120 hr in advance.
- The mesoscale model showed better performances on typhoon genesis forecasts.



120h



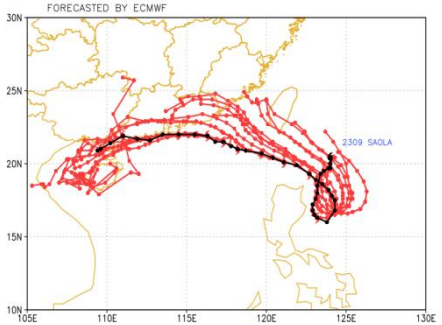
96h

Comparisons of Typhoon genesis forecasts by Operational NWP models

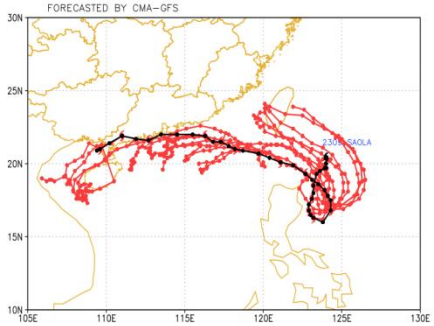
Operational performance–Typhoon Saola（2309）

- In general, CMA-TRAMS can predict the typhoon track with smaller spread tendency and faster moving speed than the other models.

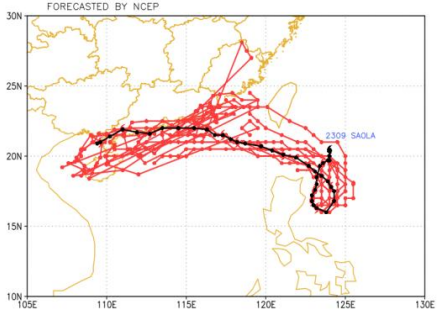
ECMWF



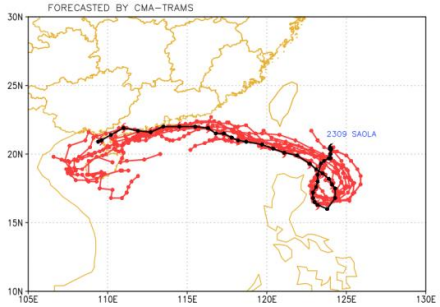
CMA-GFS



NCEP



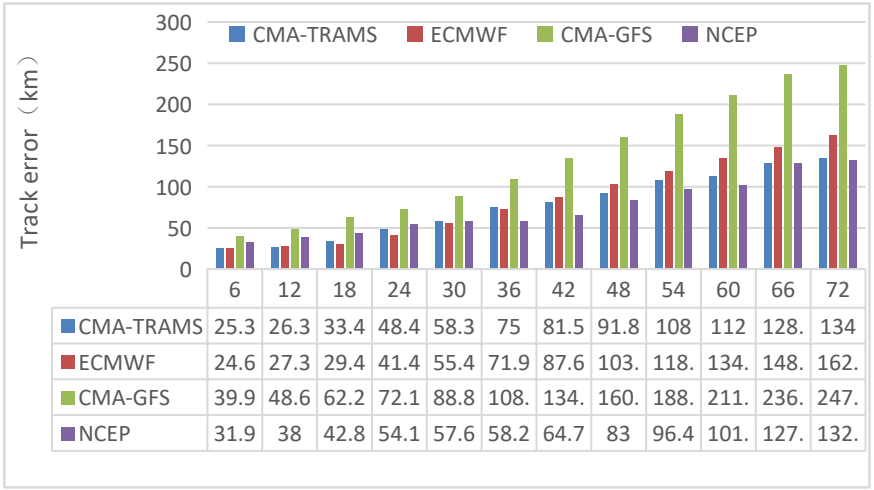
TRAMS



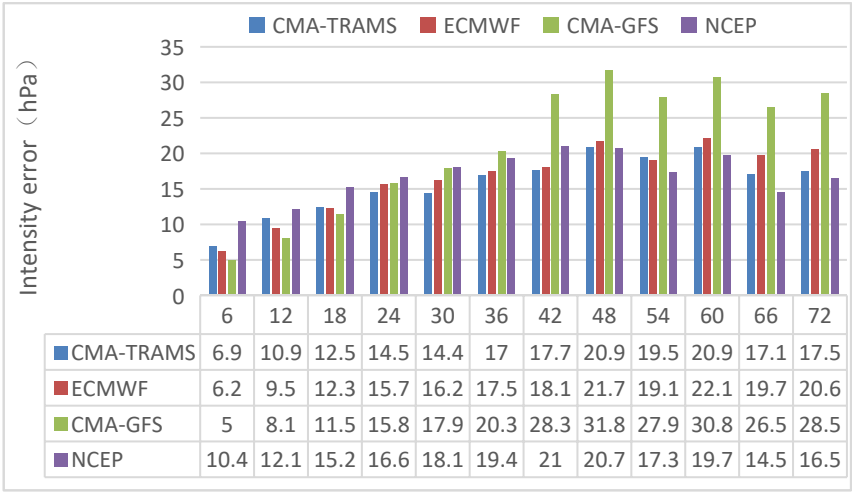
Comparisons of Typhoon track forecasts by Operational NWP models

Operational performance–Typhoon Saola（2309）

- CMA-TRAMS and NCEP model showed smaller tracker error of typhoon Saola.
- CMA-TRAMS showed smaller intensity error of typhoon Saola in 2 days forecast.



	6	12	18	24	30	36	42	48	54	60	66	72
CMA-TRAMS	25.3	26.3	33.4	48.4	58.3	75	81.5	91.8	108	112	128.	134
ECMWF	24.6	27.3	29.4	41.4	55.4	71.9	87.6	103.	118.	134.	148.	162.
CMA-GFS	39.9	48.6	62.2	72.1	88.8	108.	134.	160.	188.	211.	236.	247.
NCEP	31.9	38	42.8	54.1	57.6	58.2	64.7	83	96.4	101.	127.	132.

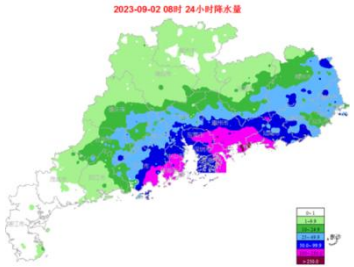


	6	12	18	24	30	36	42	48	54	60	66	72
CMA-TRAMS	6.9	10.9	12.5	14.5	14.4	17	17.7	20.9	19.5	20.9	17.1	17.5
ECMWF	6.2	9.5	12.3	15.7	16.2	17.5	18.1	21.7	19.1	22.1	19.7	20.6
CMA-GFS	5	8.1	11.5	15.8	17.9	20.3	28.3	31.8	27.9	30.8	26.5	28.5
NCEP	10.4	12.1	15.2	16.6	18.1	19.4	21	20.7	17.3	19.7	14.5	16.5

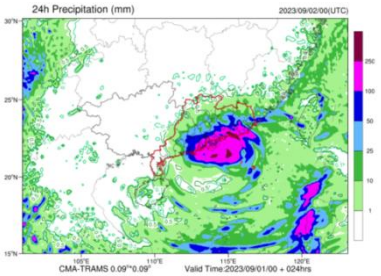
Comparisons of Typhoon track error by Operational NWP models

Operational performance–Typhoon Saola（2309）

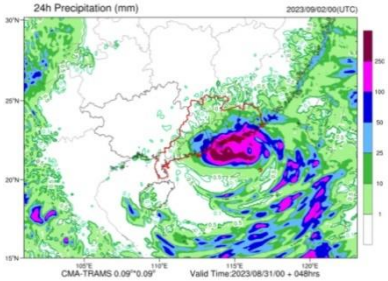
- CMA-TRAMS showed realistic forecast of the 24h accumulative precipitation by typhoon landing of Saola.



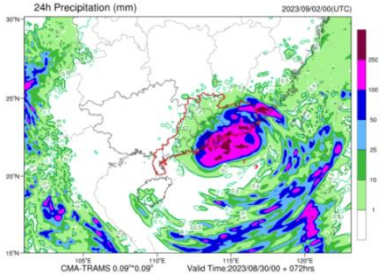
24 Acc-Pre by 1th-2th Sep



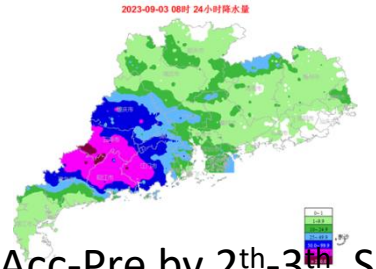
24h



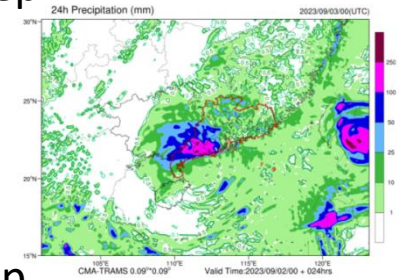
48h

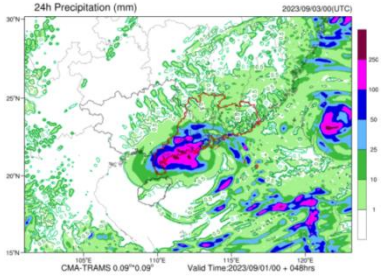


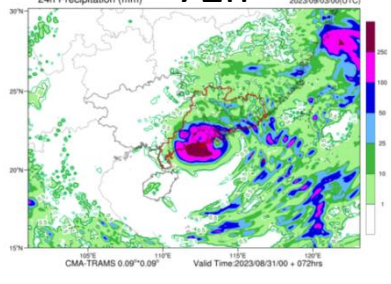
72h



24 Acc-Pre by 2th-3th Sep





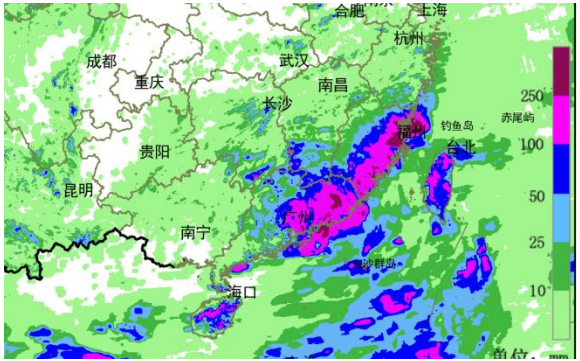


24h accumulative precipitation forecast of Typhoon landing

Operational performance–Typhoon HAIKUI（2311）

- The 11th typhoon of this year, "Haikui", was generated on the northwest Pacific Ocean on August 28.
- It strengthened to a super typhoon level on September 3 and made landfall three times in Taiwan, Fujian, and Guangdong province.

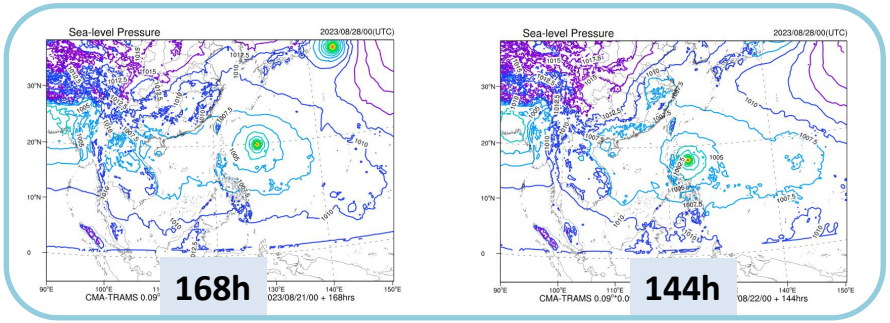
Typhoon path of HAIKUI



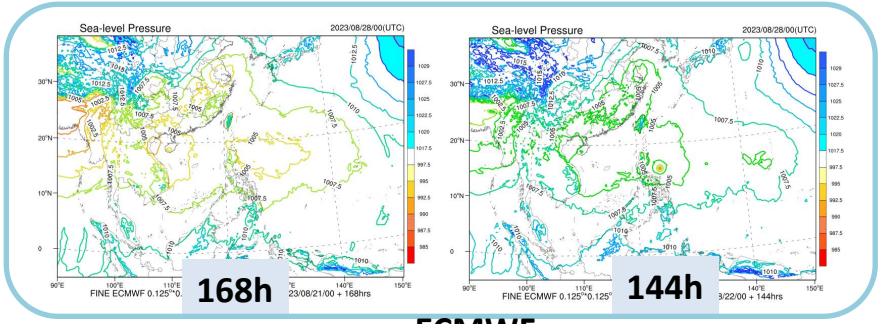
72h accumulative precipitation

Operational performance–Typhoon HAIKUI（2311）

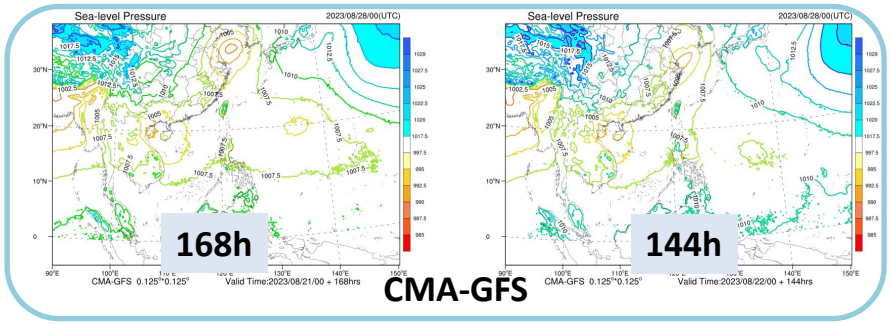
- CMA-TRAMS can predict the typhoon genesis of HAIKUI with 168 hr in advance.
- The mesoscale model showed better performances on typhoon genesis forecasts.



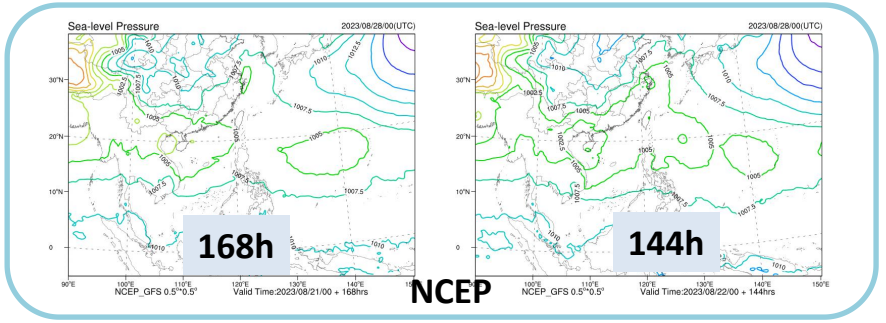
TRAMS



ECMWF



CMA-GFS

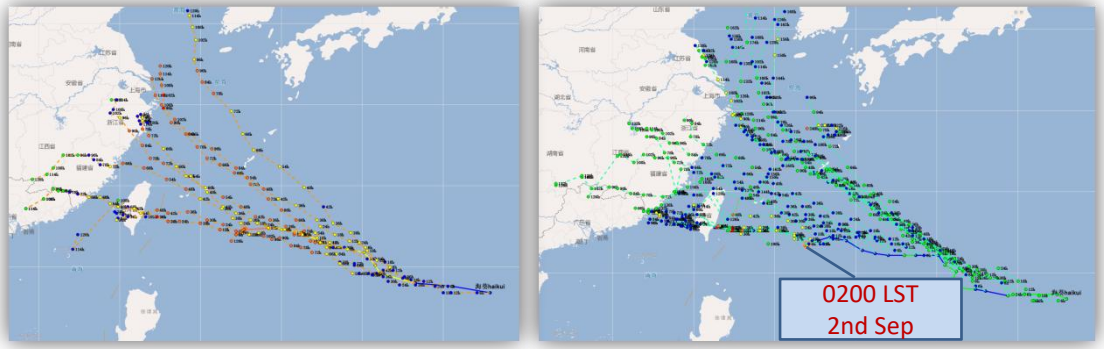


NCEP

Comparisons of Typhoon genesis forecasts by CMA-TRAMS

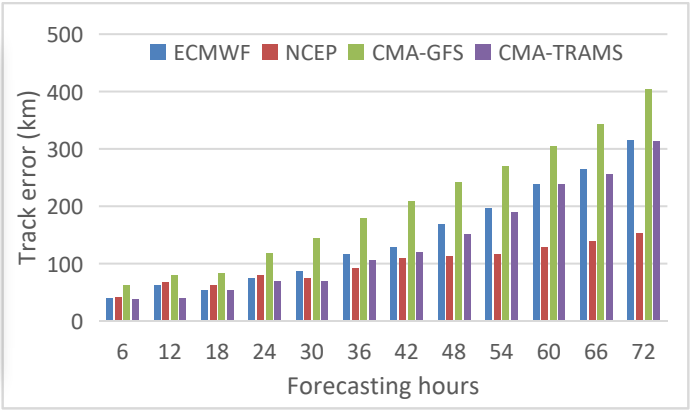
Operational performance–Typhoon HAIKUI（2311）

- Both ECMWF and CMA-TRAMS showed northward bias before September 2nd.
- The NCEP showed the smallest typhoon track error of HAIKUI.



CMA-TRAMS　　ECMWF

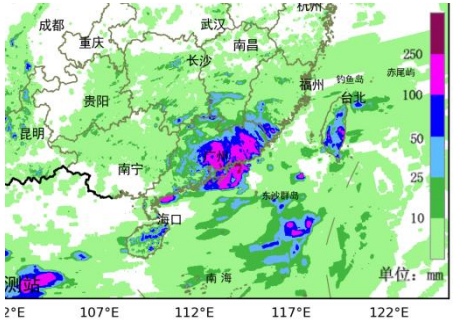
Comparisons of Typhoon track forecasts



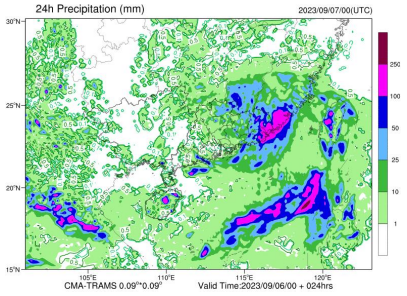
Typhoon track error

Operational performance–Typhoon HAIKUI（2311）

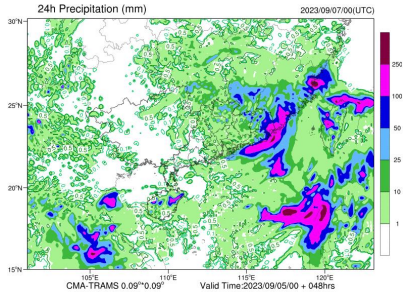
- The precipitation forecast highly depended on the model performances on the typhoon path forecasting.
- CMA-TRAMS can predict the torrential rains caused by the landing of typhoon HAIKUI over the east of Guangdong in 5 days forecast.



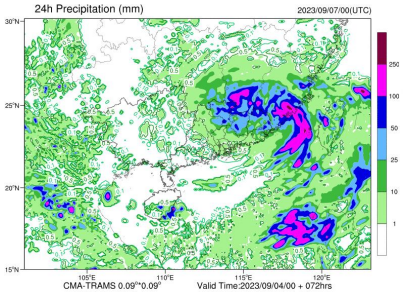
24 Acc-Pre by 6th-7th Sep



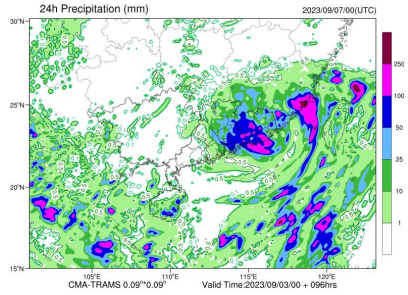
24h



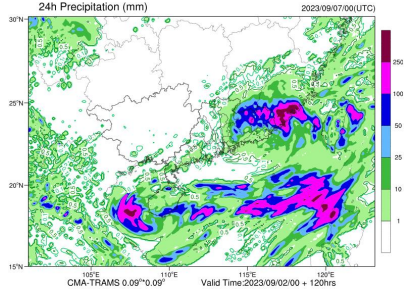
48h



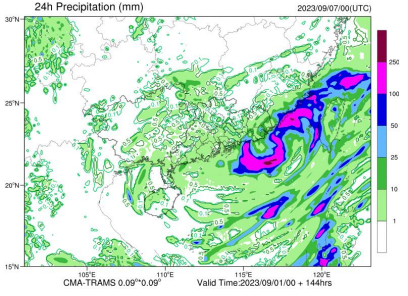
72h



96h



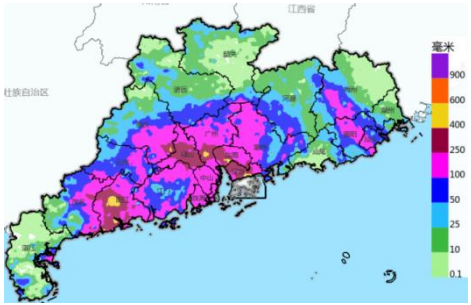
120h



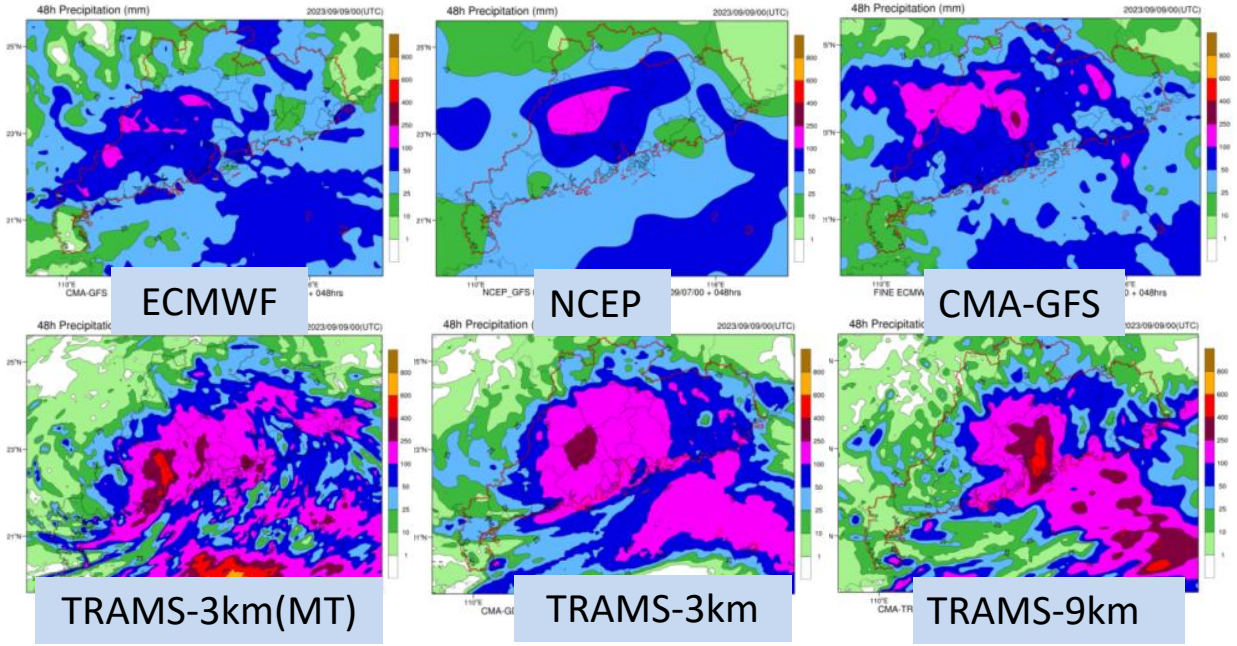
144h

Operational performance–Typhoon HAIKUI（2311）

- The global model generally underestimated the heavy rainfall caused by the typhoon HAIKUI within 48 hr forecasting.
- TRAMS showed better intensity forecast of the rainfall, especially the forecast with the MOTOR-DA system.



48h Acc-Pre by 7th-9th Sep



Operational performance–Typhoon HAIKUI（2311）

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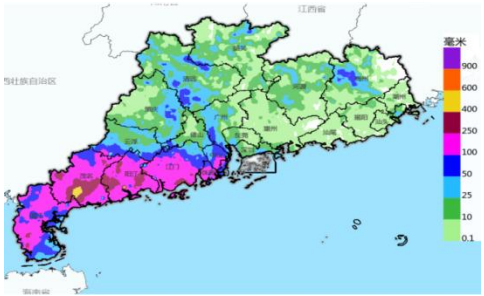
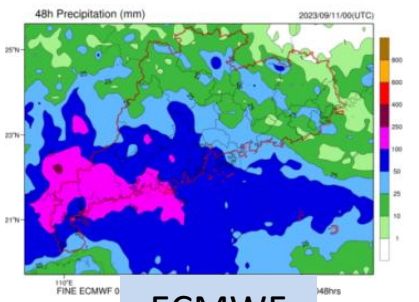
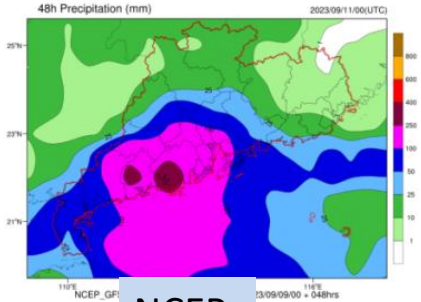


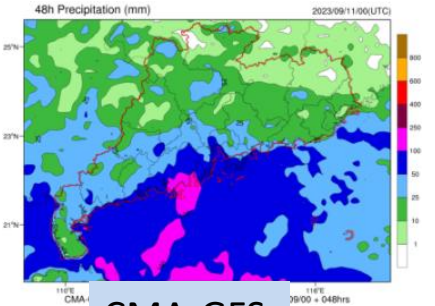
48h Acc-Pre by 9th-11th Sep



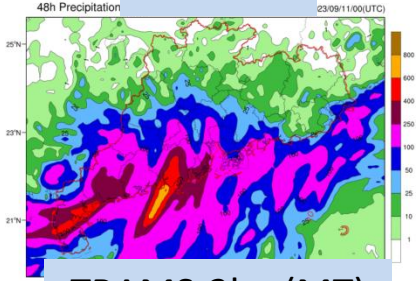
ECMWF



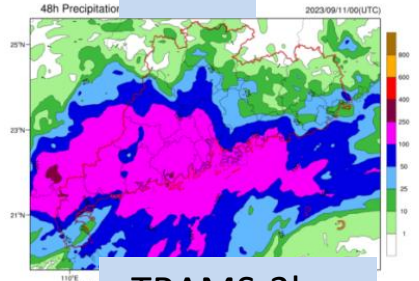
NCEP



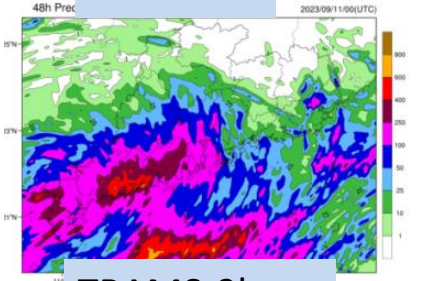
CMA-GFS



TRAMS-3km(MT)



TRAMS-3km

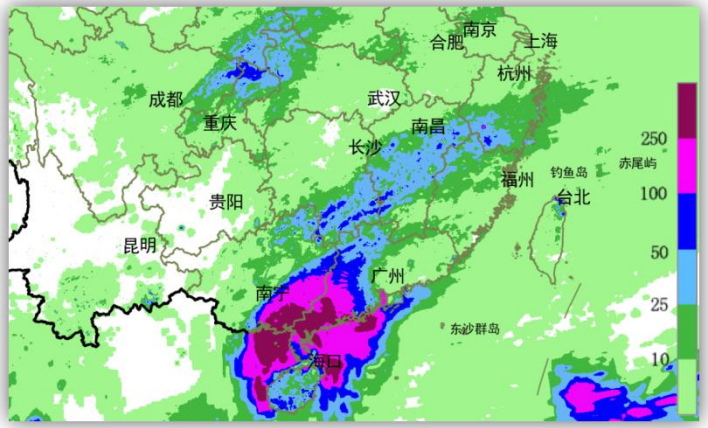


TRAMS-9km

Operational performance–Typhoon SANBA（2316）

- Typhoon "Sanba" (tropical storm) was generated on October 18th over the southern part of Hainan Island.
- Made landfall three times, Typhoon "Sanba" caused extreme heavy rainfall over the coastal regions of South China.

Typhoon path of SANBA

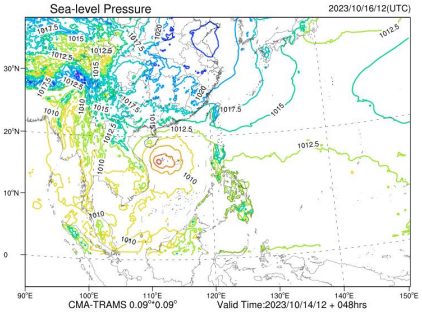


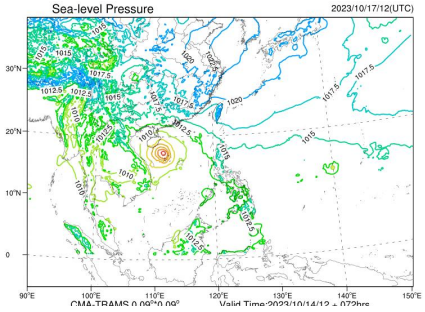
48h Acc-Pre by 7th-9th Sep
(maximum 72hr accumulative rainfall: 681 mm)

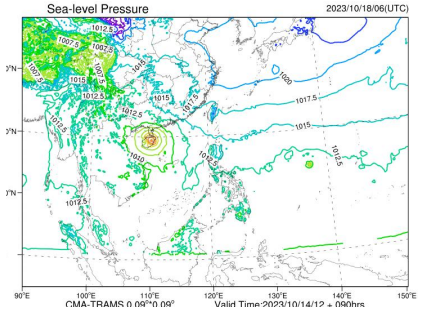
Operational performance–Typhoon SANBA（2316）

- CMA-TRAMS can predict the typhoon genesis of SANBA, whereas it showed too early genesis and too fast moving speed bias, especially for the longer forecasting period.

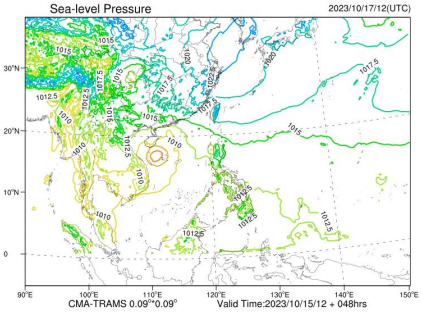
Initial time: 1200UTC 14 Oct

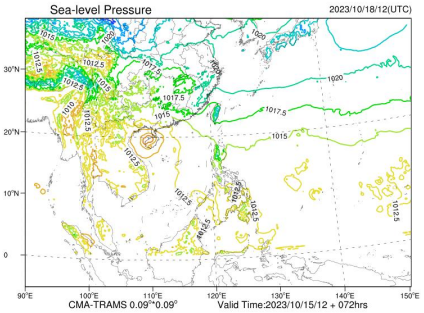






Initial time: 1200UTC 15 Oct

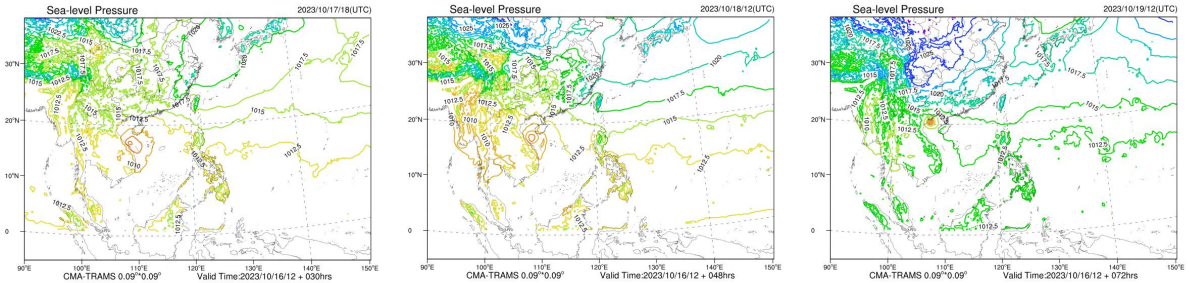




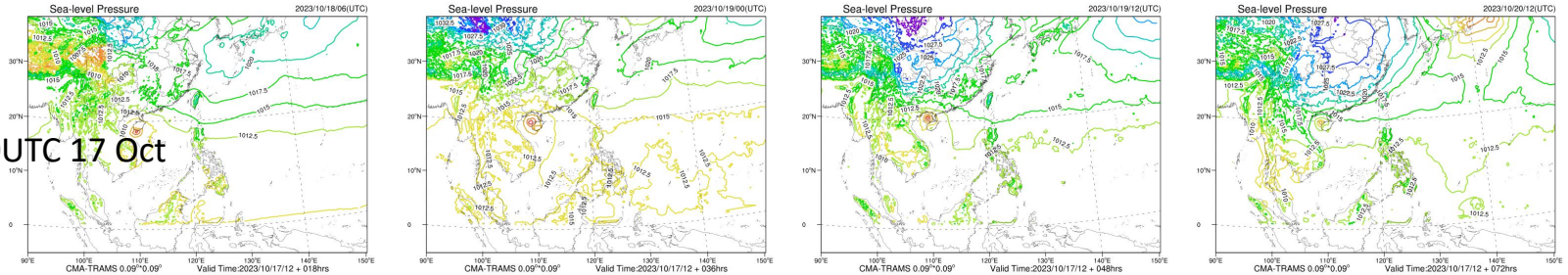
Operational performance–Typhoon SANBA（2316）

- CMA-TRAMS showed more accurate prediction of the typhoon genesis of SANBA with closer forecasting products (… 3days < 2 days< 1 day).

Initial time: 1200UTC 16 Oct



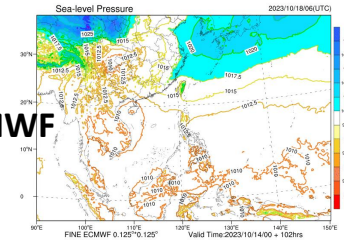
Initial time: 1200UTC 17 Oct

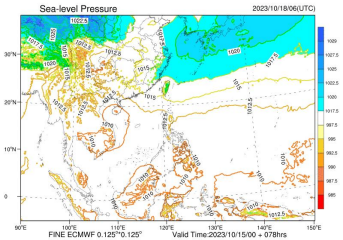


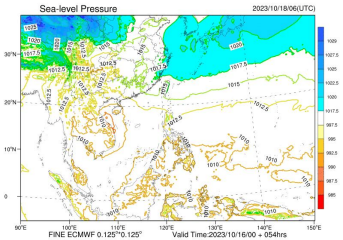
Operational performance–Typhoon SANBA（2316）

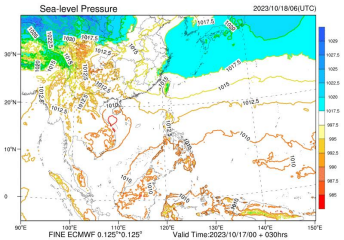
- The global models showed weak forecast abilities of the typhoon genesis of SANBA over the South China Sea.

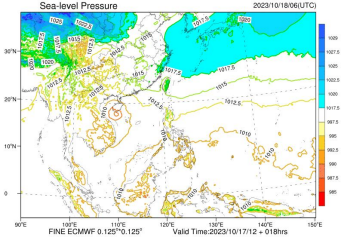
ECMWF



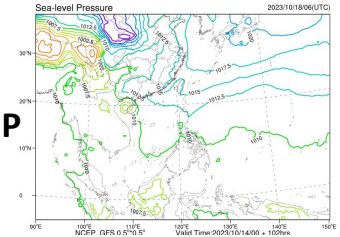


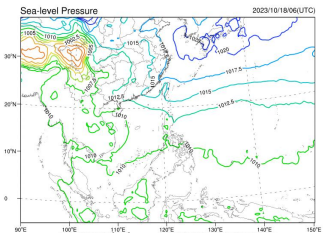


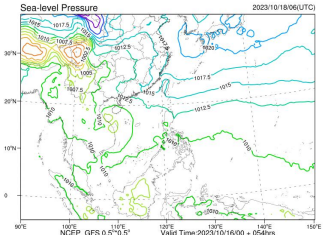


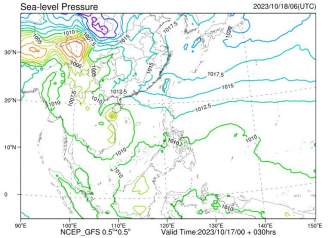


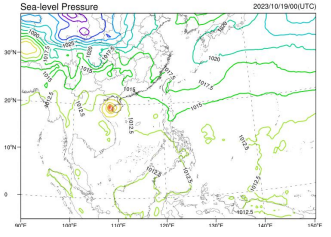
NCEP



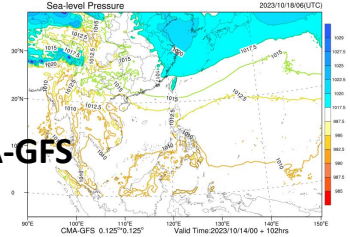


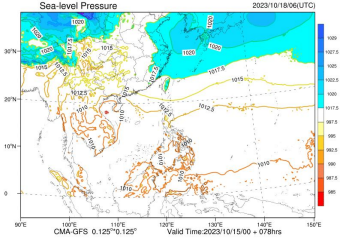


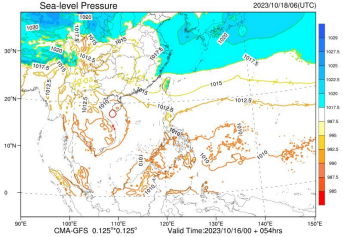


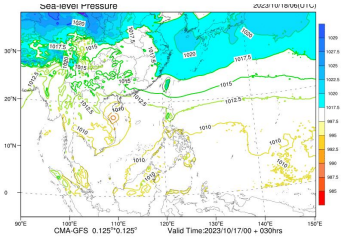


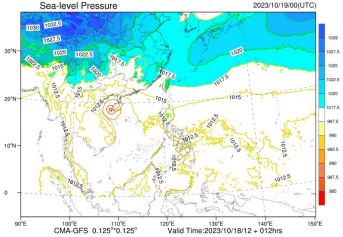
CMA-GFS





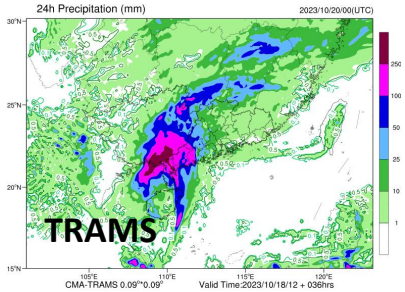


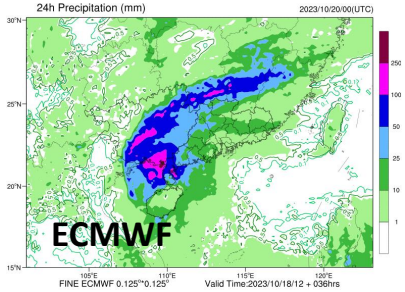


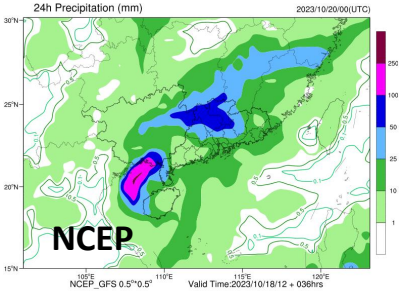


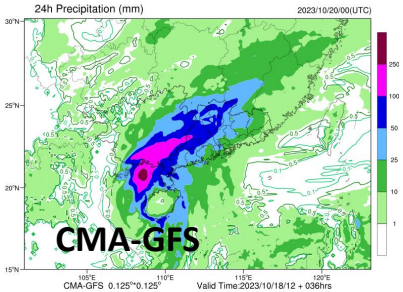
Operational performance–Typhoon SANBA（2316）

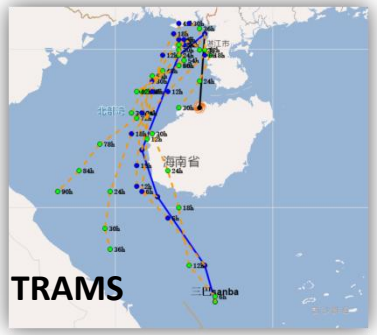
- Both models can predict the northward path and the rotating path over the beibu gulf of typhoon SANBA.
- TRAMS showed a better forecasting of the heavy rainfall by typhoon landing. NCEP underestimated the intensity of the rainfall











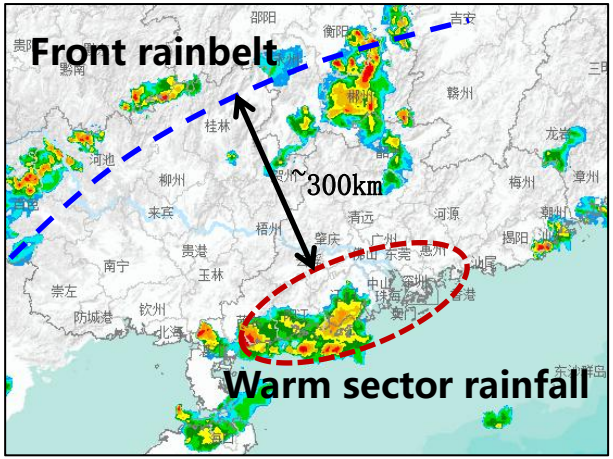
	24h	48h	72h
ECMWF	64. 9	92. 2	196
TRAMS	48	51. 1	127. 6

Typhoon track error

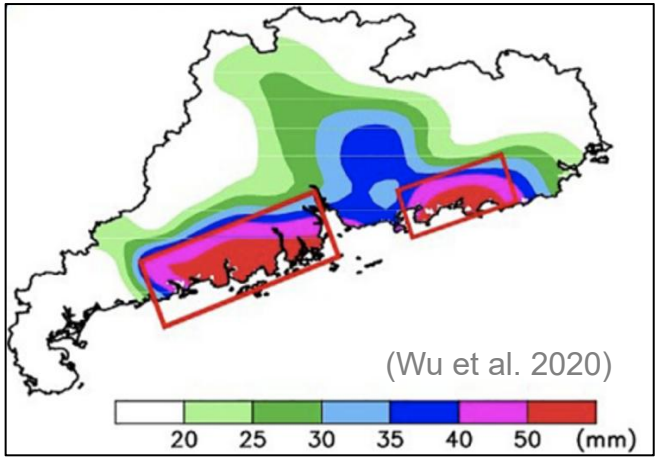
Operational performance–Limitations： warm sector rainfall

- The warm rainstorm is one of the most significant characteristics of the rainstorm in the pre-flood season in South China, which mostly occurs in the warm zone 200-300km ahead of the front, or in the airflow of southwest wind and southeast wind, or even in the southwest airflow without front and shear (Huang Shisong et al. 1986).
- Weakly forced baroclinic forcing at the weather scale, exhibiting mesoscale convective characteristics.

Mostly occurs over the coastal regions



Daily mean rainfall intensity



Operational performance–Limitations： warm sector rainfall

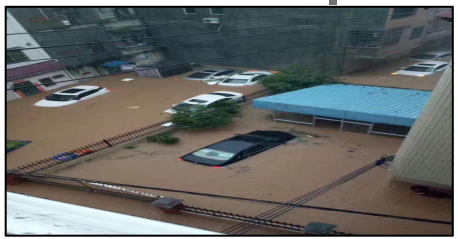
The rainstorm in the warm sector of South China is highly disastrous: strong suddenness, great amount, concentrated precipitation, and extreme process rainfall.

Rainstorm in East Guangdong from June 13 to 14

from August 27th to 1st Sep, Continuous heavy rainfall along the coast of Guangdong, affecting 1.208 million people

From June 5th to 9th: resulting in 5 deaths and economic loss of 3.972 billion yuan.

2016 2017 2018 2019 2020 2021



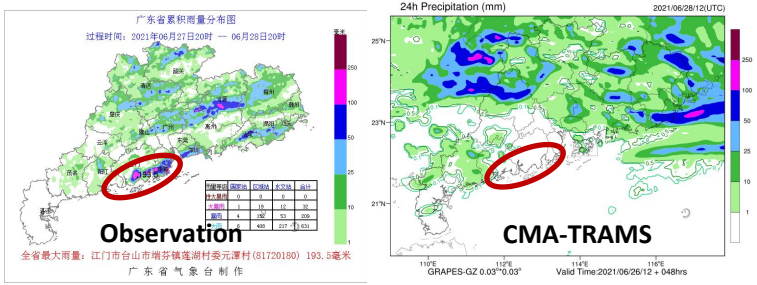
The direct economic loss on May 7 was 177 million yuan

western Guangdong on May 27-31 caused economic loss of 320 million yuan

Severe urban waterlogging in Zhuhai on June 1

Operational performance–Limitations： warm sector rainfall

- **The operational performances of NWP models are generally weak in forecasting rainfall in warm sector: Based on the assessment of rainstorm in flood season in South China (2016-2020), the forecast ability of tropical cyclone rainstorm is the best, between 0.25-0.3; The forecast ability of rainstorm in warm regions is relatively weak, and the TS score above rainstorm is only 0.06-0.13.**



Precipitation from June 27-28, 2021

Fail to predict the local heavy rainfall

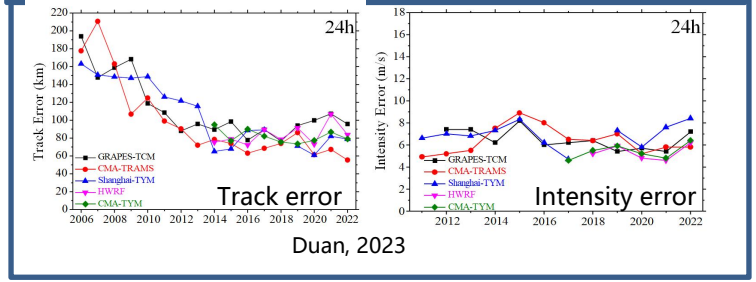
TS (2016-2020)			
	front (54samples)	**warmsector** (50samples)	**Tropical cyclones** (81samples)
GRAPES	0.16	**0.13**	0.24
ECMWF	0.11	**0.10**	0.26
JMA	0.13	**0.06**	0.25

（provided by the weather forecasters）

Operational performance–Limitations： strong wind forecast

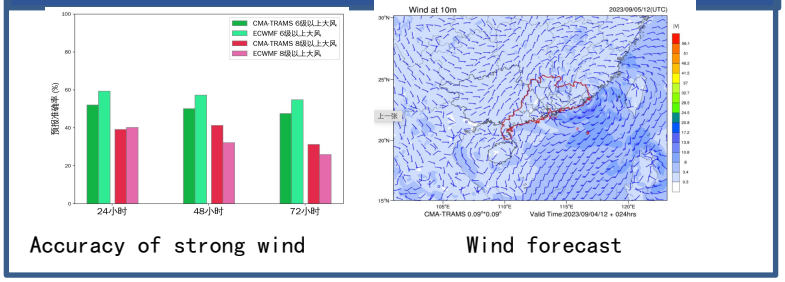
- **In terms of NWP models, the improvement of typhoon intensity forecasting ability is slow, with a 24-hour error of 5.8 m/s in the 2022 typhoon intensity forecast of the China South Sea Typhoon Model (CMA-TRAMS);**
- **The accuracy of the CMA-TRAMS model for 24-hour forecasting in 2022 is about 52% for strong winds above level 6, and about 39% for strong winds above level 8.**

Typhoon intensity



Duan, 2023

South China Sea strong wind forecast



Accuracy of strong wind

Wind forecast

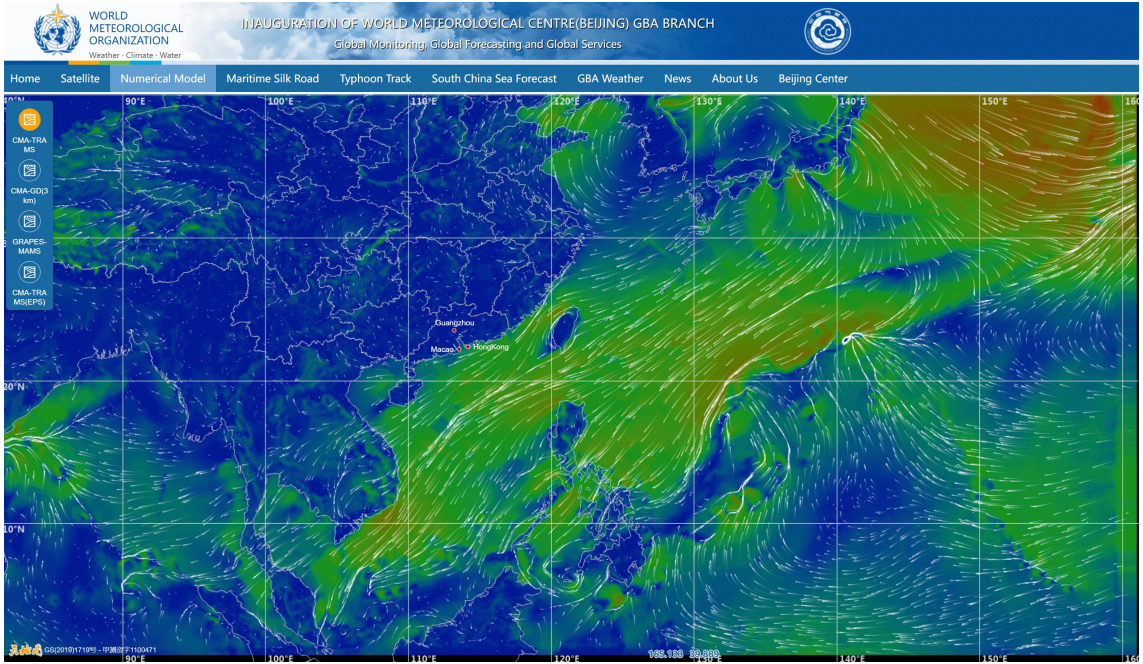
1. Comprehensive observation experiments from underwater to the lower atmosphere;
2. Research on the impact mechanism of multi-scale interactions between the ocean and atmosphere on strong winds in the boundary layer
3. Develop boundary layer parameterization schemes suitable for strong wind conditions
4. Developing high-resolution ocean atmosphere coupling mode technology

Operational performance

1. Performance evaluation
2. Cases demonstration
3. Model application

Operational performance – Model application

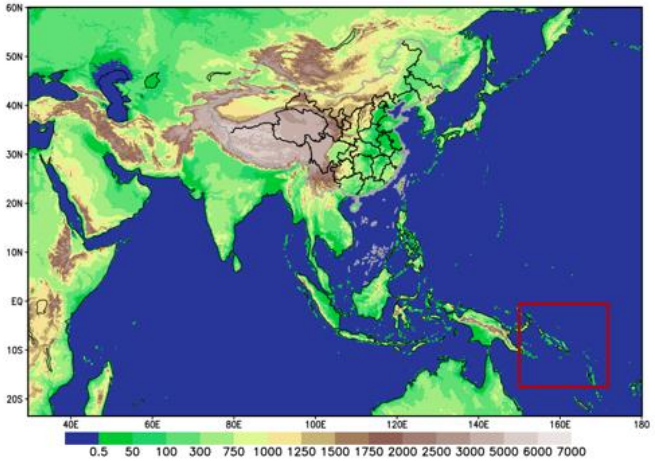
- The operational results can be referred on the website of the WMO-GBA branch, including the TRAMS (9km, 3km and ensemble forecasting system) and ocean model.



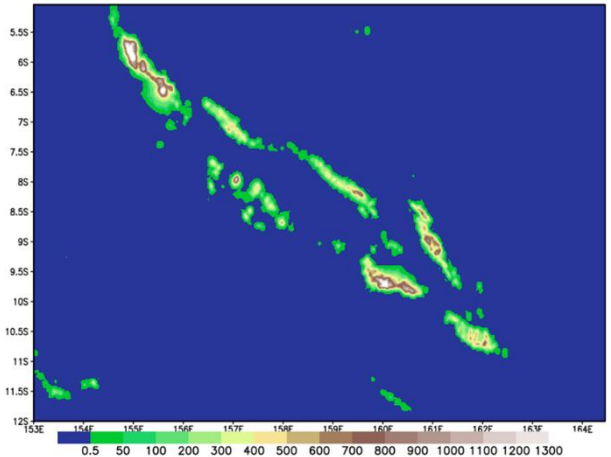
Website: http://www.wmc-gba.net/en

Operational performance – Model application

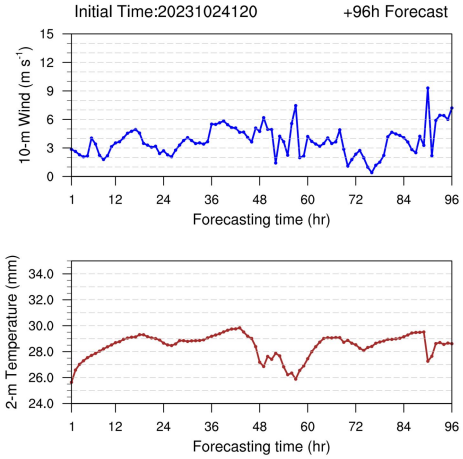
- The customized model prediction systems have been established (TRAMS-3km and the ocean model) for the Pacific Games in Solomon islands.
- TRAMS-3km provides 4days forecast, which initialized 2 times a day.



The Belt and Road Initiative - model



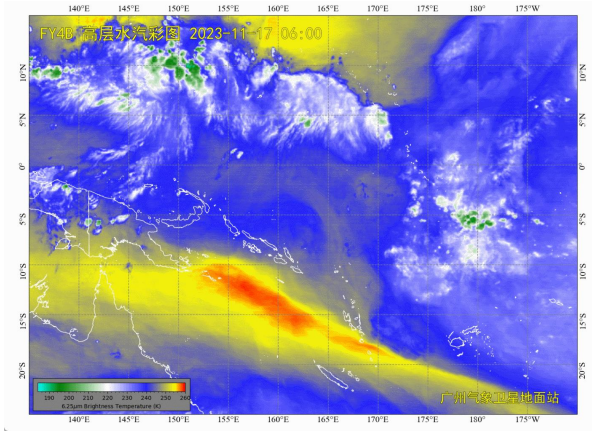
TRAMS-3km



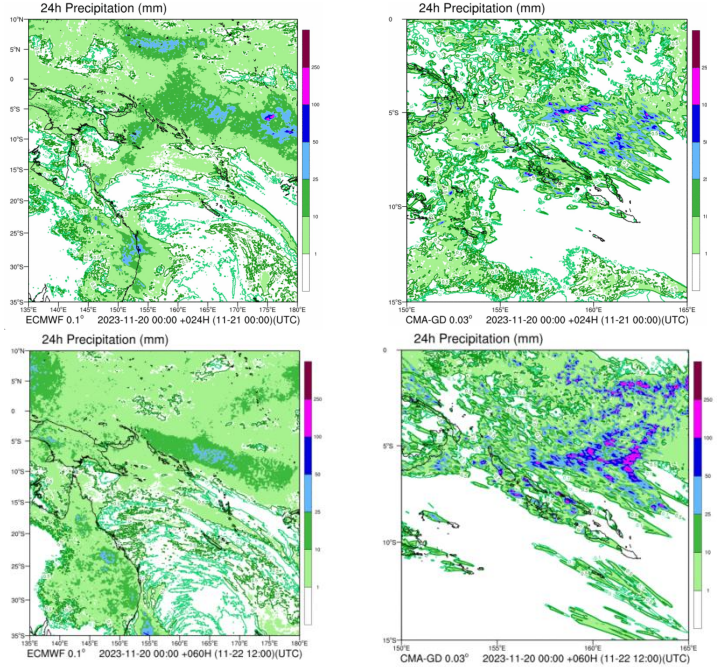
4 Days forecast at Honiara (capital of Solomon)

Operational performance – Model application

- The customized model prediction systems have been established (FY4B Satellite data, TRAMS-3km and the ocean model) for the Pacific Games in Solomon islands.



FY4B high level water vapor

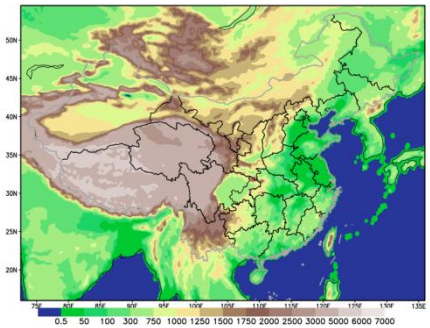


http://www.wmc-gba.net/qxfw/slmqdydh/

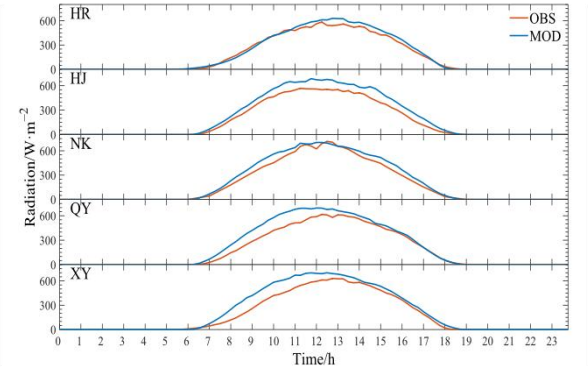
In Chinese

Operational performance – Model application

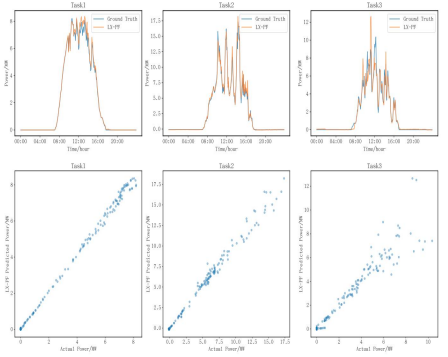
- **Guangdong High Resolution Wind and Solar Energy Meteorological Forecasting System has been in operation since September 1st.**
- It provides downward shortwave radiation and wind speed prediction(10m, 30m, 50m, 70m, 80m, 85m, 90m, 100m, 140m).



Guangdong High Resolution Wind and Solar Energy Meteorological Forecasting System (6km), 4days forecast.



Observation and Model Prediction Trends of Solar Radiation at Five Photovoltaic Power Stations in Yangjiang



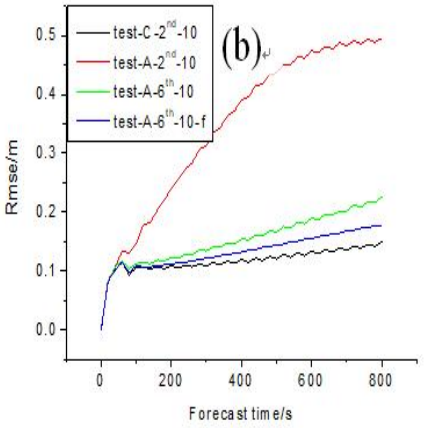
Integrated learning algorithm framework can achieve good prediction results

Outline

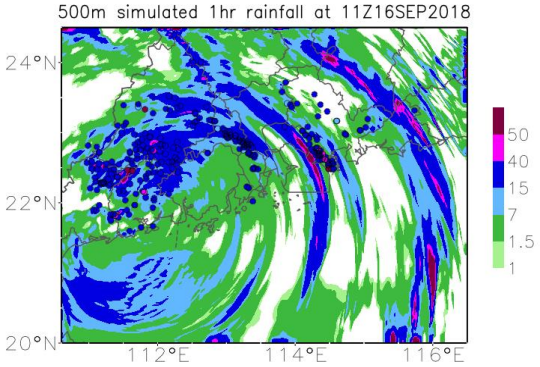
1. Overview of TRAMS model
2. Technical development
3. Operational performance
4. Future plan

Future plan – model dynamics

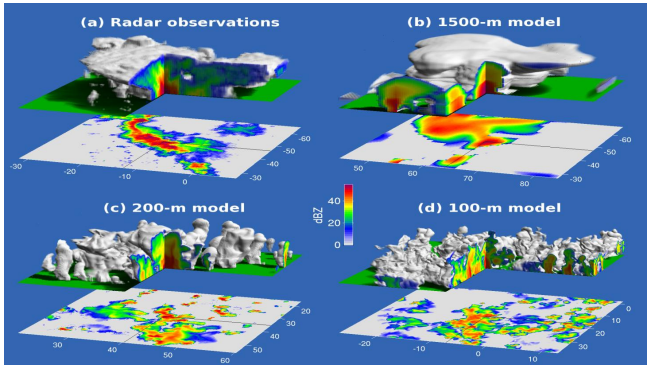
- **Improve the accuracy of semi Lagrangian advection calculation and enhancing conservation;**
- **Develop a high order accuracy (fourth/sixth order) difference scheme;**
- **Time-varying reference atmosphere, reducing calculation errors in the near and upper layers;**
- **Enhance the spatiotemporal resolution of lateral boundaries to drive 1km/500m model.**



RMSE by High Order Precision Calculation Scheme



CMA-GD 500m model



UK 200m model

Future plan – model physics

- Build up a cooperation bridge between observation and NWP forecasting.
- Land surface and near surface solutions suitable for stable and rapidly changing temperatures associated with convective triggering
- 3D boundary layer scheme
- Microphysical scheme

Longmen Cloud Physics Field Scientific Experiment Base

$$C_g \frac{\partial T_g}{\partial t} = R_n - H_m - H_s - L_v E_s$$

$$H_m = k_m C_g (T_g - T_m)$$

$$\tau = \rho u_*^2 = \rho C_d U_{\square}^2 \quad (14)$$

$$HF = -\rho c_p u^* \theta^* = -\rho c_p C_h U(\theta_a - \theta_g) = H_c(\theta_a - \theta_g) \quad (15)$$

$$QF = \rho u^* q^* = -\rho M C_q U(q_a - q_g) = Q_c(q_a - q_g) \quad (16)$$

Land surface scheme

3D PBL scheme

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_{Hh}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_{Hh}\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_{Vh}\left(\frac{\partial T}{\partial z} - \gamma_c\right)\right)$$

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_{Hh}\frac{\partial T}{\partial x}\right)$$

增加经向和纬向各个变量的离散模块

$$\Rightarrow \left(-\frac{\Delta t}{\Delta x}\frac{k_{Hh}(i-1)}{\Delta x}\right)T_{i-1} + \left(1 + \frac{\Delta t}{\Delta x}\frac{k_{Hh}(i)}{\Delta x} + \frac{\Delta t}{\Delta x}\frac{k_{Hh}(i-1)}{\Delta x}\right)T_i + \left(-\frac{\Delta t}{\Delta x}\frac{k_{Hh}(i)}{\Delta x}\right)T_{i+1} = t_i$$，T_i是该时刻的，t_i是上一时刻的

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_{Hh}\frac{\partial T}{\partial y}\right)$$

$$\Rightarrow \left(-\frac{\Delta t}{\Delta y}\frac{k_{Hh}(j-1)}{\Delta y}\right)T_{j-1} + \left(1 + \frac{\Delta t}{\Delta y}\frac{k_{Hh}(j)}{\Delta y} + \frac{\Delta t}{\Delta y}\frac{k_{Hh}(j-1)}{\Delta y}\right)T_j + \left(-\frac{\Delta t}{\Delta y}\frac{k_{Hh}(j)}{\Delta y}\right)T_{j+1} = t_j$$，T_j是该时刻的，t_j是上一时刻的

Horizontal diffusion coefficient calculation

$$K_{mh} = C_s{}^2 l^2 [0.25\,(2D_{11} - 2D_{22})^2 + \overline{D_{12}{}^2}^{xy}]^{\frac{1}{2}}$$
$$K_{hh} = K_{mh}/P_r$$
其中，$C_s = 0.25, l = (\Delta x \Delta y)^{\frac{1}{2}}, P_r = \frac{1}{3}$

$$D_{11} = \left(\frac{\mu_\varphi}{a\cos\varphi}\frac{\partial u}{\partial \lambda}\right)_{\hat{z}} + Z_{sx}\left(\left(\frac{\partial u}{\partial \hat{z}}\right)_{\hat{z}}\right)$$
$$D_{22} = \left(\frac{\mu_\varphi}{a\cos\varphi}\frac{\partial \cos\varphi v}{\partial \varphi}\right)_{\hat{z}} + Z_{sy}\left(\frac{\partial v}{\partial \hat{z}}\right)_{\hat{z}}$$
$$D_{12} = \left(\frac{\mu_\varphi}{a\cos\varphi}\frac{\partial u}{\partial \varphi}\right)_{\hat{z}} + Z_{sy}\left(\frac{\partial u}{\partial \hat{z}}\right)_{\hat{z}} + \left(\frac{\mu_\varphi}{a\cos\varphi}\frac{\partial \cos\varphi v}{\partial \lambda}\right)_{\hat{z}} + Z_{sx}\left(\frac{\partial v}{\partial \hat{z}}\right)_{\hat{z}}$$
其中，$Z_{sx} = -\frac{\Delta Z_{\hat{z}}}{\Delta Z_s}\phi_{sx}$，$Z_{sy} = -\frac{\Delta Z_{\hat{z}}}{\Delta Z_s}\phi_{sy}$

$$\phi_{sx} = \frac{\mu_\varphi}{g} \times \frac{\partial \phi_s}{a\cos\varphi \partial \lambda}, \quad \phi_{sy} = \frac{\mu_\varphi}{g} \times \frac{\partial \phi_s}{a \partial \varphi}$$

Future plan – data assimilation

- ◆ **Conduct research on AI alternatives for assimilation systems**
- ◆ **Develop 4DVar systems**
- ◆ **Develop Direct Assimilation Observation Operator for Radar Data**
- ◆ **Conduct Research on Direct Assimilation of Satellite Radiation**
- ◆ **CMA-GFS background+IAU, reducing dependence on foreign global models**

数值预报模式:

$$X^{n+1} = N(X^n) + \eta^{n+1}$$

其中误差 $\eta^{n+1} = g(X^n)$

其切线性模式:

$$X'^{n+1} = \boldsymbol{N}_{n\to n+1}X'^n + \eta'^{n+1}$$

令

$$\eta'^{n+1} = \boldsymbol{G}_n X'^n$$

雅可比

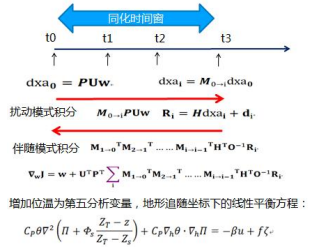
利用ML构造$\eta = g(X)$的替代物。假定构造N层神经元构成的网络，经过学习后我们得到连接权值w_i和偏置b_i:

$$\eta_i = \begin{cases} w_0 X + b_0 & i = 0 \\ w_i h(\eta_{i-1}) + b_i & 0 < i < N \end{cases}$$

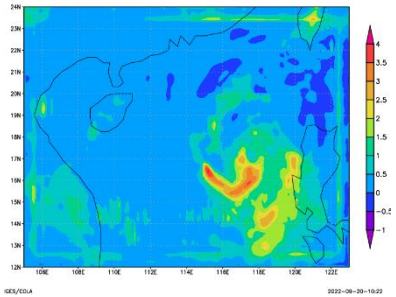
于是

$$\eta'_i = \begin{cases} w_0 X' & i = 0 \\ w_i h'(\eta_{i-1})\,\eta'_{i-1} & 0 < i < N \end{cases}$$

Replacing Convection and Cloud Microphysics Solutions with Deep Learning Models



Assimilating Radar and Satellite Data



Deep learning of the increment of water vapor by microphysics

Wish you a good day!

a nice journey!

a happy life!