Key technologies and recent performance of CMA-TRAMS

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

Outline

Key laboratory of Regional NWP

In 2012, the Guangdong Provincial Key Laboratory of Regional NWP, CMA, was jointly established by the Guangdong Provincial Government and CMA.

Academician Qingcun Zeng, recipient of the International Meteorological Prize (IMO) and the National Top Science and Technology Award of China, serves as the director of the academic committee.

Key technologies

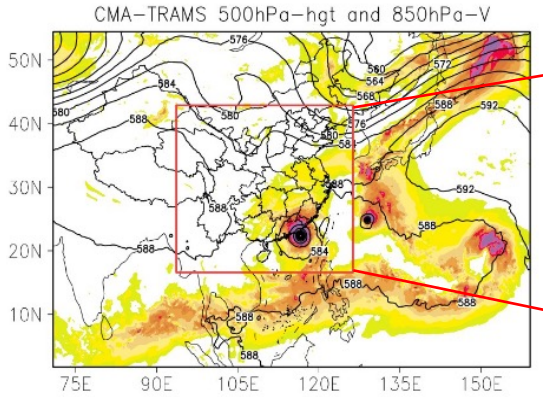
Key technologies in dynamic core, physical scheme, data assimilation, and ensemble forecasting have been independently developed for the regional NWP models over tropics.

Dynamic core	1	3D Reference Scheme Predictor-Corrector Scheme	Physical scheme	2	Scale-Aware Cumulus Parameterization Tropical Convection Parameterization
Data assimilation	3	X-Band Phased-Array Radar Data MOTOR-DA	Ensemble forecasting	4	Mesoscale EPS for TC Forecasting Convection-Permitting ensemble

Operational Model System

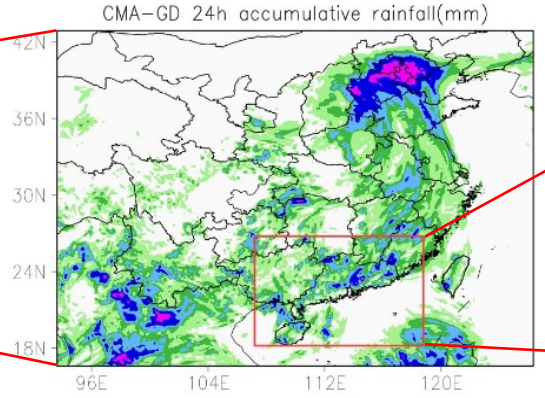
Currently, the **"9-3-1"** high-resolution regional NWP system has been established, which includes the **first 1-km-resolution operational model** in China. With independent-developed key NWP technologies, the system provides scientific support for accurate forecasting of TCs, rainstorms and severe convection.

9 **9km：CMA-TRAMS**
（Synoptic situations; track, intensity, rainfall, and wind of TCs）



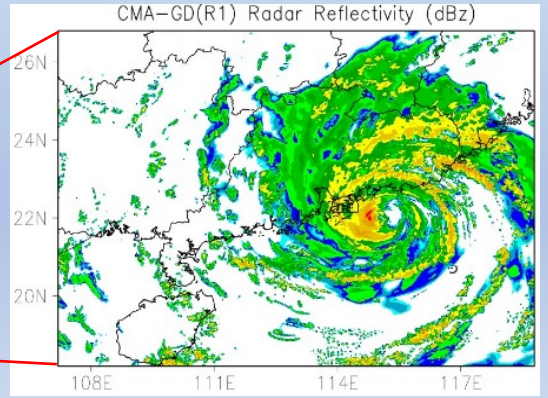
- 4 forecasts per day
- 7-day forecasts issued at 0000 and 1200 UTC
- 3-day forecasts issued at 0600 and 1800 UTC
- 3-hourly output

3 **3km：CMA-GD**
（Rainfall, temperature, and wind at surface; high-level synoptic situations）



- 24 forecasts per day
- 4-day forecasts issued at 0000 and 1200 UTC
- 30-h forecasts for the rest of the day
- Hourly output

1 **1km：CMA-GD (R1)**
（local severe convection and heavy rainfall）

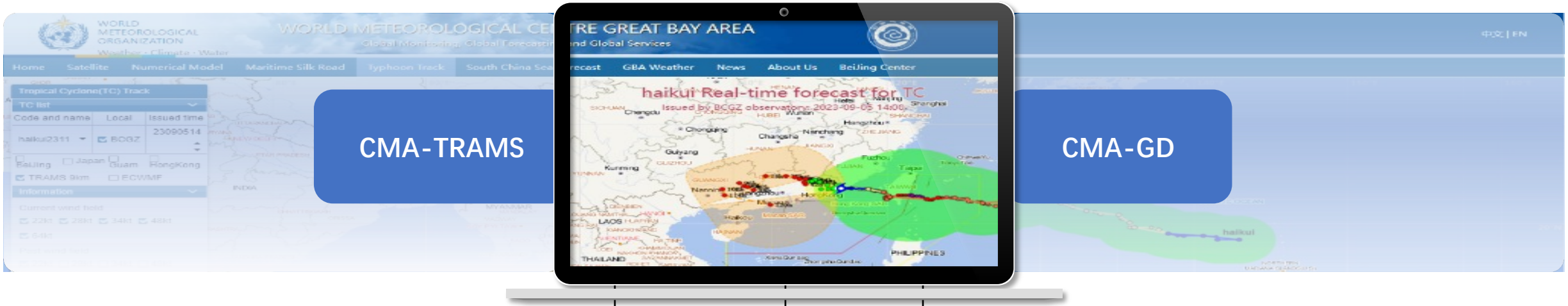


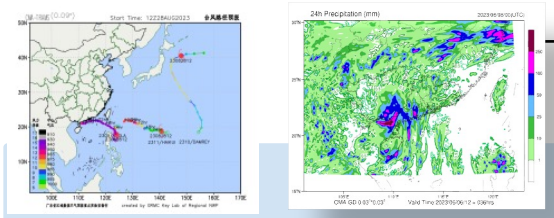
- Updated every 12 minutes
- 6-h forecasts
- 12-minutely output

Operational service

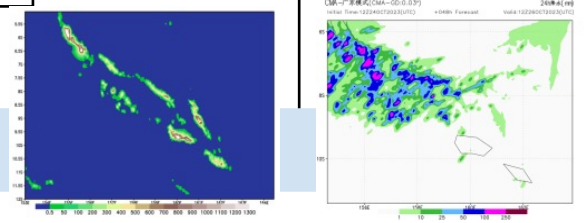
High-resolution forecast products

Supporting governmental policy and various industries in China
Offering products for the countries and regions along Belt and Road

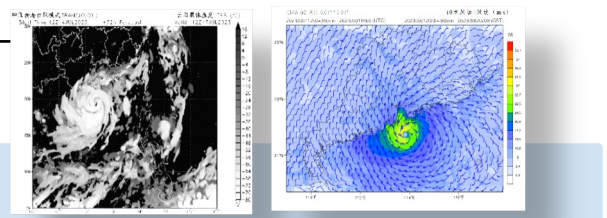




National Meteorological Center;
Meteorological observatories in Pan-Pearl River Delta Region;
Hong Kong Observatory;
Macao Meteorological and Geophysical Bureau
.....



Designed model for Solomon Islands;
ESCAP/WMO Typhoon Committee;
World Meteorological Centre Great Bay Area;
ASEAN
.....



Civil Aviation;
Guangdong Emergency Department;
Guangdong Hydrological Bureau;
Guangzhou Municipal Public Security Bureau
.....

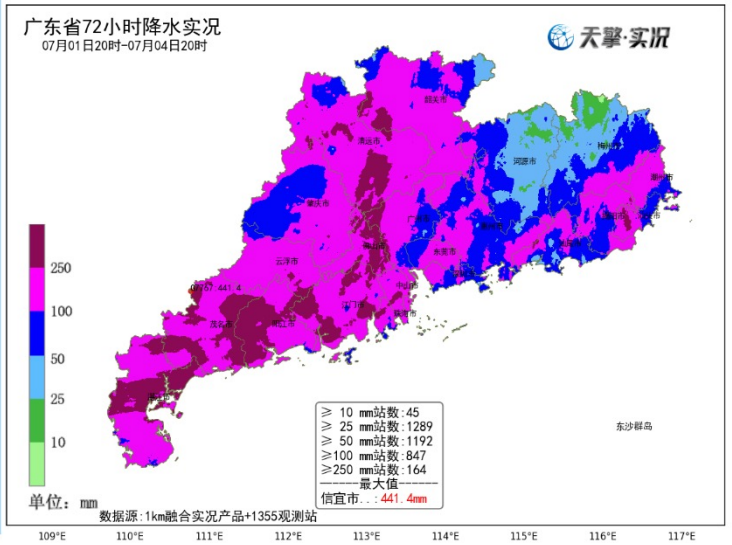
CMA-TRAMS

Aiming to precisely predict the genesis, movement and intensity of TCs over SCS, as well as their heavy rainfall and strong wind.

Features of TCs over SCS:

- Short life span, 1~2 days
- Heavy rainfall
- High risks to offshore operation, fishing vessels

Genesis forecast of TCs over SCS is important.



CMA-TRAMS

Resolution: 0.09°, 65 vertical layers

Region: 70~161°E, 0~51°N

Initialization: (Cloud Analysis) Nudging + Land surface analysis

Init Time: 00z, 12z, 06, 18z; T+168hrs FCS

Products:

- Typhoon Forecasting
- Precipitation Forecasting
- Atmospheric Variables

CONFIG	CMA-TRAMS
DYN FRAME	Fully Compressive, Non-hydrostatic, Predictor-Corrector Method For SISL(alpha=0.55), 3D Reference Atmosphere Scheme, Terrain Following Coordinate with Charney-philip Staggering, Lon-lat Grid with Arrakawa-c Stagerring
Microphysics	WSM6
Radiation	RRTMG
PBL	TRAMS PBL
LAND	SMS
Cumulus	Deep convection: scale-aware NSAS; Shallow convection: CSC

Outline

01 Intro

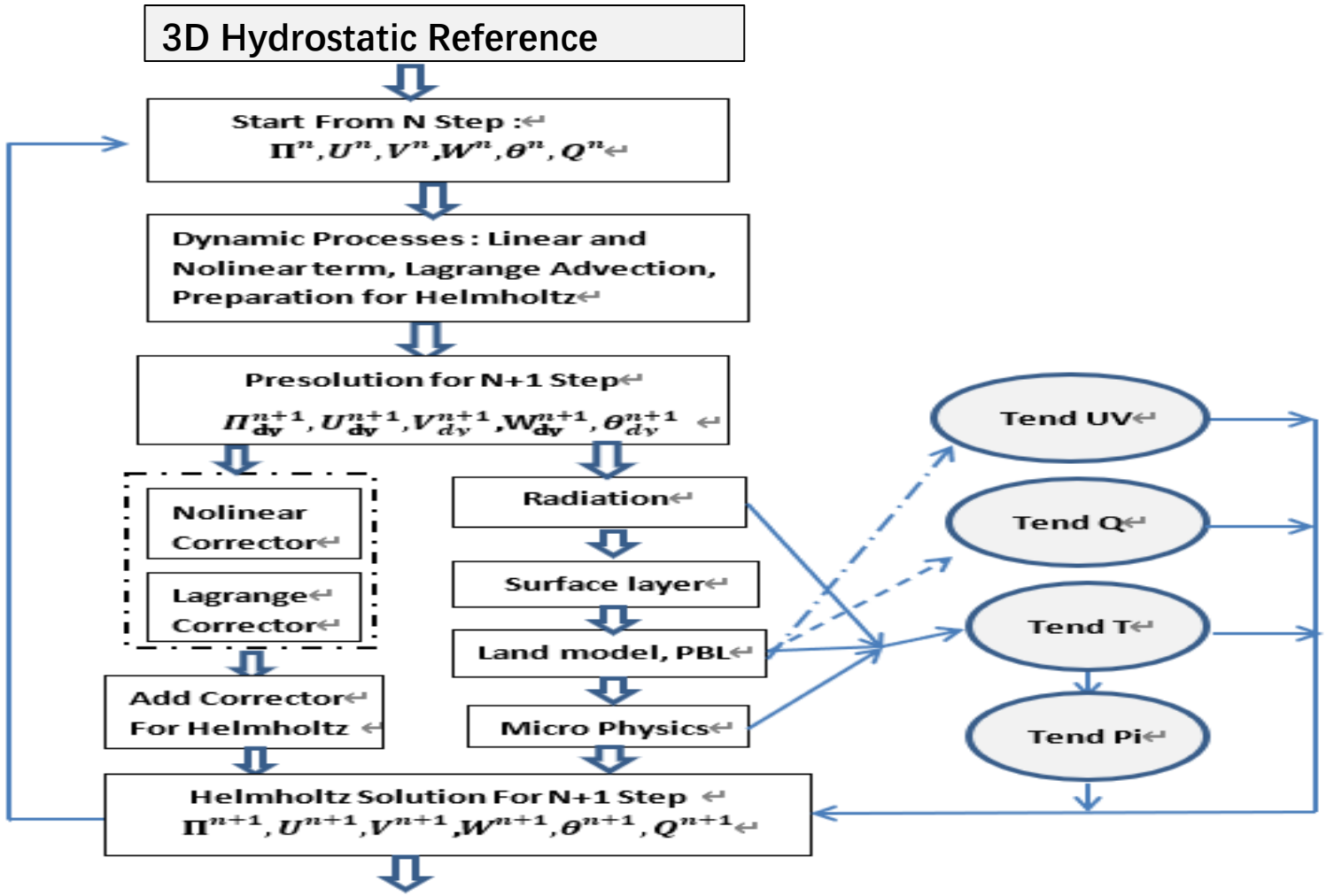
02 Key technologies

03 Forecast performance

04 Future planning

Key technologies -Model Dynamics

Dynamical Frame of 3-D Ref Scheme combining with predictor corrector method



Key technologies -Model

3-D hydrostatic ref atm

$$\frac{du}{dt} = -\frac{C_p\theta}{a\cos\varphi}\frac{\partial \Pi'}{\partial\lambda} - \frac{C_p\theta}{a\cos\varphi}\frac{\partial \tilde{\Pi}}{\partial\lambda} + fv + F_u + \delta_M G_u - \delta_\varphi f_\varphi w$$

$$\frac{dv}{dt} = -\frac{C_p\theta}{a}\frac{\partial \Pi'}{\partial\varphi} - \frac{C_p\theta}{a}\frac{\partial \tilde{\Pi}}{\partial\varphi} - fu + F_v - \delta_M G_v$$

$$\delta_{NH}\frac{dw}{dt} = -C_p\theta\frac{\partial \Pi'}{\partial z} - C_p\theta'\frac{\partial \tilde{\Pi}}{\partial z} + F_w + \delta_M G_w + \delta_\varphi f_\varphi u$$

$$\frac{d\Pi'}{dt} = -\frac{d\tilde{\Pi}}{dt} - \frac{\Pi}{(\gamma-1)}D_3 + \frac{F_\theta^*}{(\gamma-1)\theta}$$

$$\frac{d\theta'}{dt} = -\frac{d\tilde{\theta}}{dt} + \frac{F_\theta^*}{\Pi}$$

$$(\Pi')^{n+1} = cpi1\cdot u^{n+1} + cpi2\cdot v^{n+1} + cpi3\cdot \hat{w}^{n+1} + cpi4\cdot (D_3)_{\hat{z}} + A_\Pi$$

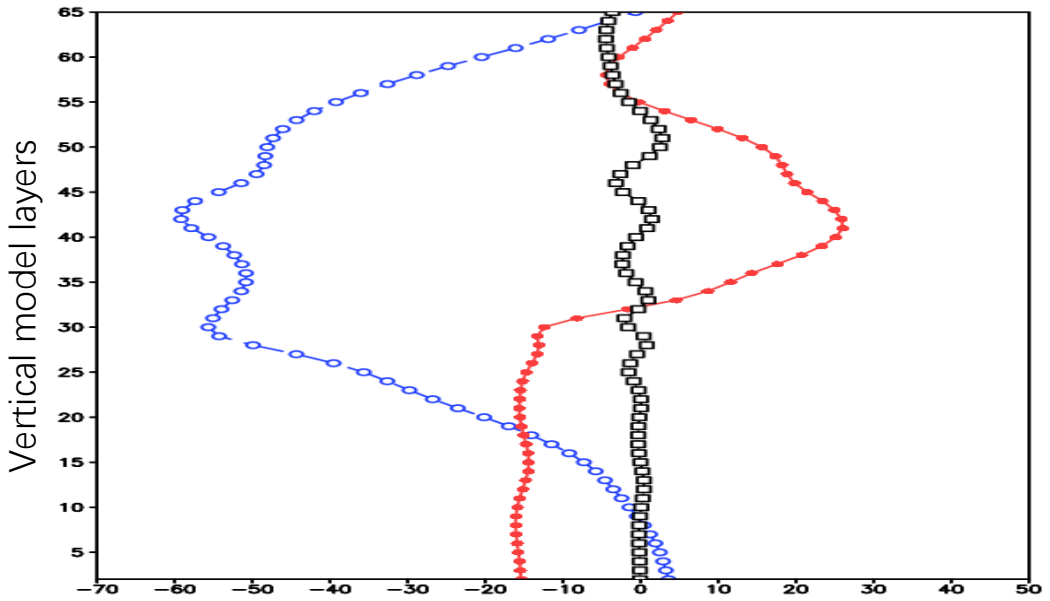
$$cpi1 = \Delta t\alpha_\varepsilon\cdot\left(\frac{\tilde{\Pi}}{\gamma-1}\cdot\frac{\varphi_{sx}}{\Delta Z_s} - \frac{\partial\tilde{\Pi}}{a\cos\phi\partial\lambda}\right)$$

$$cpi2 = \Delta t\alpha_\varepsilon\cdot\left(\frac{\tilde{\Pi}}{\gamma-1}\cdot\frac{\varphi_{sy}}{\Delta Z_s} - \frac{\partial\tilde{\Pi}}{a\partial\phi}\right)$$

$$cpi3 = -\Delta t\alpha_\varepsilon\cdot\frac{\partial\tilde{\Pi}}{\partial\hat{z}}$$

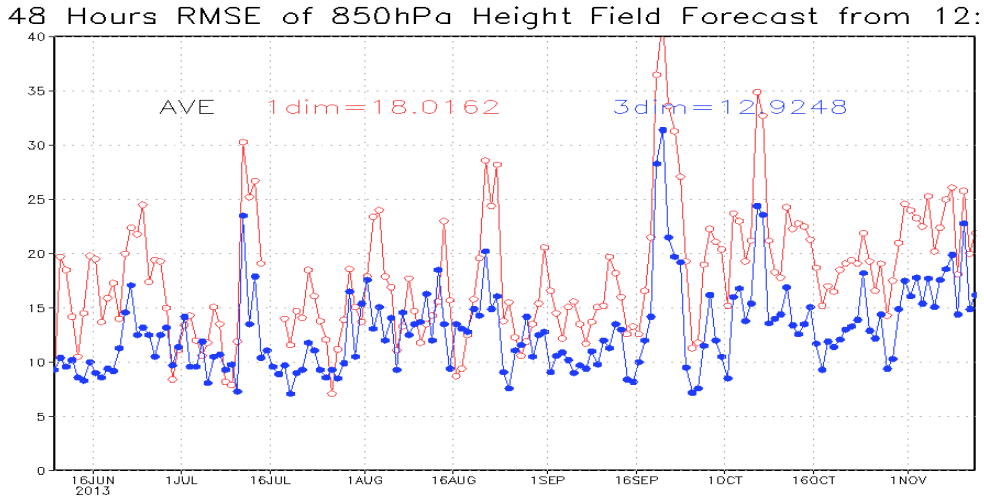
$$cpi4 = -\Delta t\alpha_\varepsilon\cdot\frac{\tilde{\Pi}}{\gamma-1}$$

- Adding terms like horizontal gradient terms and horizontal advection terms
- **Reducing perturbations of forecast variables**
- Reducing forecast errors



θ' after deducting ref atm

BLK:3-D ref atm; BL:1-D isothermal ref atm; RD: 1-D ref atm



RMS of 48-hr FCS on 850hPa in batch tests

BL:3-D ref atm; RD: 1-D isothermal ref atm

Key technologies -Model Dynamics

3-D ref scheme combined with predictor-corrector method

1) original - simple SISL scheme

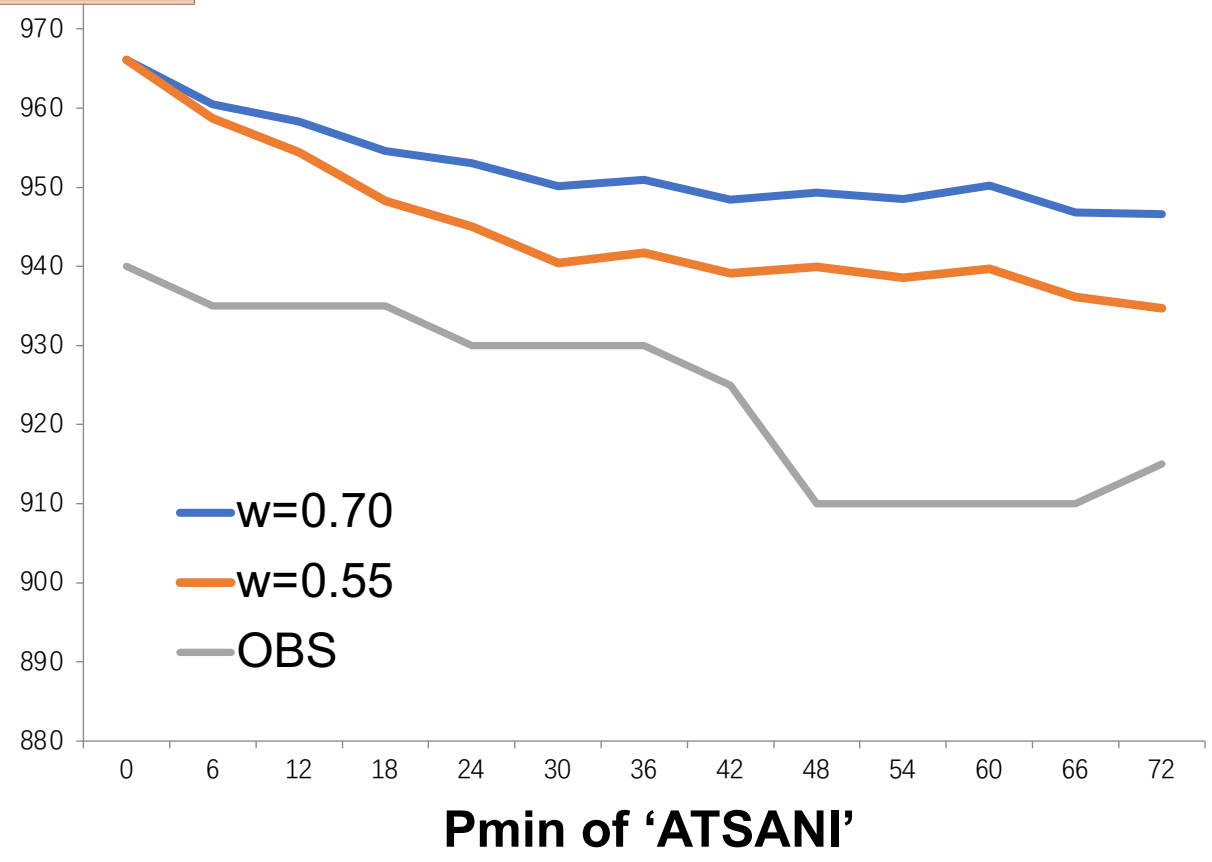
- implicit weighting >= 0.7,
- otherwise unstable intergration

2) New - using predictor-corrector method

- implicit weighting decreasing to 0.55
- higher precision
- mitigating the issue of underestimation

$$\frac{A^{n+1}-A_*^n}{\Delta t}=\alpha_\varepsilon\left(L_A+N_A\right)^{n+1}+\beta_\varepsilon\left(L_A+N_A\right)_*^n+phys$$

implicit weighhting **explicit weighting**



Pmin of 'ATSANI'

Decreasing implicit weighting → improving TC intensity forecasting

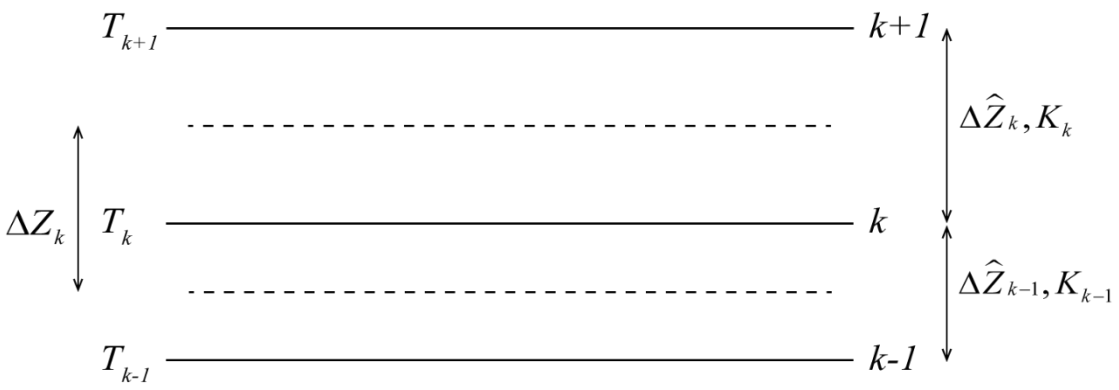
Key technologies -Physical Process

PBL Scheme suited for vertical un-uniform layering

- Re-design a PBL scheme suited for the un-uniform C-P layering in CMA-TRAMS
- Based on **non-local K theory** and MRF and YSU schemes

Eddy Diffusion

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}[k_T(\frac{\partial T}{\partial z} - \gamma_T + \frac{g}{C_P})]$$



$$A_u(k) = -\frac{\Delta t}{\Delta Z_k}\frac{K_k}{\Delta\hat{Z}_k}$$

$$A_l(k) = -\frac{\Delta t}{\Delta Z_k}\frac{K_{k-1}}{\Delta\hat{Z}_{k-1}}$$

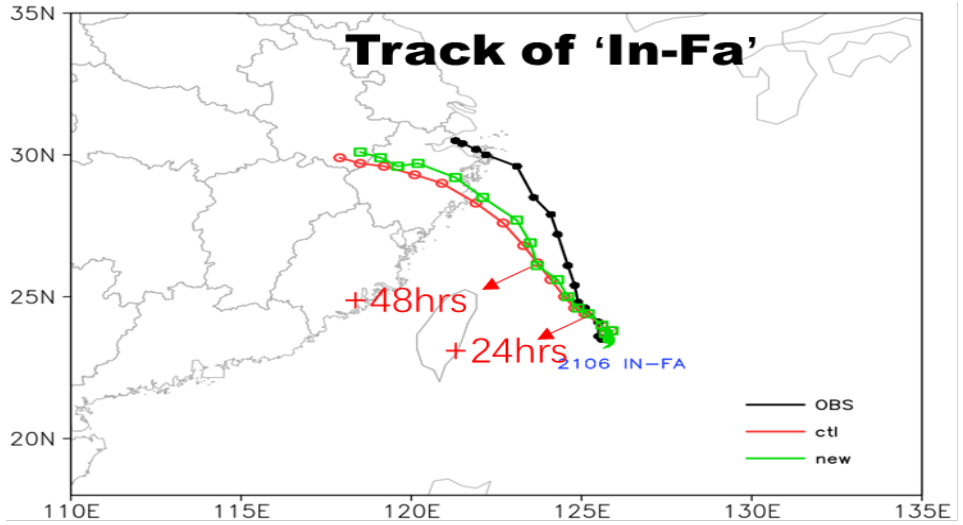
$$A_D(k) = 1 - A_u(k) - A_l(k)$$

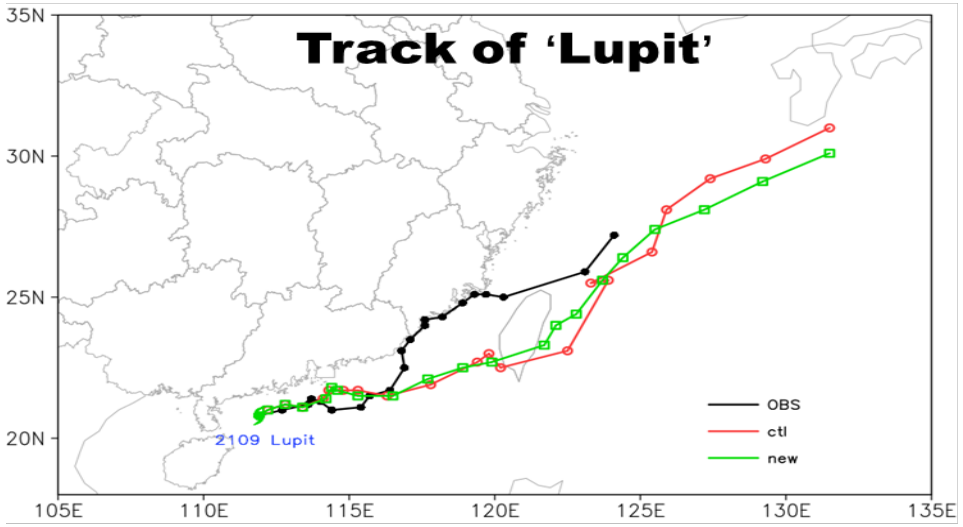
$$R(k) = T_k^n - \frac{\Delta t\gamma_T}{\Delta Z_k}(K_k - K_{k-1}) + \frac{\Delta t}{\Delta Z_k}\frac{g}{C_P}(K_k - K_{k-1})$$

$$A_u(k)T_{k+1}^{n+1} + A_D(k)T_k^{n+1} + A_l(k)T_{k-1}^{n+1} = R(k)$$

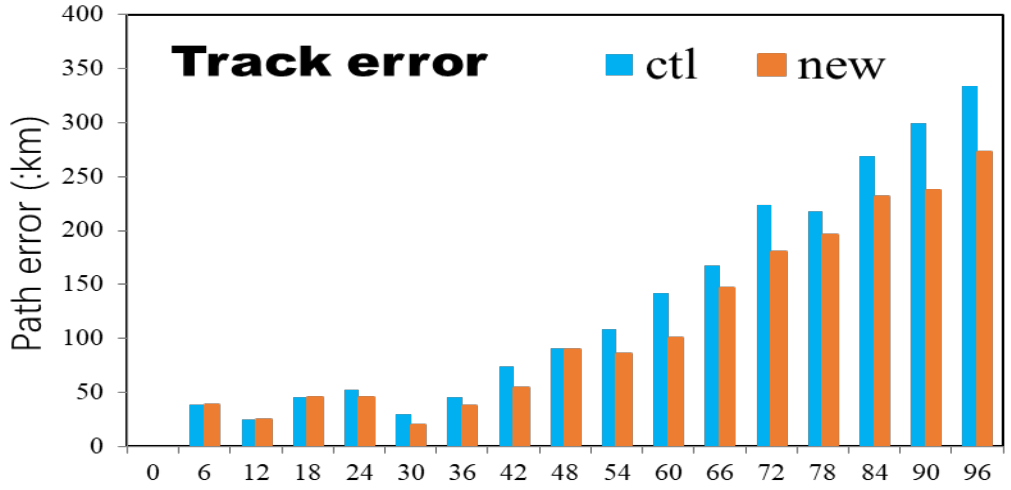
Key technologies -Physical Process

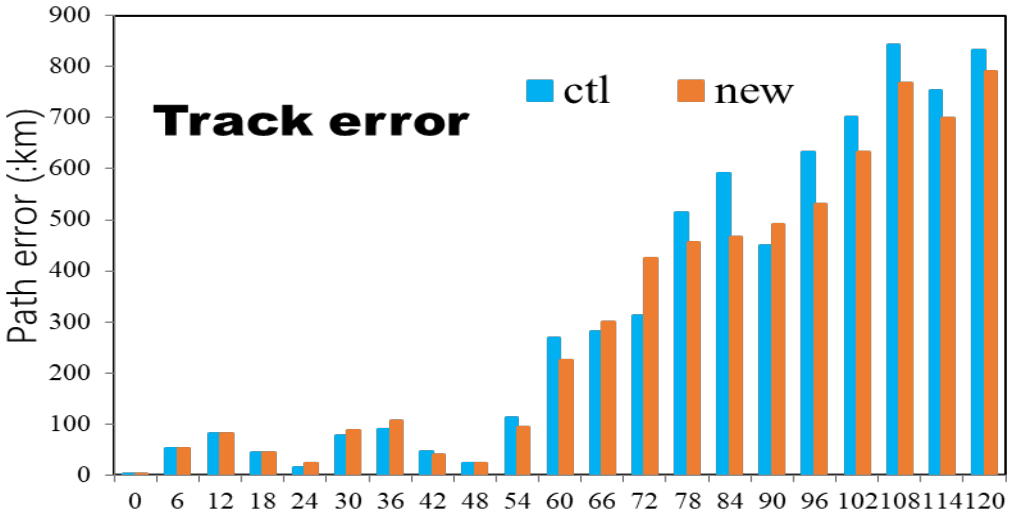
PBL Scheme suited for vertical un-uniform layering





Reducing track errors





Key technologies -Physical Process

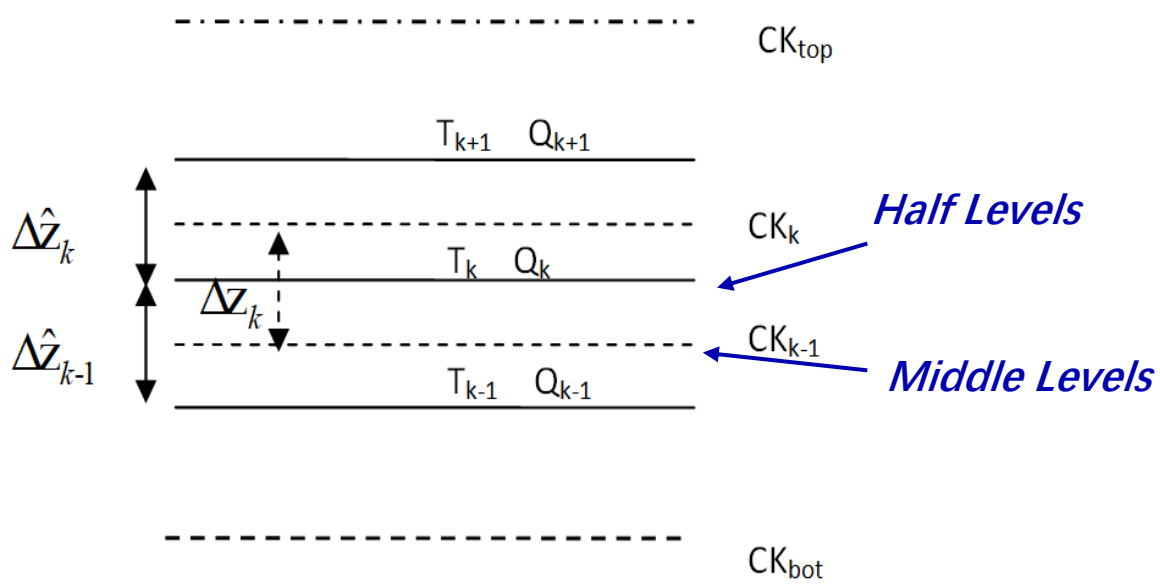
Shallow Convection Scheme

1）Shallow convection mainly for consuming weak convection or spurious unstable energy

2) Using **the same vertical layering as in PBL scheme**

3) In high-res model, vertical diffusion method based on K theory

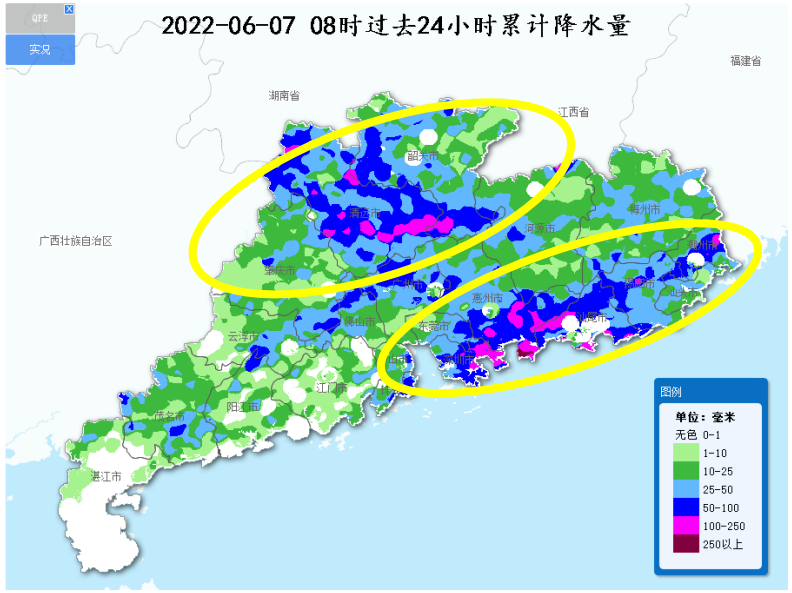
Vertical Discretization Schematics



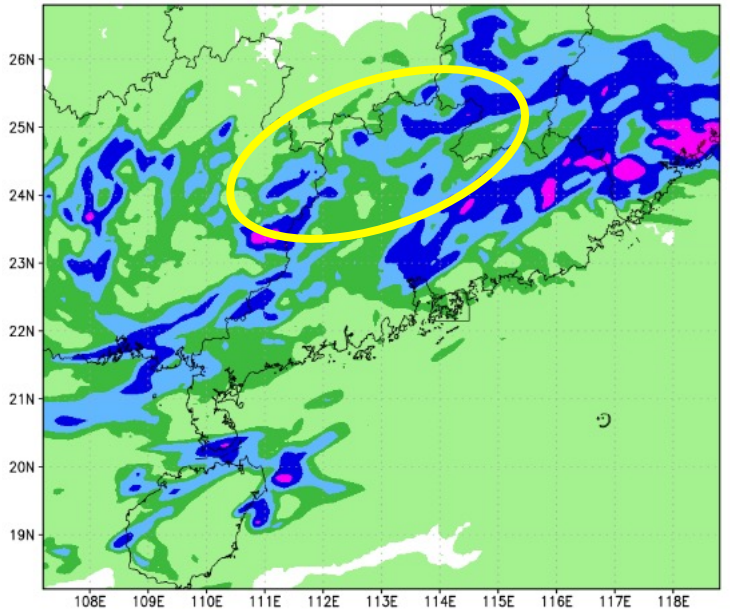
Key technologies -Physical Process

Shallow Convection Scheme

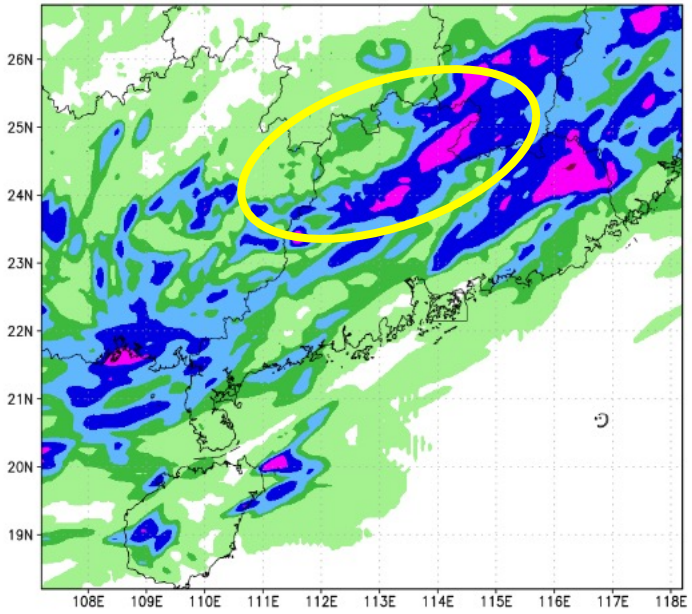
EXP TIME: Starting at 00UTC 2022/06/05



OBS OF 24-HR RAINFALL



NSAS +48hr

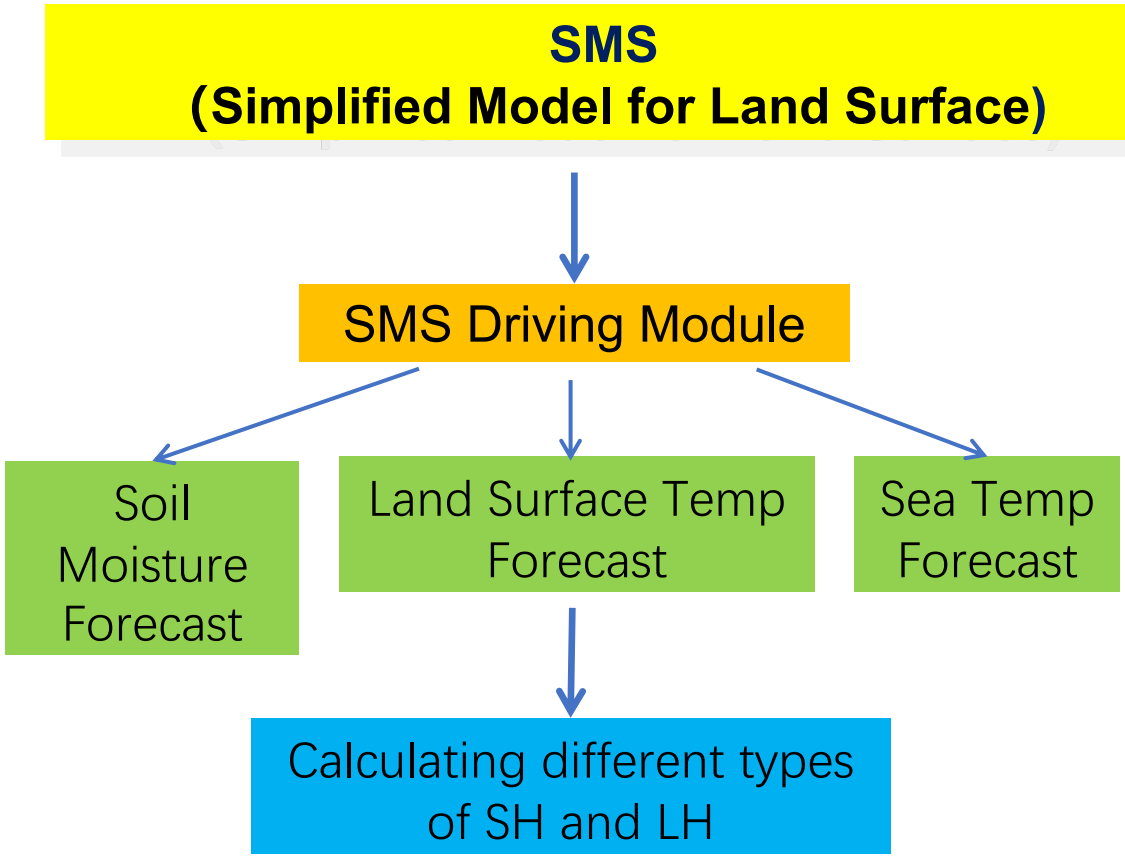


SCS +48hr

Improving rainfall forecasting

Key technologies -Physical Process

Land-Sea surface parameterization



1) Referring to SLAB and NOAH, developing SMS suitable for low-latitude area

2) Simplified Soil Moisture Forecasting model

3) Land Surface Model

4) SST parameterization

5) Calculation of SH and LH

Key technologies -Physical Process

Land-Sea surface parameterization

Forecast Func. Of SST:

$$T_s = T_b + (T_s - T_{-\delta}) + (T_{-\delta} - T_{-d})$$

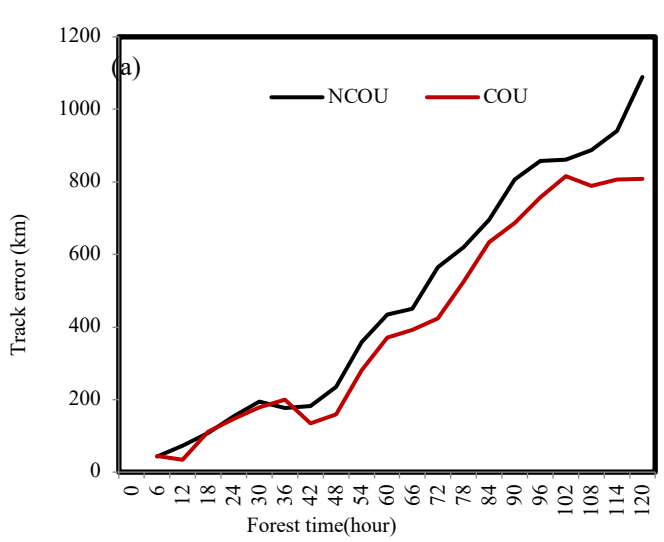
Cooling temp of the cool ocean skin:

$$T_s - T_{-\delta} = \frac{\sigma}{\rho_w c_w k_w}(Q + R_s f_s)$$

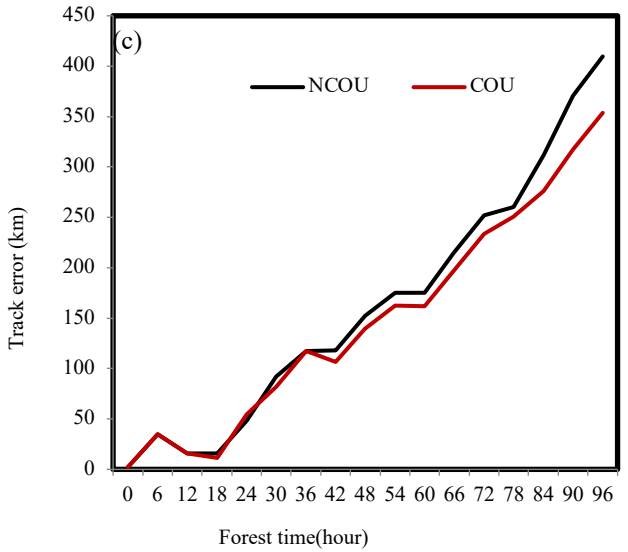
Warming temp of the warm layer:

$$\frac{\partial}{\partial t}(T_{-\delta} - T_{-d}) = \frac{Q + R_s - R(-d)}{d\rho_w c_w v/(v+1)} - \frac{(v+1)ku_{*w}}{d^2\phi_t(d/L)}(T_{-\delta} - T_{-d})$$

Tests of TRAMS coupling SST scheme



Severe TY“Malakas”



Super TY“Haima”

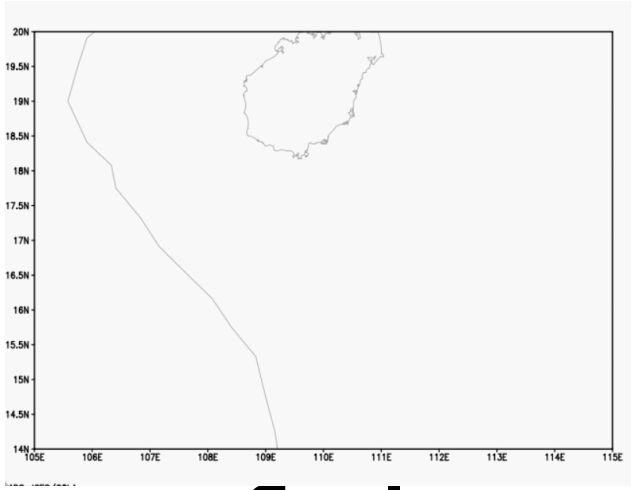
The new SST scheme (COU) can reduce track error especially at longer lead times.

Key technologies –Data assimilation

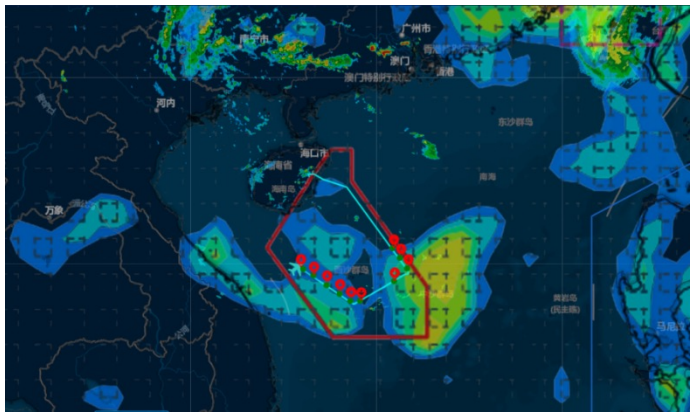
Assimilation of UAV dropsounds

The dropsounds from unmanned aerial vehicle (UAV) and Beidou sounding were assimilated in the analyses of CMA-TRAMS.

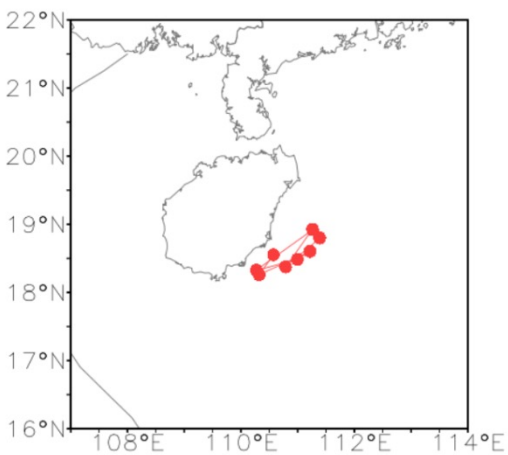
- Based on the ensemble forecasts of CMA-TRAMS (EPS), the sensitivity for the target area was calculated using the ensemble sensitivity analysis method （ESA).
- Target observations were carried out for 4 TC cases.



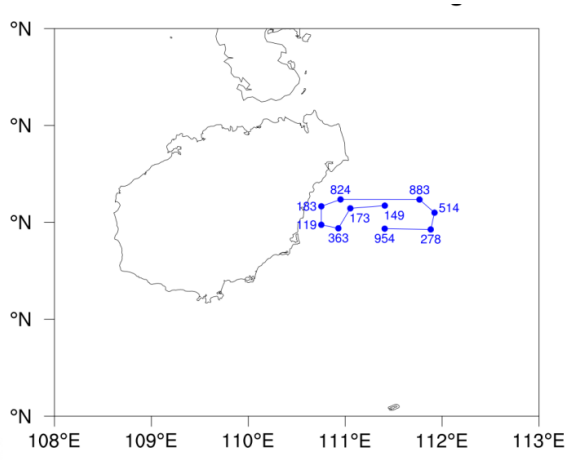
Saola



Haikui



Koinu

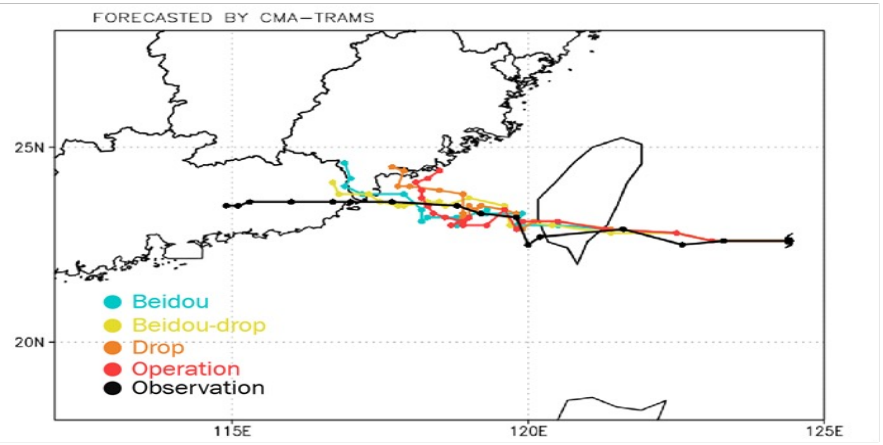


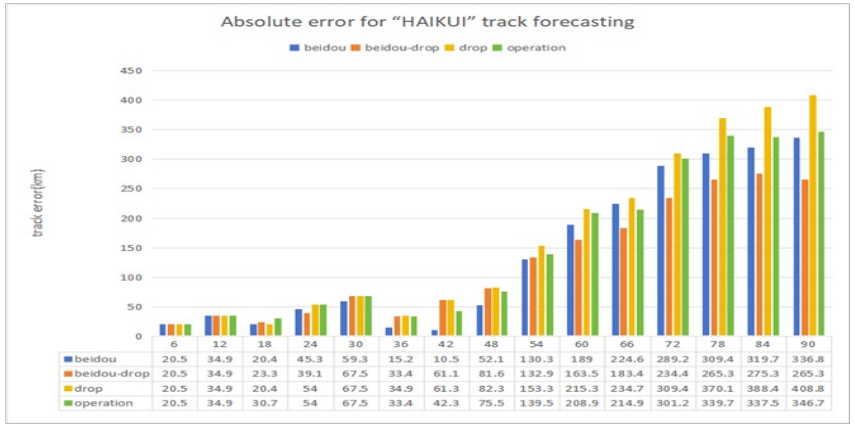
Sanba

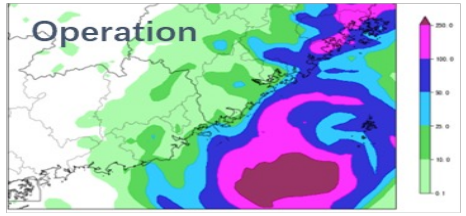
Key technologies –Data assimilation

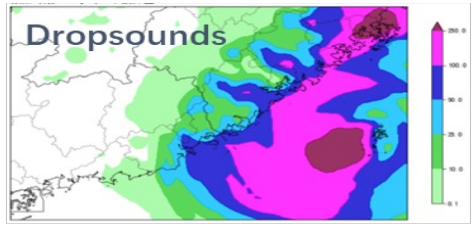
Assimilation of UAV dropsounds

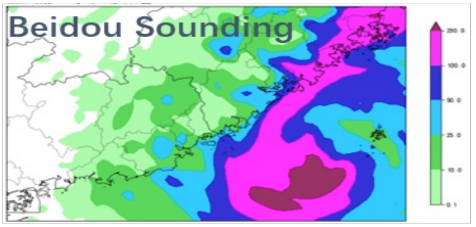
For Haikui, the assimilation of UAV dropsounds and Beidou souding improves the forecasts of CMA-TRAMS in terms of TC track and rainfall.

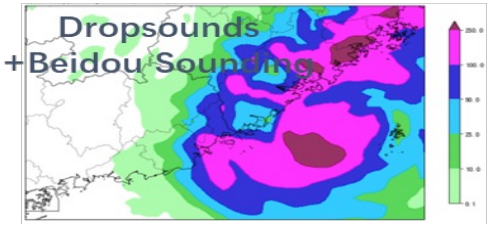


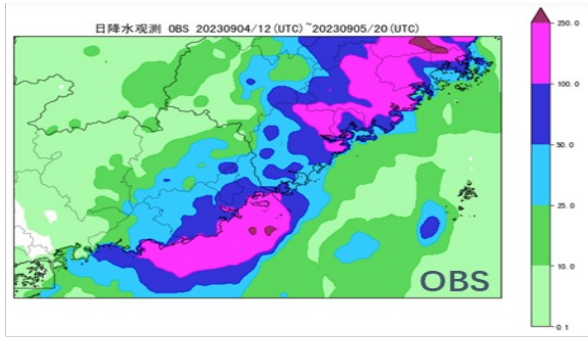


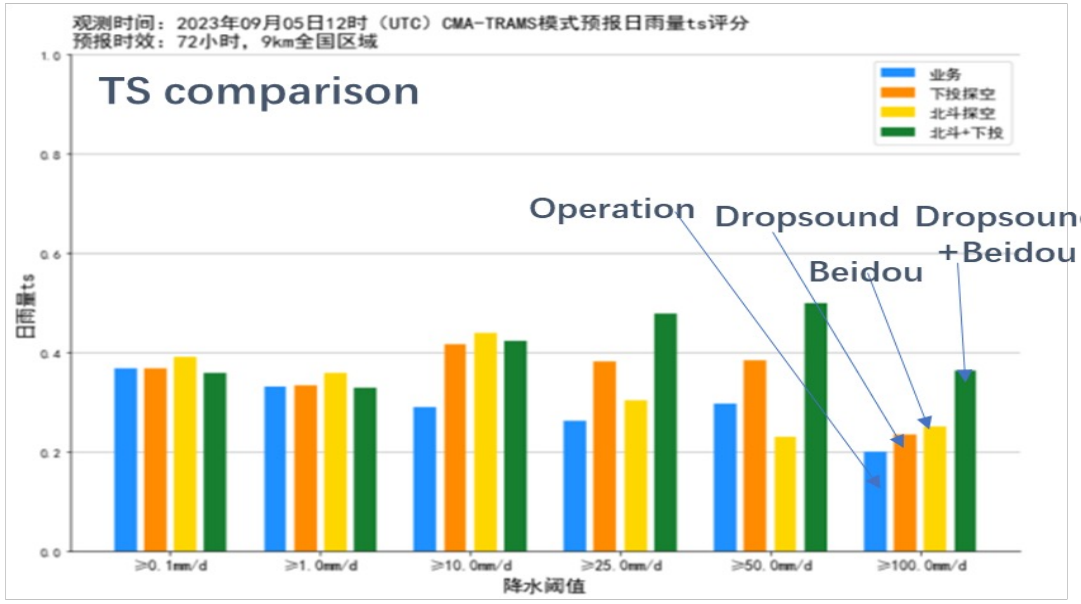






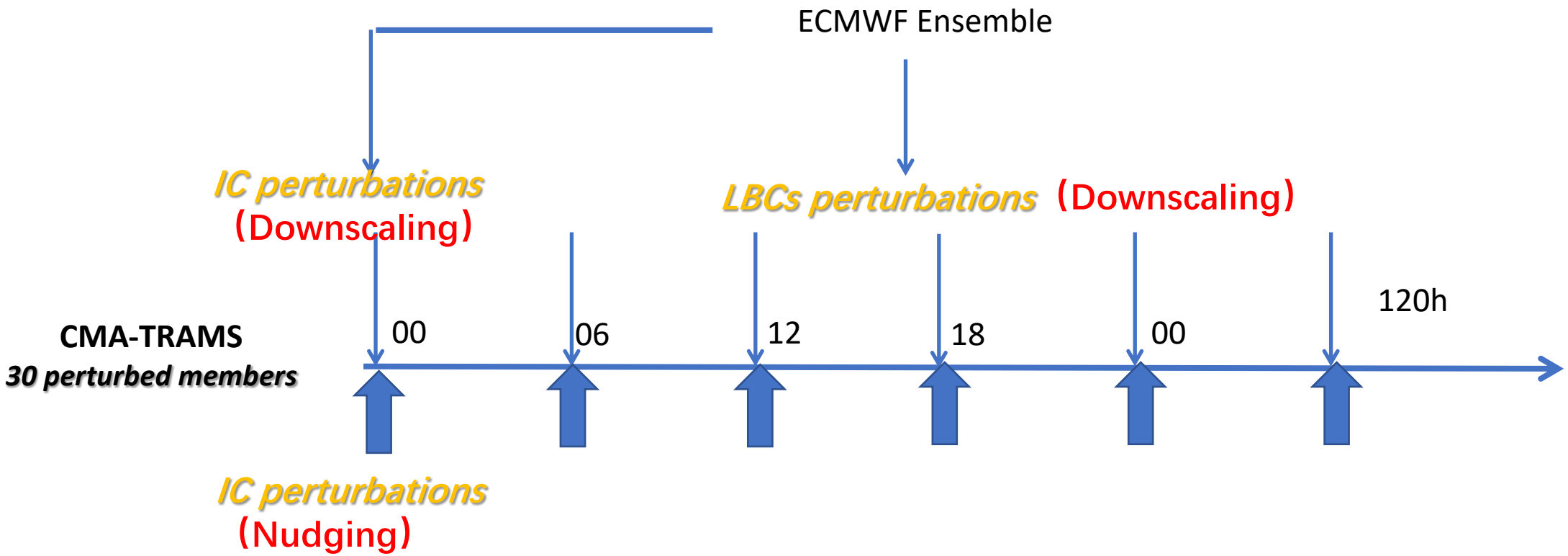






Key technologies –Ensemble forecasting

An ensemble based on CMA-TRAMS



Outline

01 Intro

02 Key technologies and recent study

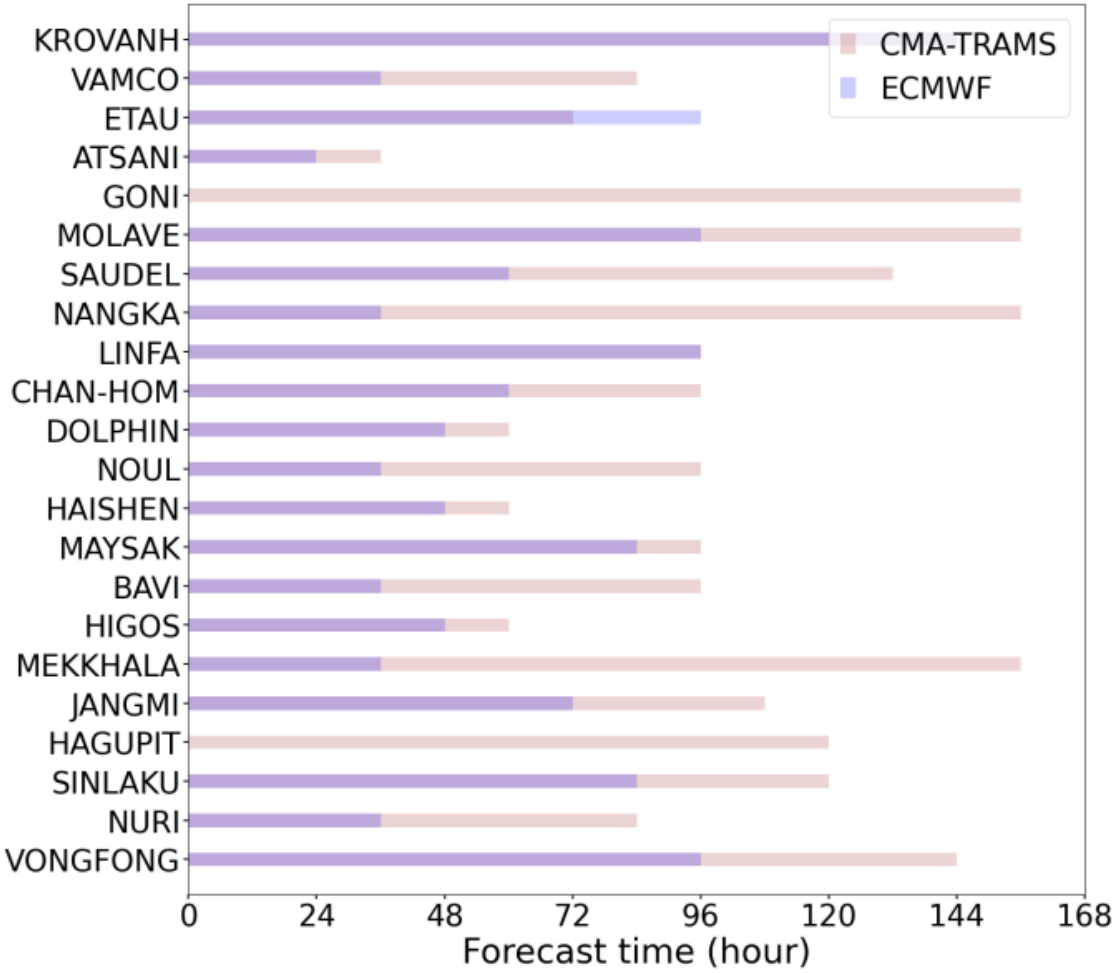
03 Forecast performance

04 Future planning

Genesis Forecast

- CMA-TRAMS is generally able to predict the cyclone genesis **more than 3 days ahead,** which is a significant advantage compared with global NWP models.

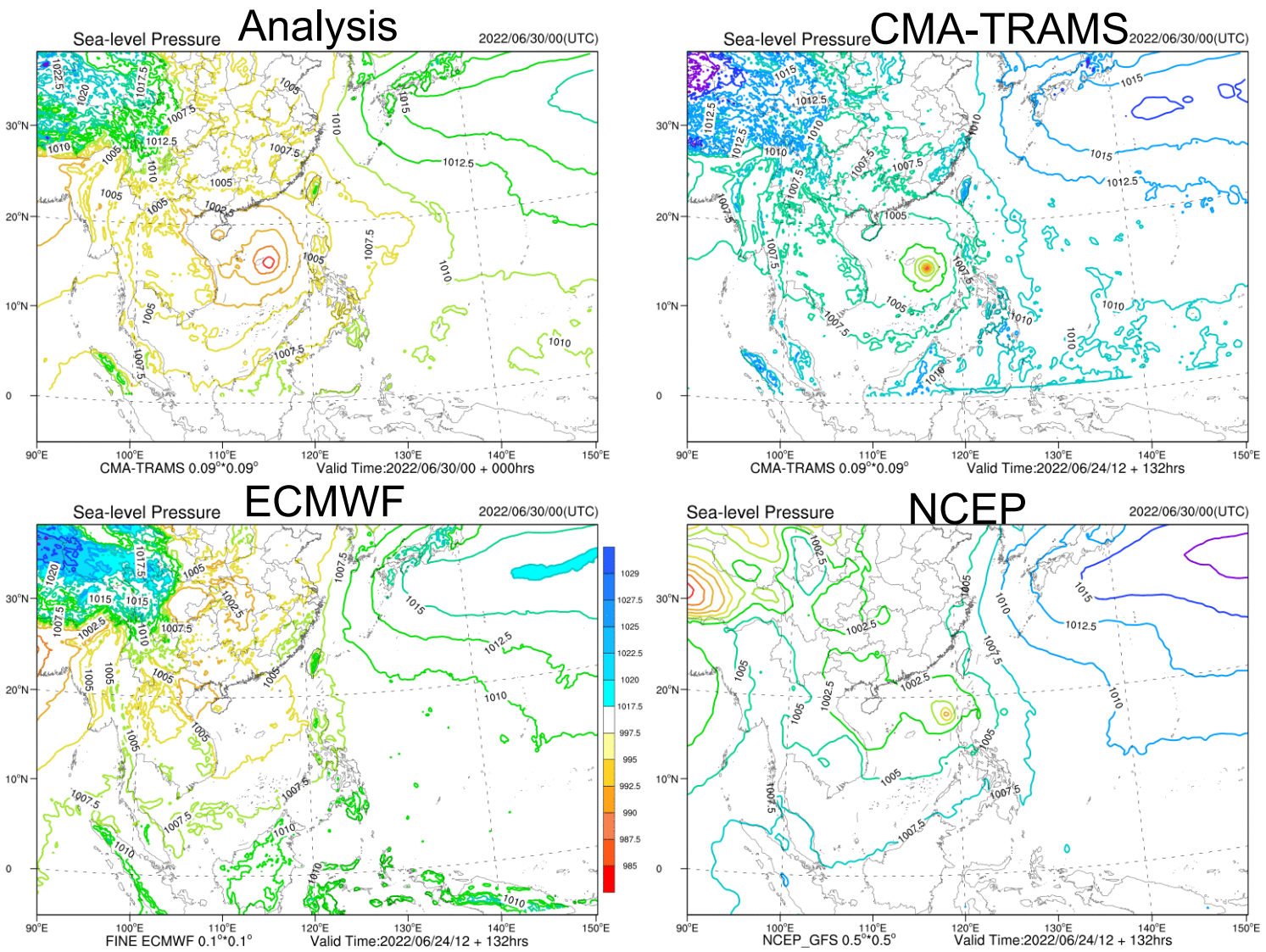
Genesis Forecast in 2020



Genesis Forecast in 2021

Numbering	TY	Lead time of genesis forecast (hr)
2101	Dujuan	96
2102	Surigae	96
2103	Choi-wan	96
2104	Koguma	96
2105	Champi	84
2106	In-fa	144
2107	Cempaka	96
2108	Nepartak	96
2109	Lupit	144
2110	Mirinae	96
2111	Nida	84
2112	Omais	144
2113	Conson	144
2114	Chanthu	60
2115	Dianmu	96
2116	Mindulle	72
2117	Lionrock	144
2118	Kompasu	144
2120	Malou	120
AVERAGE		108

Genesis Forecast

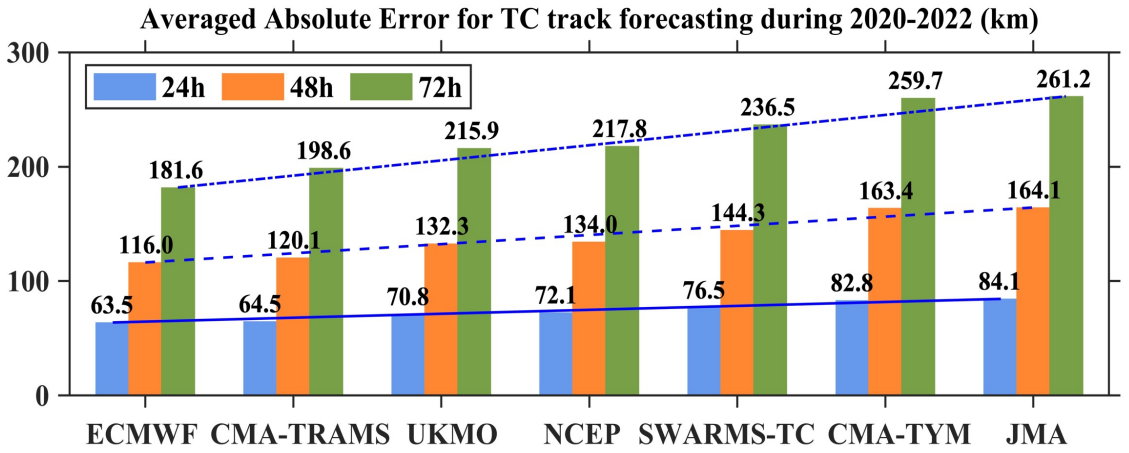


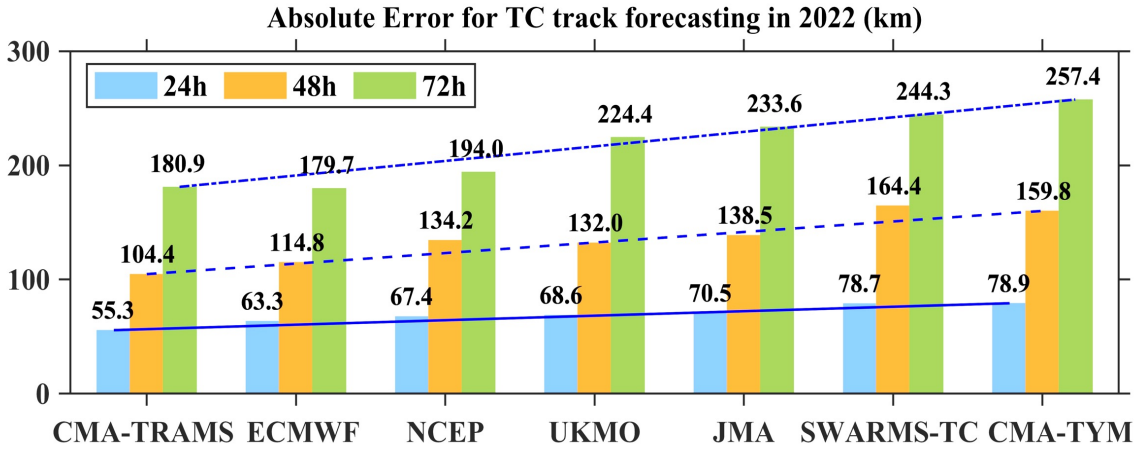
- **Chaba** is the **1st** TC made landfall on China in 2022
- CMA-TRAMS predicted the formation of tropical storm with a **132-hr** lead time, with **precise location**
- NCEP gave a more NE-ward location
- ECMWF did not predict the genesis

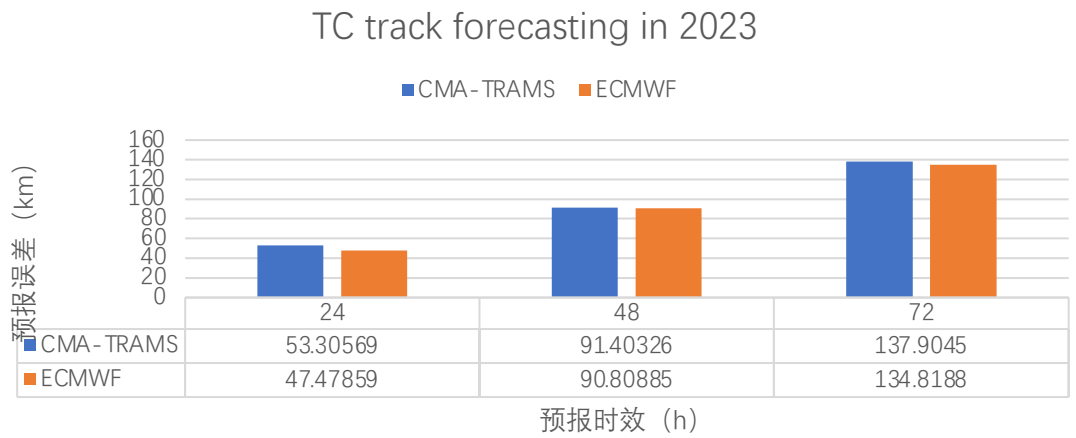
SLP at 00UTC 2022/06/30
Analysis field and +132-hr FCS

Track Forecast

- CMA-TRAMS is effective in TC forecasting, especially for the **complex** track of TCs.
- The verification for TCs over Northwest Pacific and South China Sea shows that, the performance for 24 and 48-h forecasts of TC track from CMA-TRAMS has reached the **world leading level**.

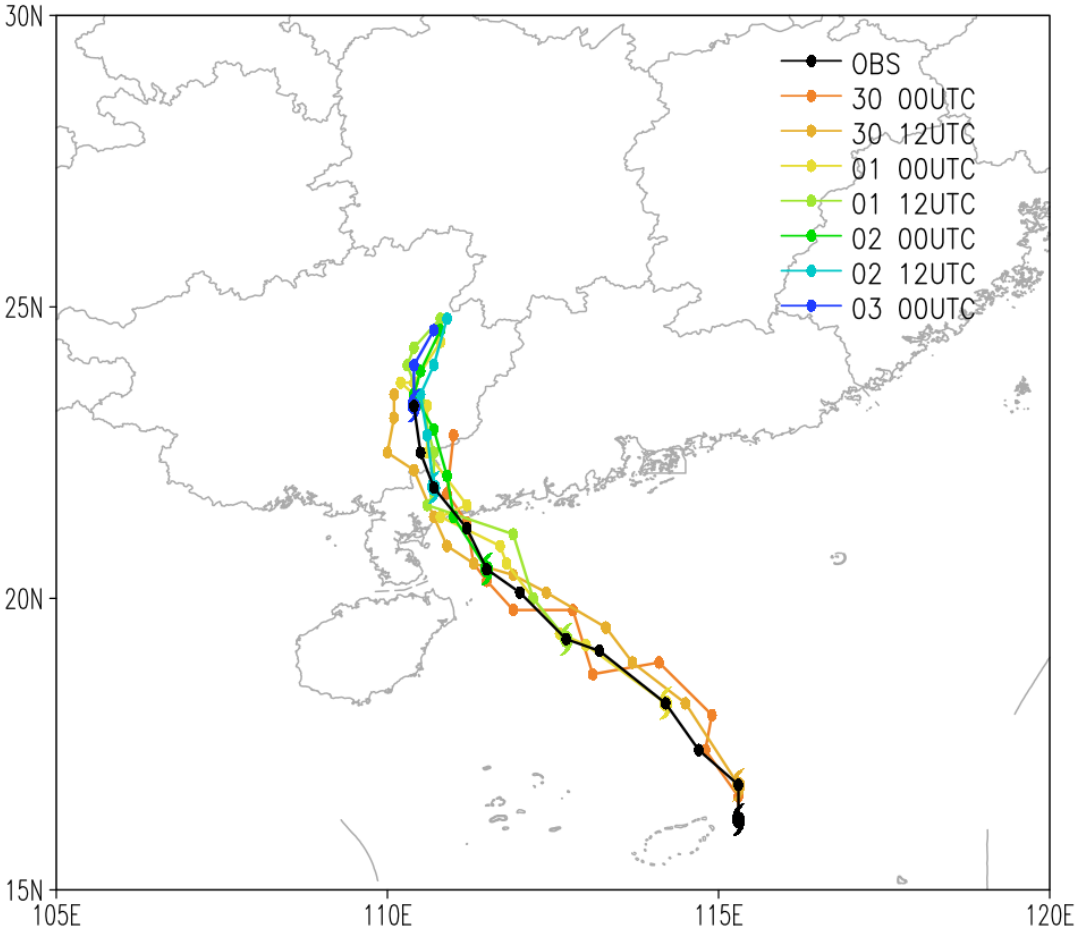




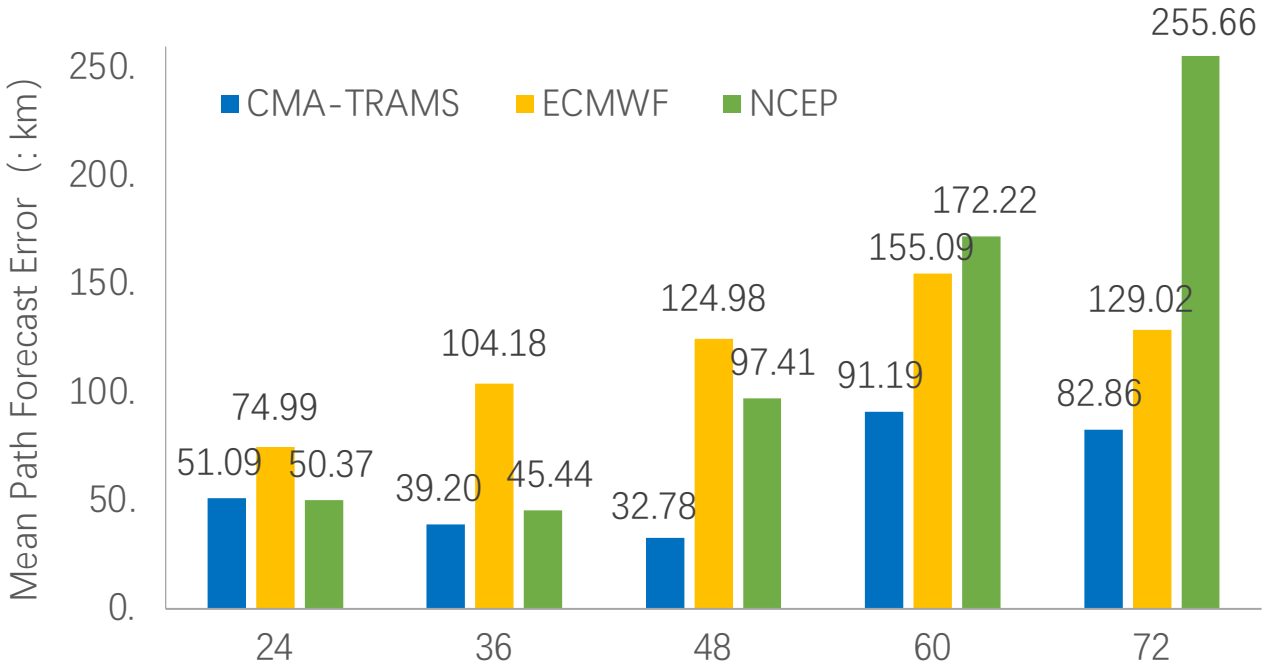


Track Forecast

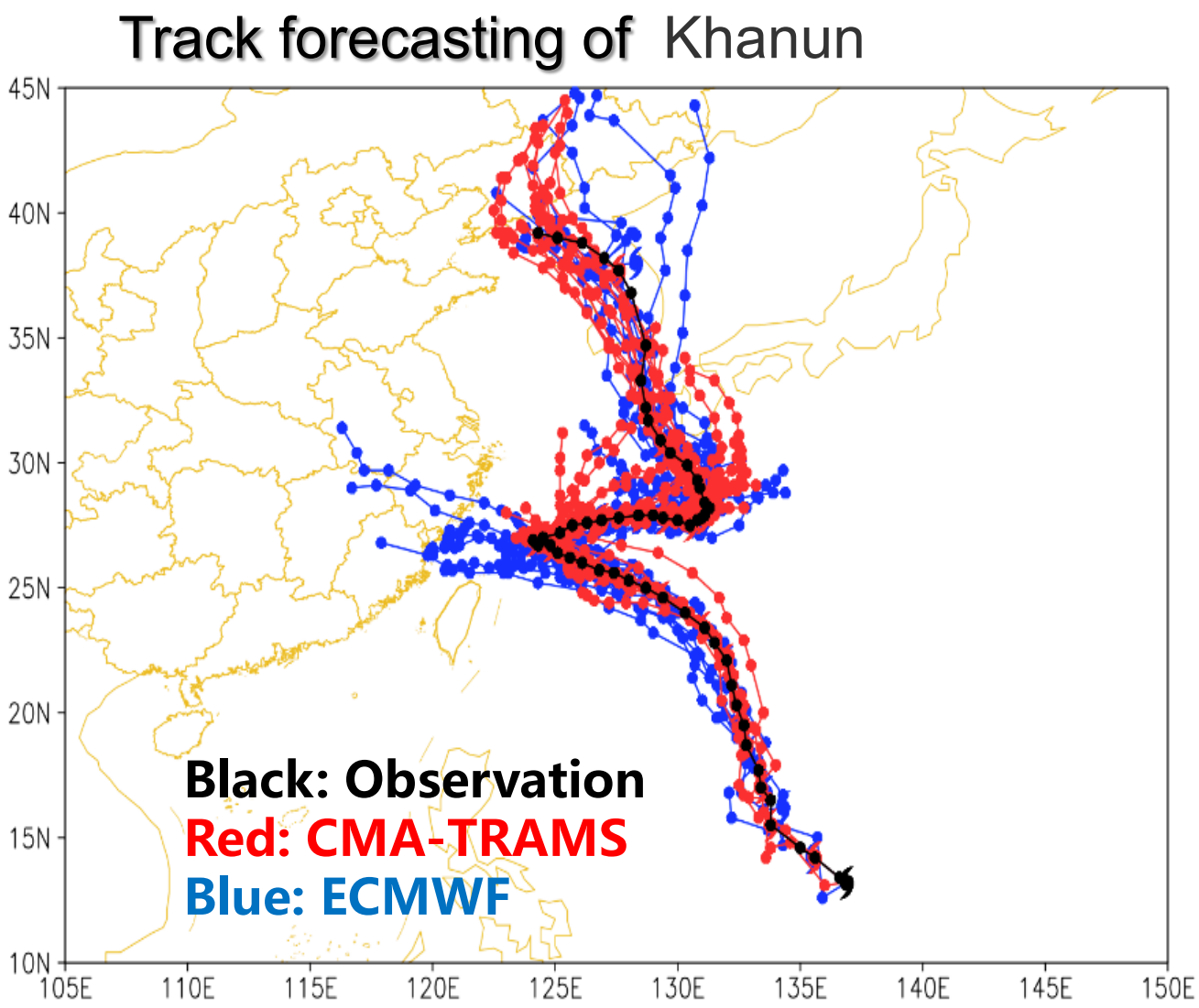
Track forecasting of Chaba



- CMA-TRAMS **provided stable and precise** track forecasting
- 1-3dy Track Errors of CMA-TRAMS were **smaller** than ECMWF and NCEP



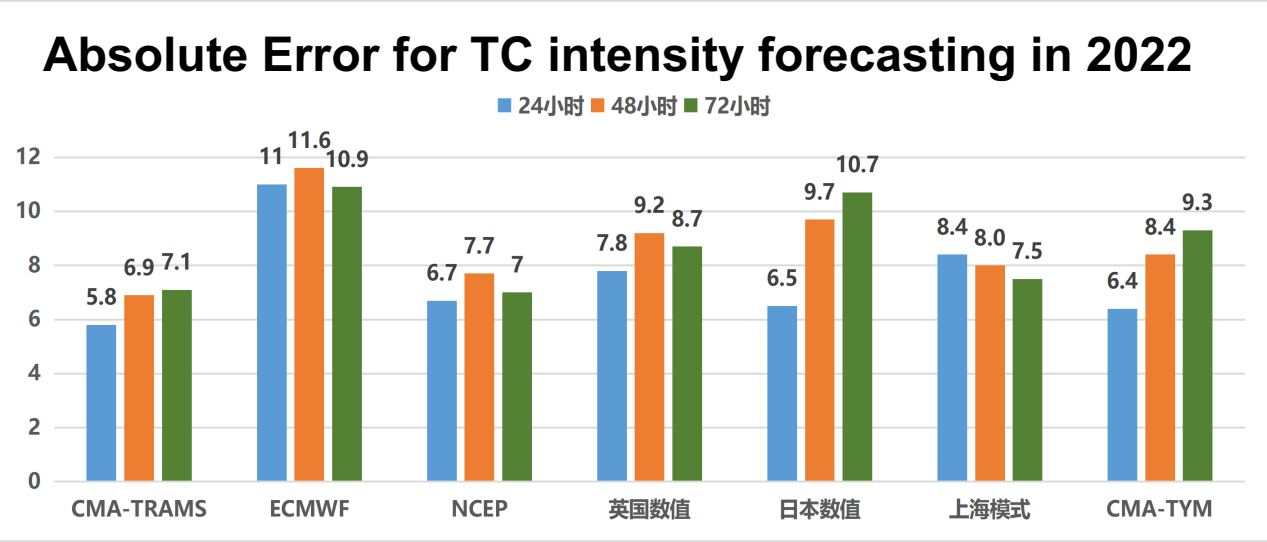
Track Forecast

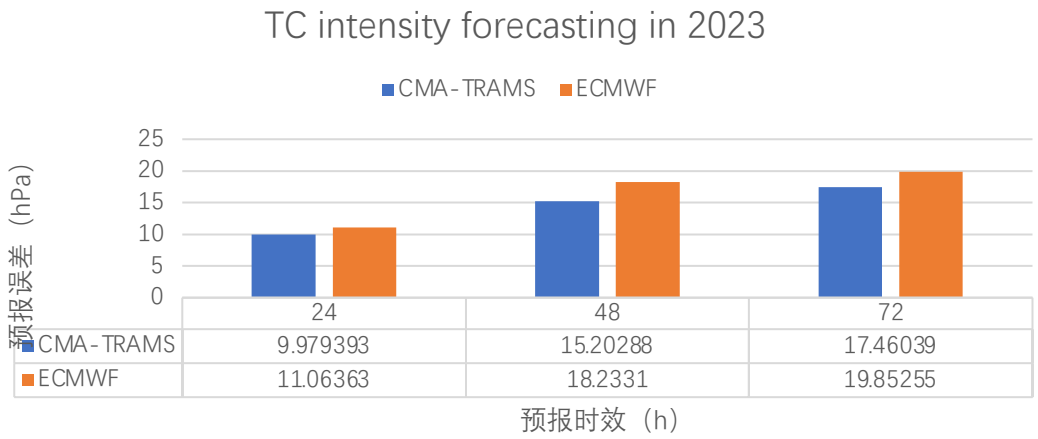


CMA-TRAMS successfully predicted the **first recurving** of typhoon KHANUN 6 days in advance and accurately predicted the **two recurving processes**.

Intensity Forecast

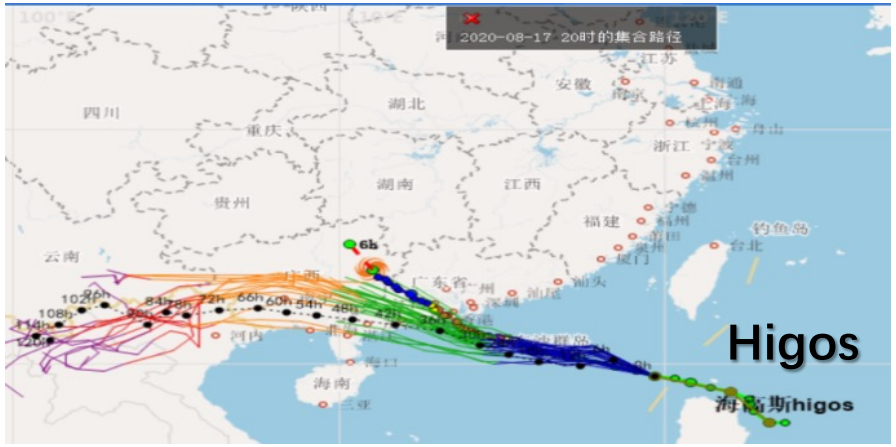
- The verification for TCs over Northwest Pacific and South China Sea shows that, the performance for 1-3-day forecasts of TC intensity from CMA-TRAMS has reached the **world leading level**.

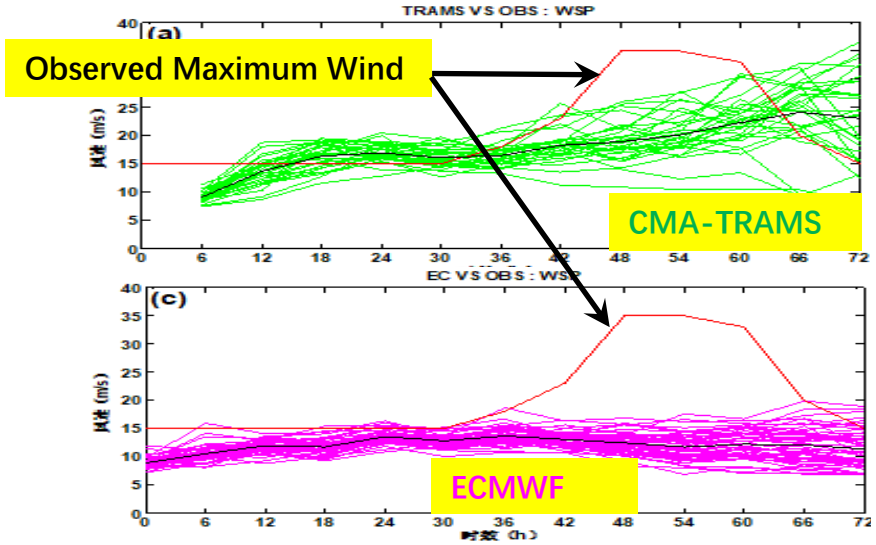


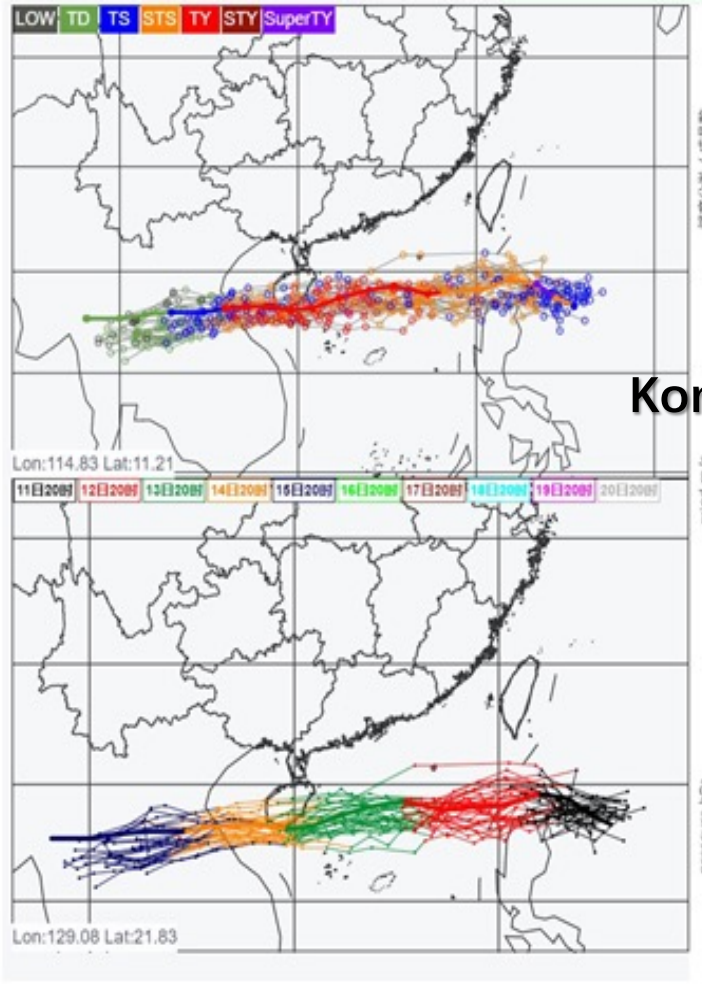


CMA-TRAMS (EPS)

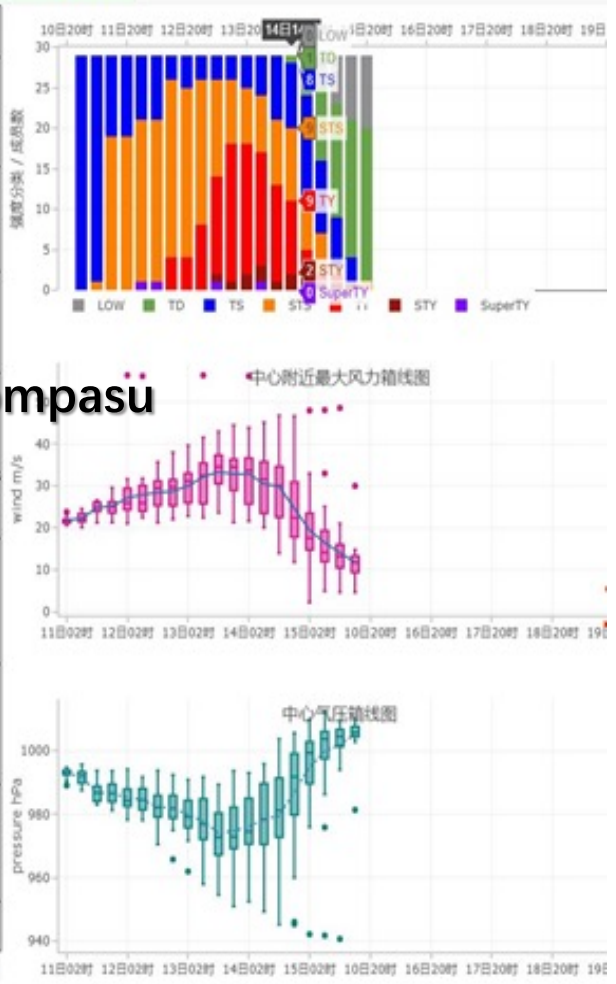
CMA-TRAMS (EPS) successfully predicted the **rapid intensification** of typhoons Higos and Kompasu in advance and accurately predicted the **NW or W-ward movement**.





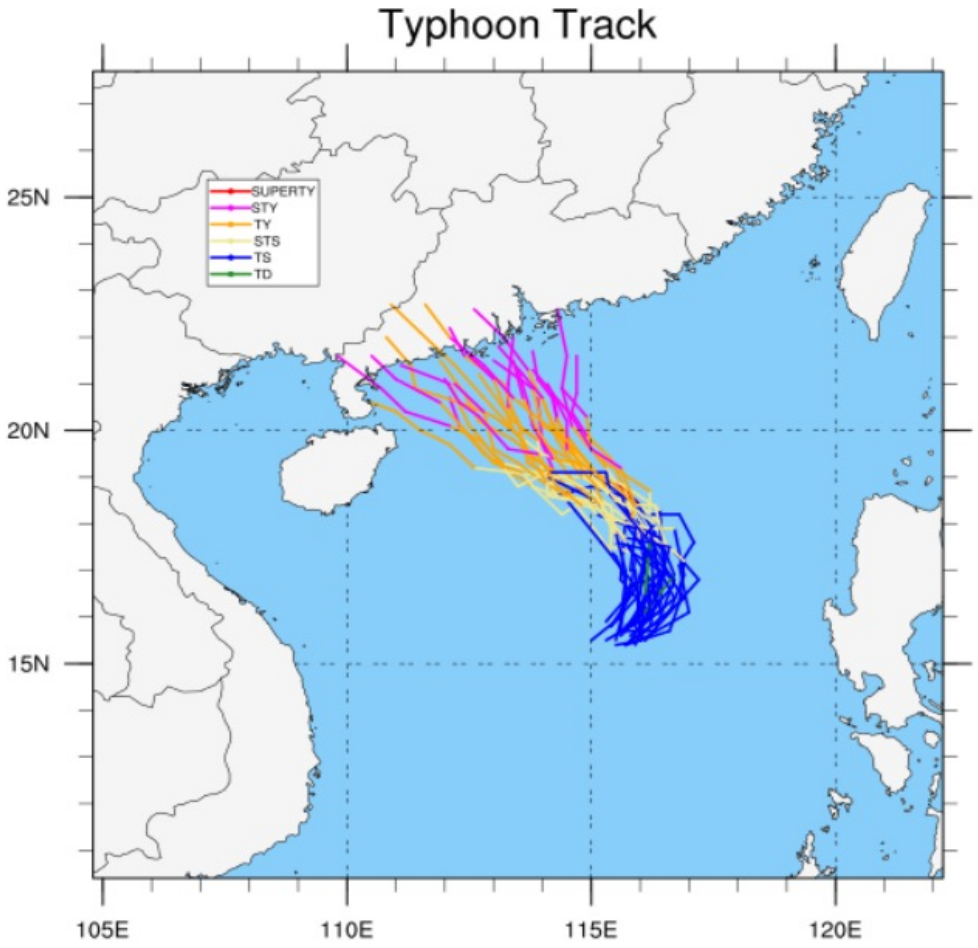


Kompasu

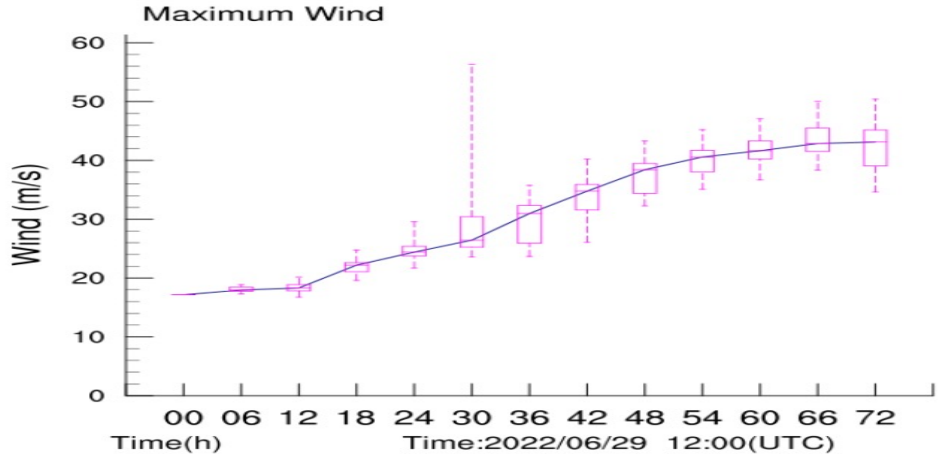


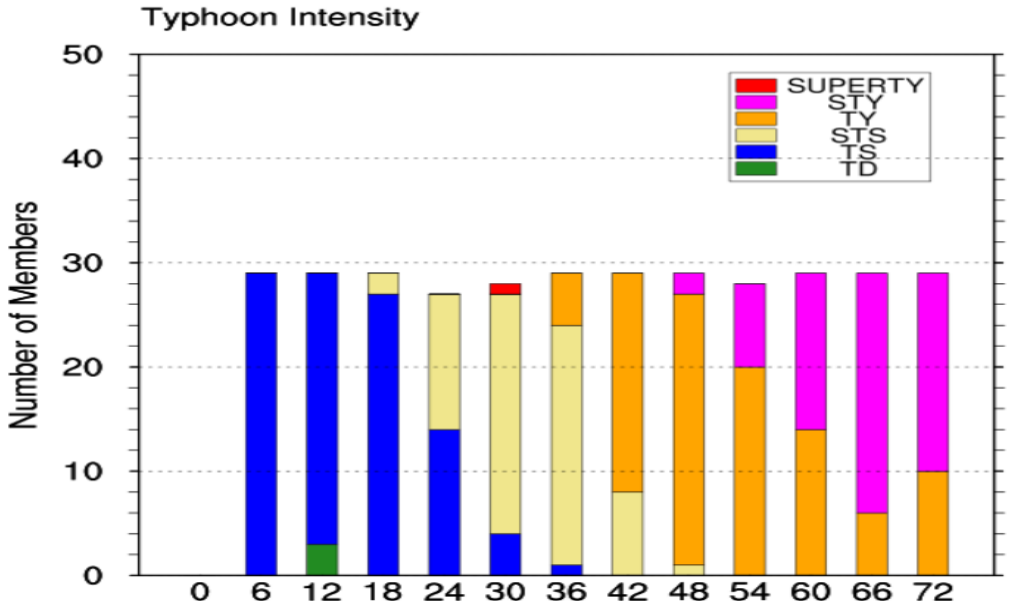
CMA-TRAMS (EPS)

CMA-TRAMS (EPS) successfully predicted the **rapid intensification** of typhoon Chaba in advance and indicated the **uncertainties in landfalling location**.



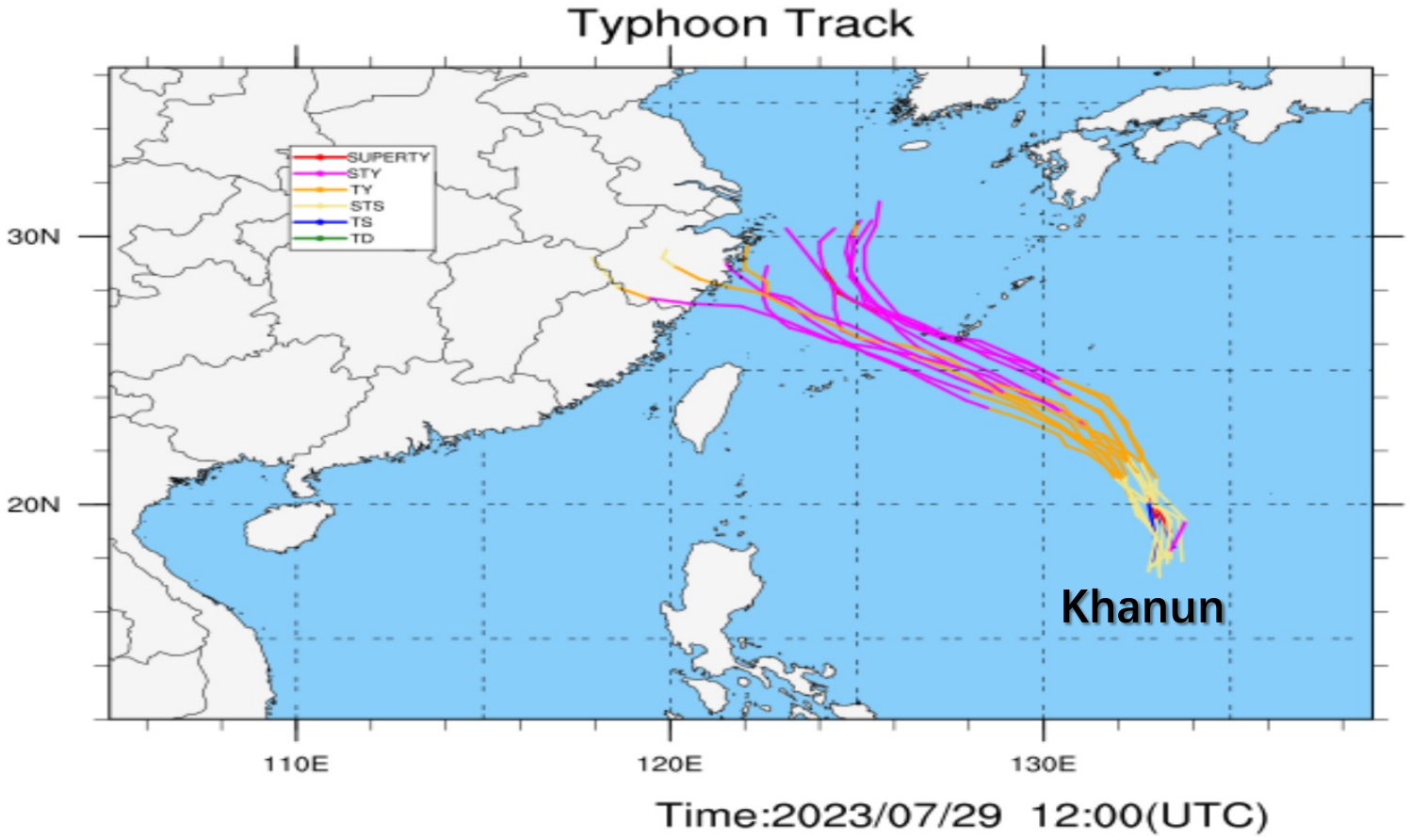
Chaba





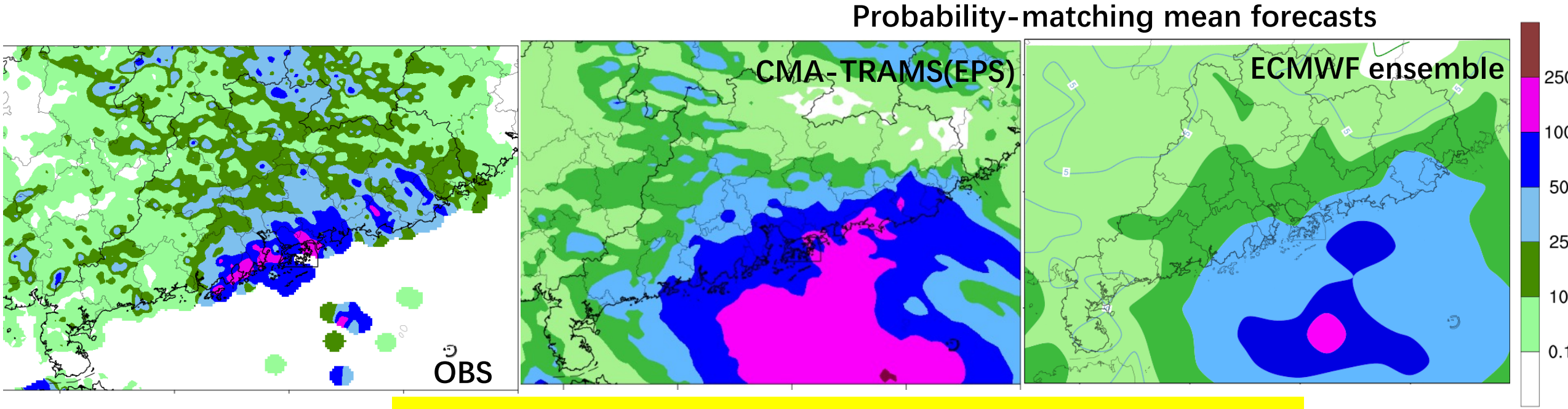
CMA-TRAMS (EPS)

CMA-TRAMS (EPS) successfully predicted the typhoon Khanun in terms of **uncertainties in movement** and indicated **the greater probabilities of recurving processes**.



CMA-TRAMS (EPS)

CMA-TRAMS (EPS) successfully predicted the **heavy rainfall related to** typhoon Higos.



24-h accumulated rainfall valid at 0000 UTC 19 Aug 2020

Outline

01 Intro

02 Key technologies and recent study

03 Forecast performance

04 Future planning

Future planning

I. Develop ***convection*** and ***microphysics*** scheme suitable for high-res TC model.

II. Further upgrade ***surface layer scheme*** and ***PBL scheme***.

III. Develop ***model initialization scheme***, including the assimilation of multiple sources of observations.

IV. Develop ***perturbation methods*** for high-res ensemble forecasts of TCs and optimize the ***post-process techniques***.

THANK YOU!