AOMSUC-15 2025 FYSUC

THE 15TH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE (AOMSUC-15)
2025 FENGYUN SATELLITE USER CONFERENCE (2025 FYSUC)

Status of FengYun Satellite Data Assimilation in CMA-GFS

C-Q WU、Q-F LU、H HAO

Thanks to: Staff in Satellite Data Assimilation at CEMC

CEMC-CMA Earth System Modeling and Prediction Centre

CONTENT

CMA National NWP Systems

GFS：12.5km

CMA-GFS：
- 87layers，top to 0.1hPa
- Global 12.5km
- 4DVAR data assimilation
- 10 day forecast (00,12UTC）
- 5day forecast (06,18UTC）
- Global tropical cyclone forecast

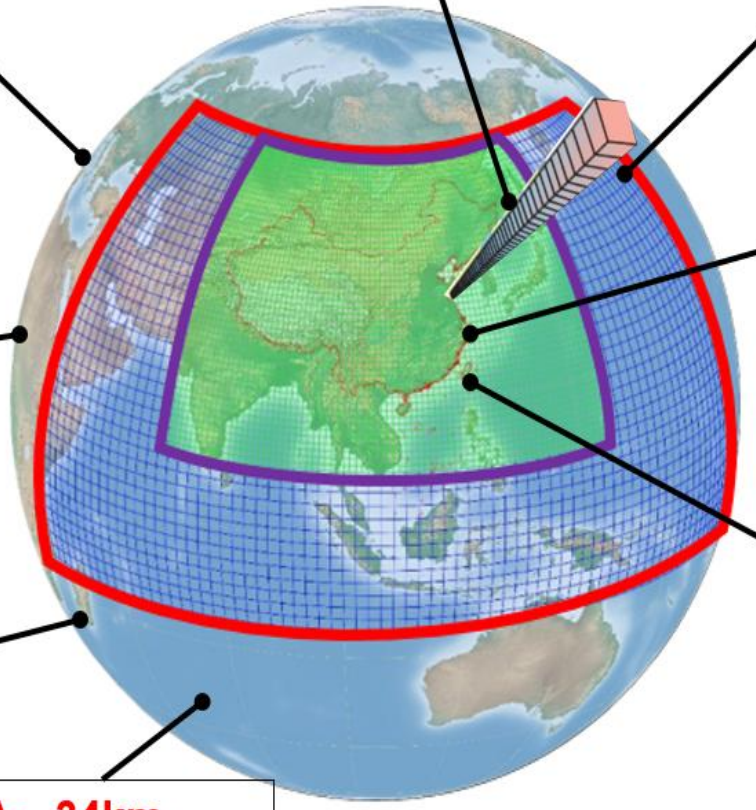
GEPS：50/25km

CMA-GEPS：
- 87 layers，top to 0.1hPa
- Global 50 km
- 1control + 30 members
- 15day forecast（00,12UTC）

CPS：45km

CMA-CPS：
- Sea-land-ice-atm coupled，56lays, top to 0.1hPa
- Global 45km
- S2S sub-system：1-60day forecast，4member per day
- Seasonal forecast：1-13month，every month，21members

87 levels，63km



RA：34km

CMA-RA：
- 64 layers，top to 0.27hPa
- Global 34 km
- DA update：6hour
- Data length：1979-to real-time

Typhoon：9km

- CMA-TYM：
- 9 km
- lon：40-180，lat：15S-60N
- 4 times perday，5day forecast

MESO：3/1km

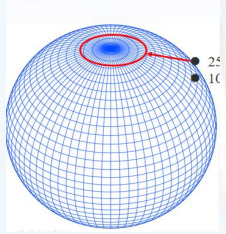
CMA-MESO：
- China domain,1km
- 8/24 times per-day, 1/3hour update
- 12 to 36 hours update

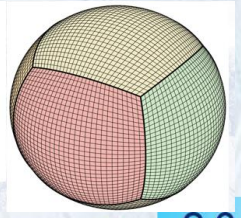
REPS：10/3km

CMA-REPS：
- China domain, 10km
- 1control +15member
- 3.5day forecast（00,12UTC）

Environment：
- dust、haze/fog forecast，00,12UTC
- Pollution model：12hour-10day forecast，
- 100m-25km

Roadmap of CMA Earth System Model





MCV: Multi-moment Constrained Finite Volume Method

2023

- CMA-GFS 12.5KM operational running
- CMA-MESO 1KM1Hr running
- New T382L70 climate model be developed

2024

- CMA-MESO 1KM1Hr rapid update cycle operational running for China domain

2025

- Continue improve CMA-GFS 12.5KM
- Develop CMA-MESO 500m system for key area
- CMA-CPSv4 quasi-operational running

2027

- Global 5km MCV model be operational running
- regional 500m model running
- Develop MCV based next-generation climate model

2030

- Develop MCV model based Earth system, model systems, and specific model system

2035

- Unified weather-climate system, earth system prediction

2023

- Accomplish stratosphere atmosphere processes,
- Accomplish ocean model design
- Accomplish global/regional 3DVar core codes development

2024

- Accomplish ocean/sea-ice component couple with MCV coupler
- Set up global/regional unified 3DVar, develop parallel version
- Accomplish tangent & adjont model develop

2025

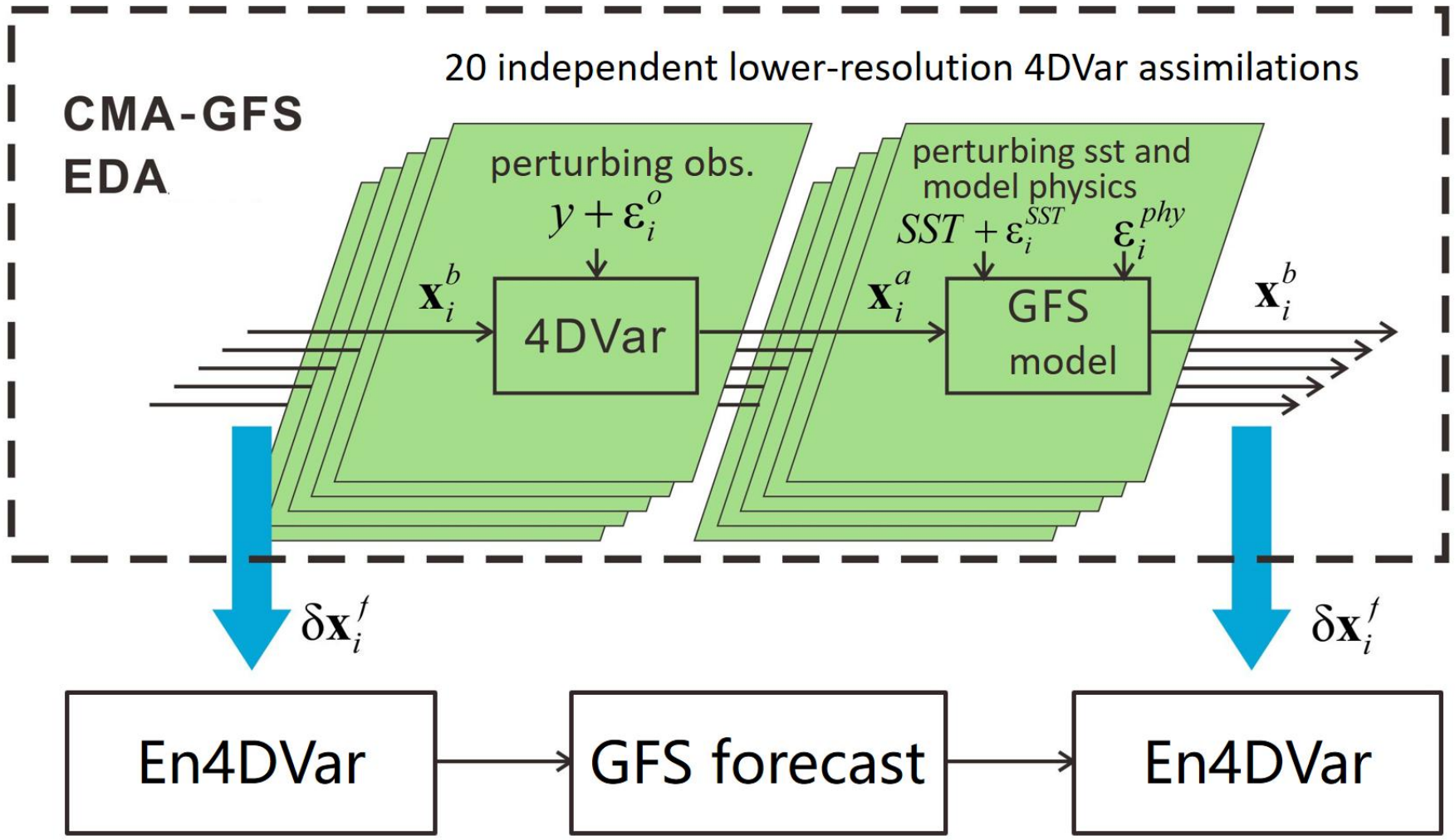
- Setup unified weather & climate model (coupled with ocean, land surface, sea-ice)
- Develop prototype 4DVar based on MCV model
- Develop Km-scale regional 3DVar system
- Regional MCV cycling DA system be quasi-operational running

More satellite data is need in the future!

Unified weather-climate system, toward earth system prediction (MCV based)

Recent Upgrades: En4DVar

CMA-GFS En4DVar configuration



CMA-GFS 12.5km analysis and forecast cycle

Recent Upgrades: Bias Correction

Radiance bias correction method: autoBC to VARBC+CBC.

Constrained bias correction (CBC)

High-level microwave sounding data are used to constrain model biases in the upper atmosphere, effectively suppressing bias growth at higher altitudes.

$$\left\langle (o - f + b)^2 \right\rangle + \alpha \left\langle (b - b_0)^2 \right\rangle = \min!$$

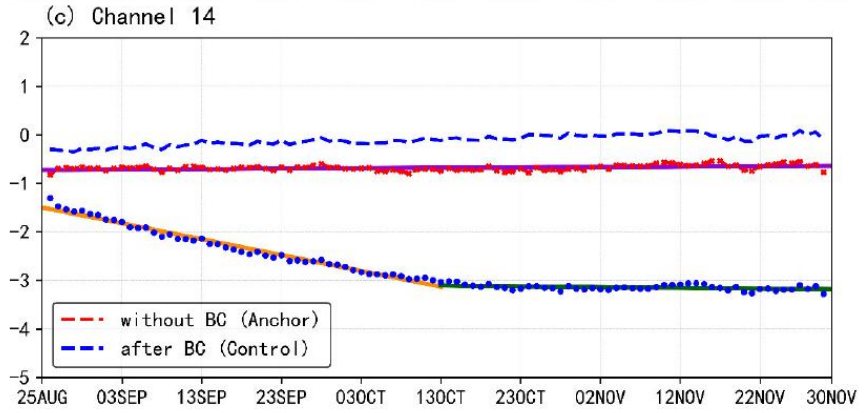


Fig. 6. The same as in Fig. 5 but for the results of the NOAA-19/AMSU-A tendency.

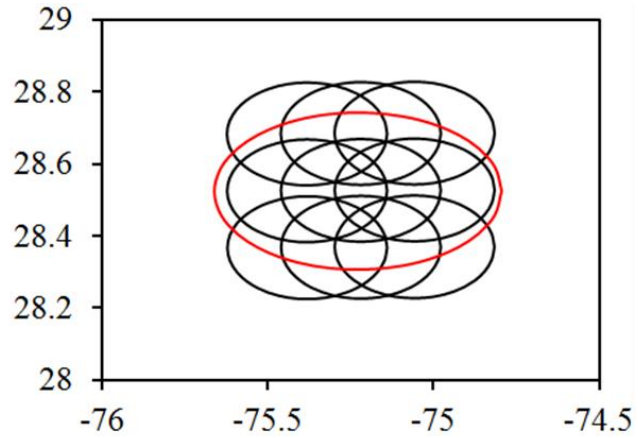
Variational bias correction (VARBC)

Bias correction terms are incorporated into the cost function minimization, enabling online bias correction within the variational assimilation framework.

$$\begin{aligned} 2J(\mathbf{x},\boldsymbol{\beta}) = {} & (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) \\ & + (\boldsymbol{\beta} - \boldsymbol{\beta}_b)^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta} - \boldsymbol{\beta}_b) \\ & + [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x},\boldsymbol{\beta})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x},\boldsymbol{\beta})] \end{aligned}$$

Challenge: High accuarcy reference satellite observation

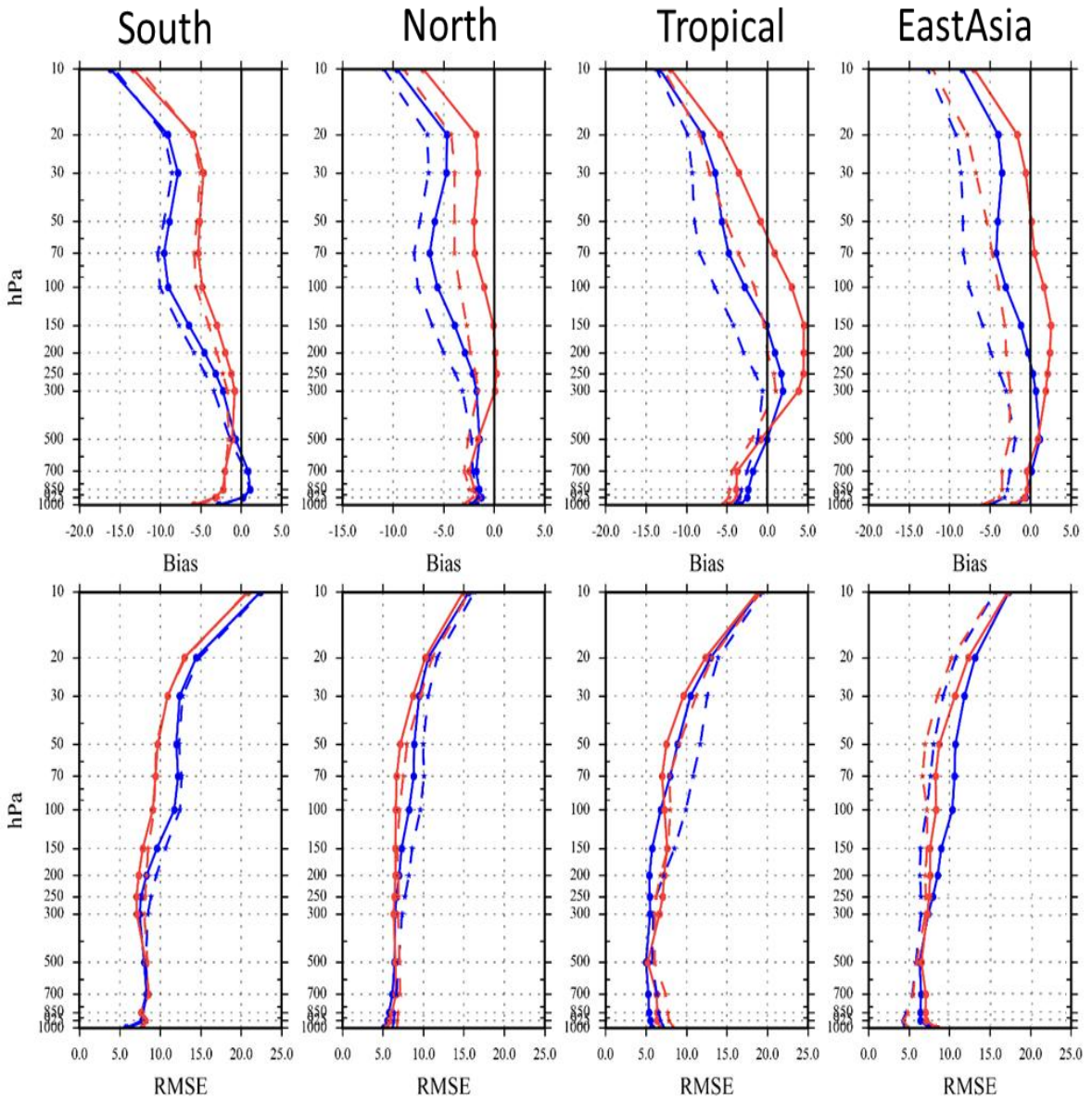
Recent Upgrades: Resampling



$$NE\Delta T = \frac{T_{sys}}{\sqrt{B \cdot \tau}} \Rightarrow NE\Delta T = \frac{T_{sys}}{3 \cdot \sqrt{B \cdot \tau}}$$

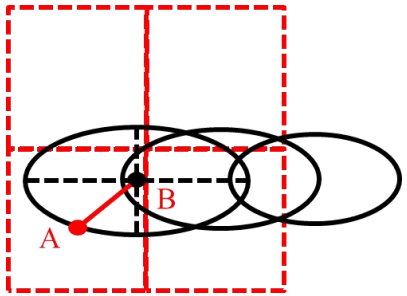
- After 3 * 3 resampling of the ATMS temperature channels equipped with NPP and NOAA-20, the channel noise was significantly reduced.

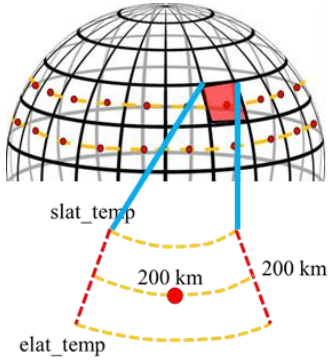
- The assimilation results after resampling (**red curve**) show a significant decrease in error and bias compared to the non resampling (**blue curve**) analysis field.

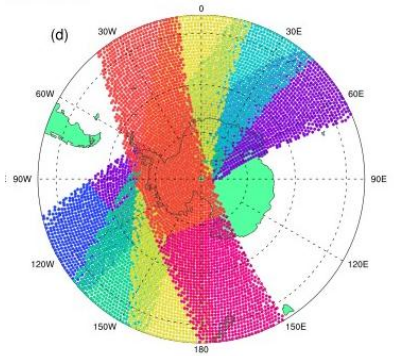


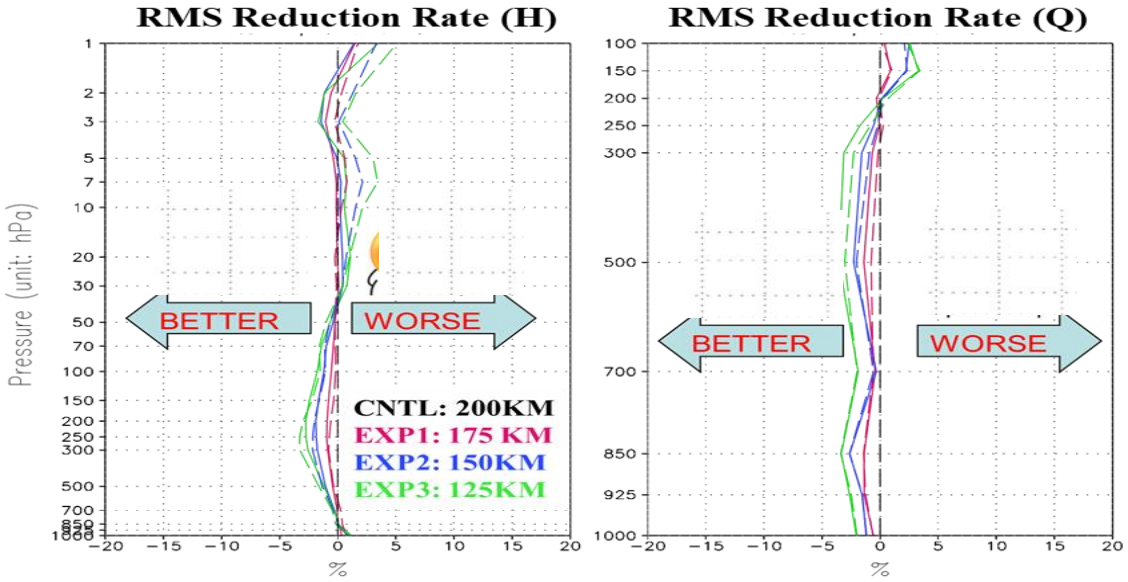
Recent Upgrades： Thinning Methods

Improved Observation Thinning and Preprocessing Techniques





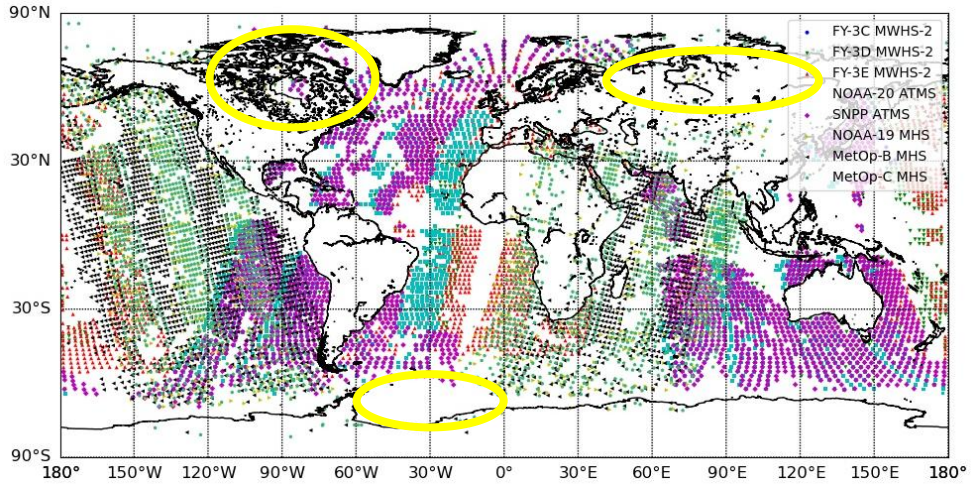


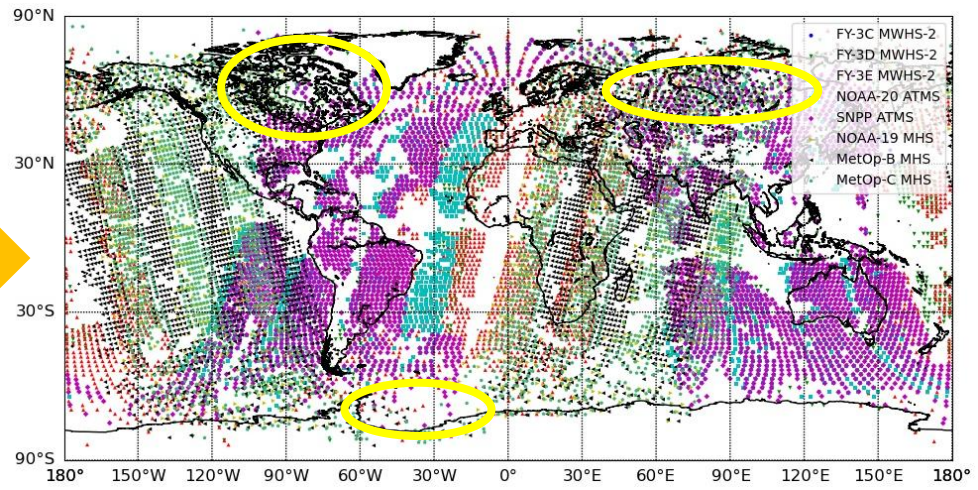


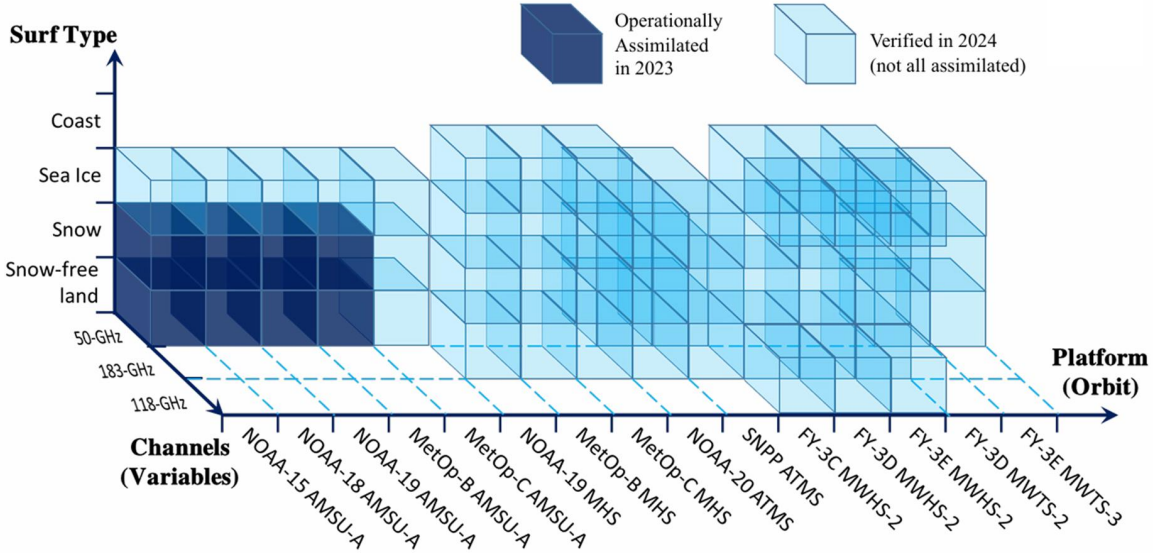
- Accounts for **pixel deformation and oversampling** at large viewing angles, reducing the assimilation of low-quality observations.
- Improved division of **Earth's standard equal-distance surface grid** in the preprocessing system.
- Utilizes **orbit overlap observation in mid- and high-latitudes** for polar-orbiting satellites, enhancing observation usage efficiency.
- Integrated multiple complex preprocessing steps into a **unified and centralized system**.

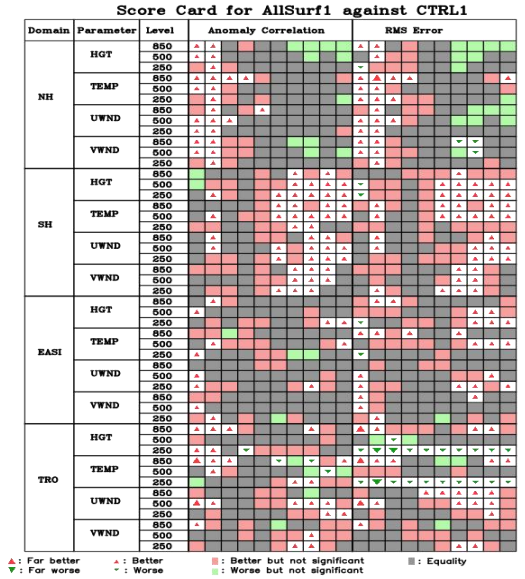
Recent Upgrades： All-Surface MW

Upgraded Microwave Assimilation over Complex Terrain



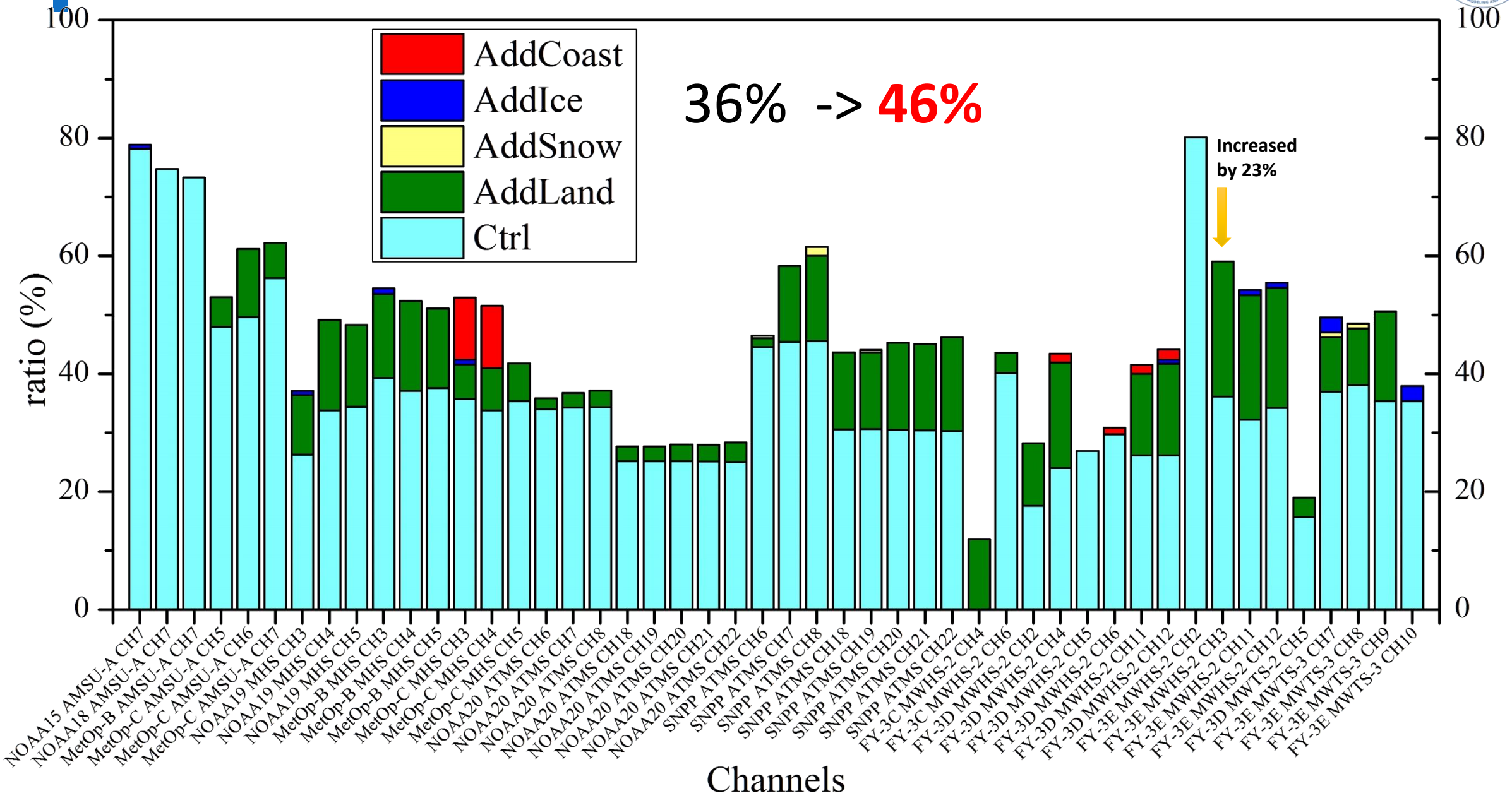






Achieved all-surface assimilation of near-surface microwave observations, improving forecast skill over **land-dominated regions** in the Northern Hemisphere.

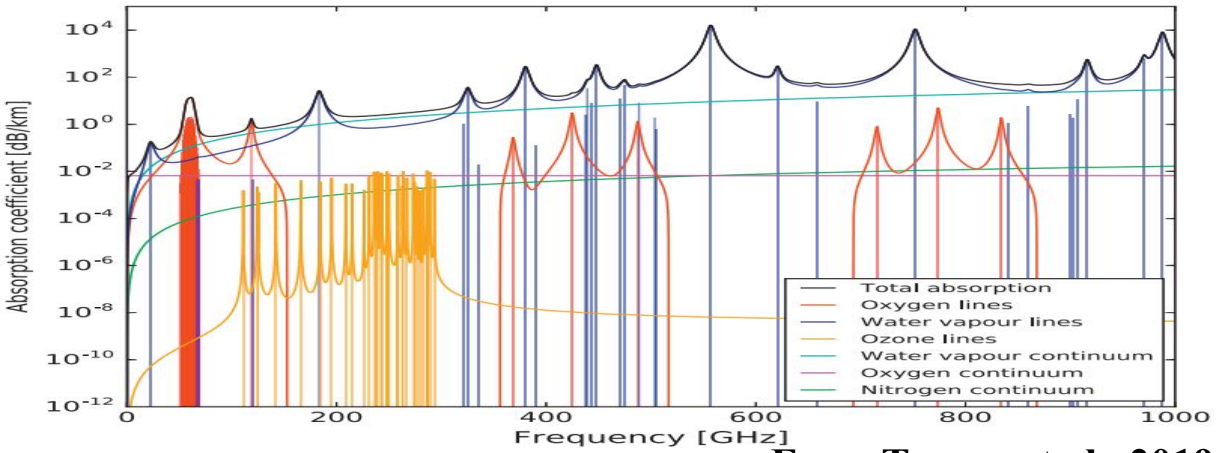
Recent Upgrades： All-Surface MW



Recent Upgrades： RT Model

ARMS 1.3.0

O3 absorption is added by this change.



From Turner et al., 2019

☐ Major Updates (Training)

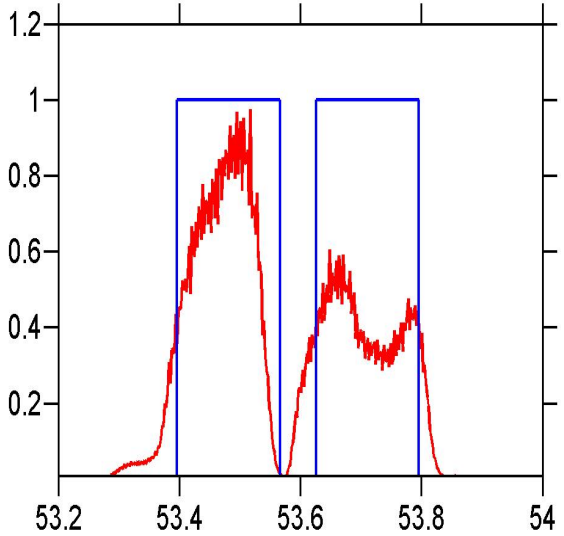
- Line-by-Line RTM:

  MPM* ⇨ MonoRTM

*** MPM is the Millimeter-wave Propagation Model**

- Channel Transmittance (**SRF**):

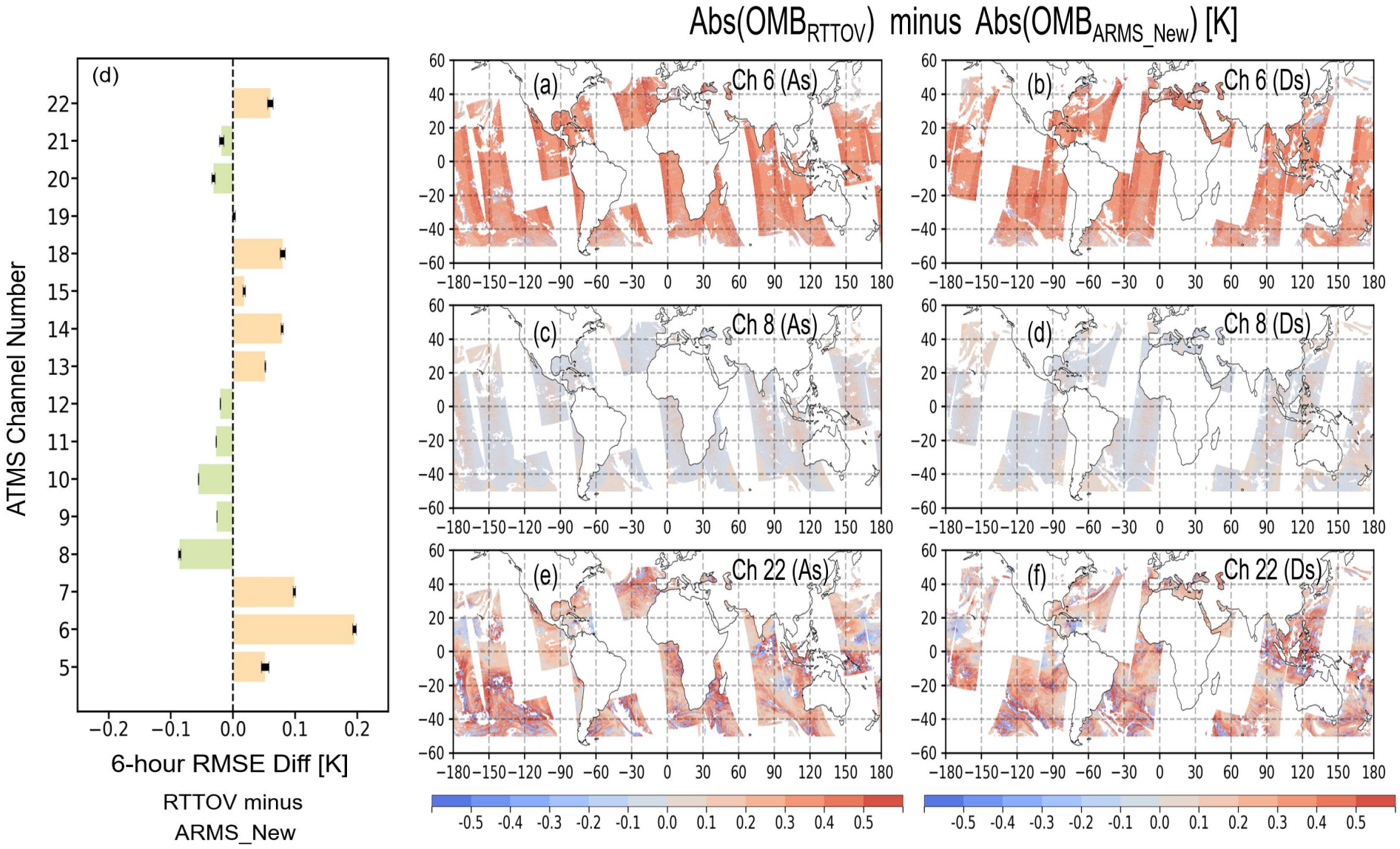
$$\Gamma_{ch,j} = \frac{\int_V \Gamma(\upsilon) d\upsilon}{\int_V d\upsilon} \Rightarrow \Gamma_{ch,j} = \frac{\int_V \Gamma(\upsilon)\mathrm{SRF}(\upsilon) d\upsilon}{\int_V \mathrm{SRF}(\upsilon) d\upsilon}$$



MWTS FY3F
Ch 7 SRF

- Predictors:
  - ✓ Add Predictors for Mixed Gas
  - ✓ Separte H2O Continuum Component and Line Component in Regressions.

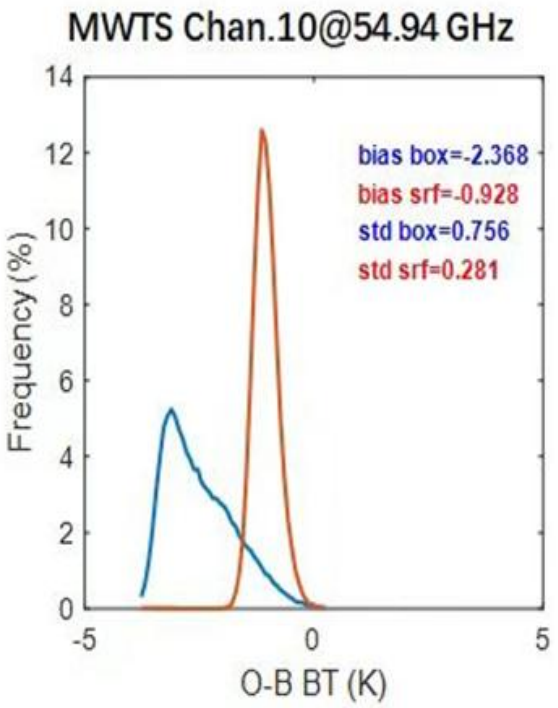
Recent Upgrades： RT Model

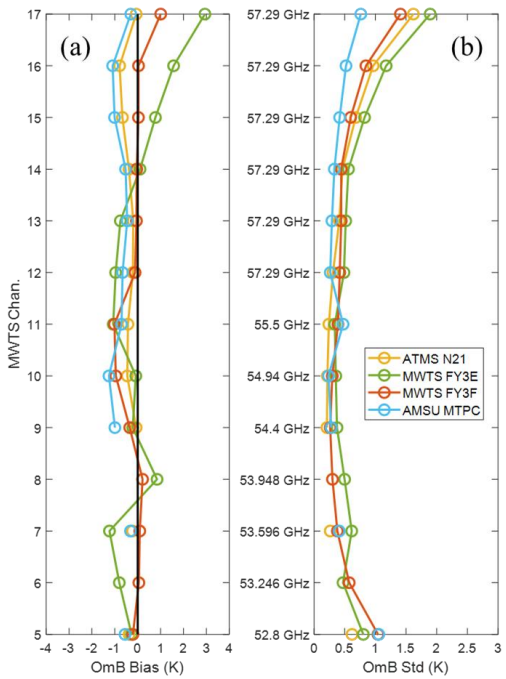


The global distribution of OMB diffs between ARMS and RTTOV follows a consistent pattern in channel 6 and channel 8.

A significant disparity between ARMS and RTTOV is observed in channel 22, where the maximum difference can reach 0.5 K.

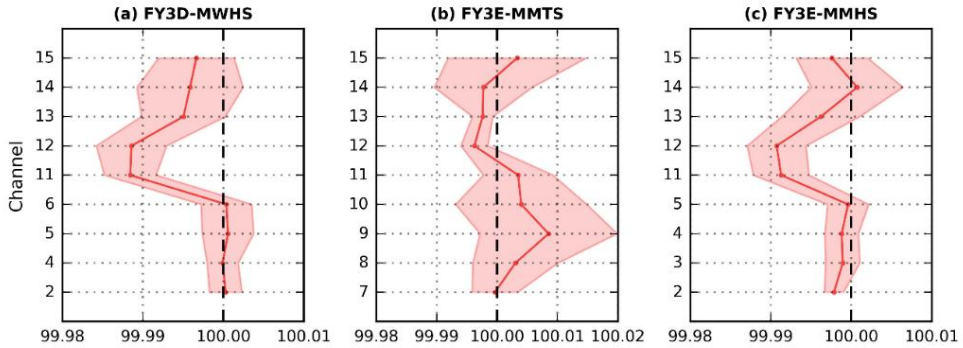
Recent Upgrades: FY3F MW sounders

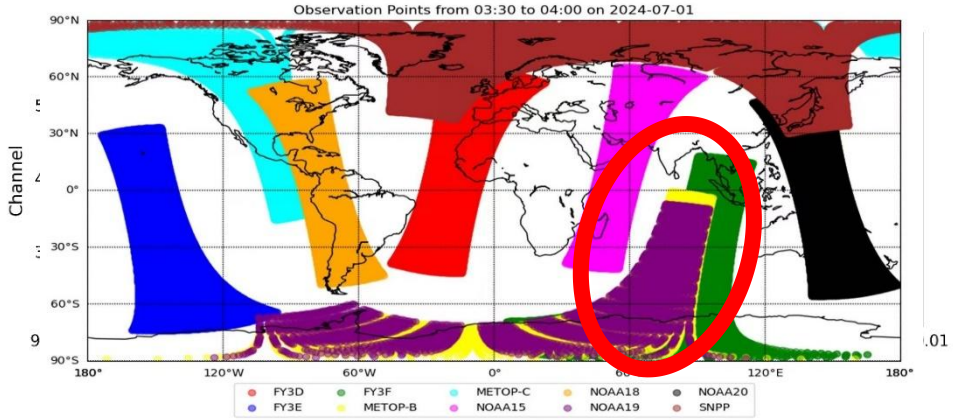




Evaluation of FY-3F MWTS/MWHS:

- Compared to FY-3E, **FY-3F MWTS shows significant data quality improvement**, particularly with reduced biases in upper-level channels.





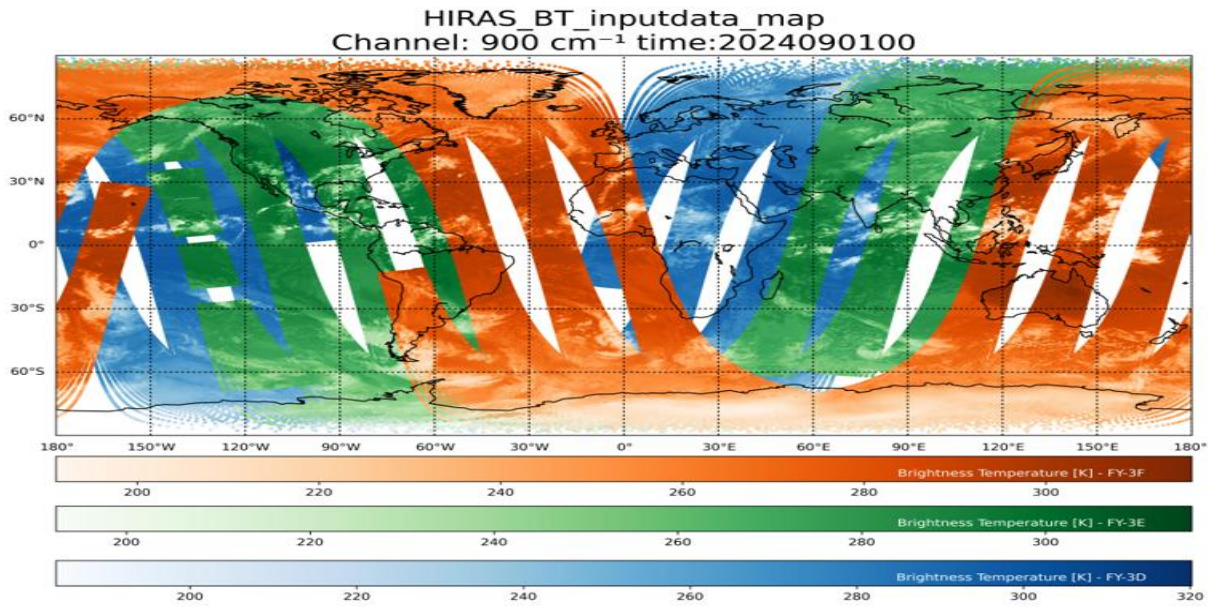
Assimilation experiments with FY-3F MWTS/MWHS:

- Positive impacts on CMA-GFS analysis and forecasts were observed, especially for temperature and humidity fields.
- Despite FY-3F being in a crowded **morning orbit**, it still contributes positively to NWP skill.
- In CMA-GFS, the current observing system is far from saturated

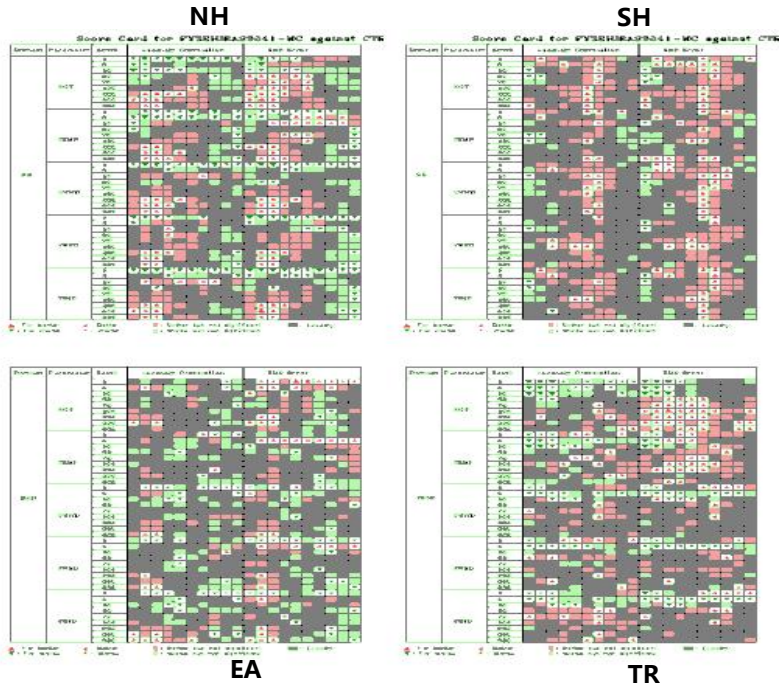
Recent Upgrades： FY-3 HIRAS

- FY-3E is the world's first civilian meteorological satellite in a dawn-dusk orbit, filling the observation gap in the early morning and evening time slots for polar-orbiting meteorological satellites. Together with other on-orbit morning and afternoon satellites from Fengyun, it enables 100% global coverage of polar-orbiting satellite data within a 6-hour assimilation window.

- Data from the three HIRAS instruments (FY-3D/3E/3F) have been operationally assimilated into the CMA-GFS, which has a positive impact on the forecast fields.

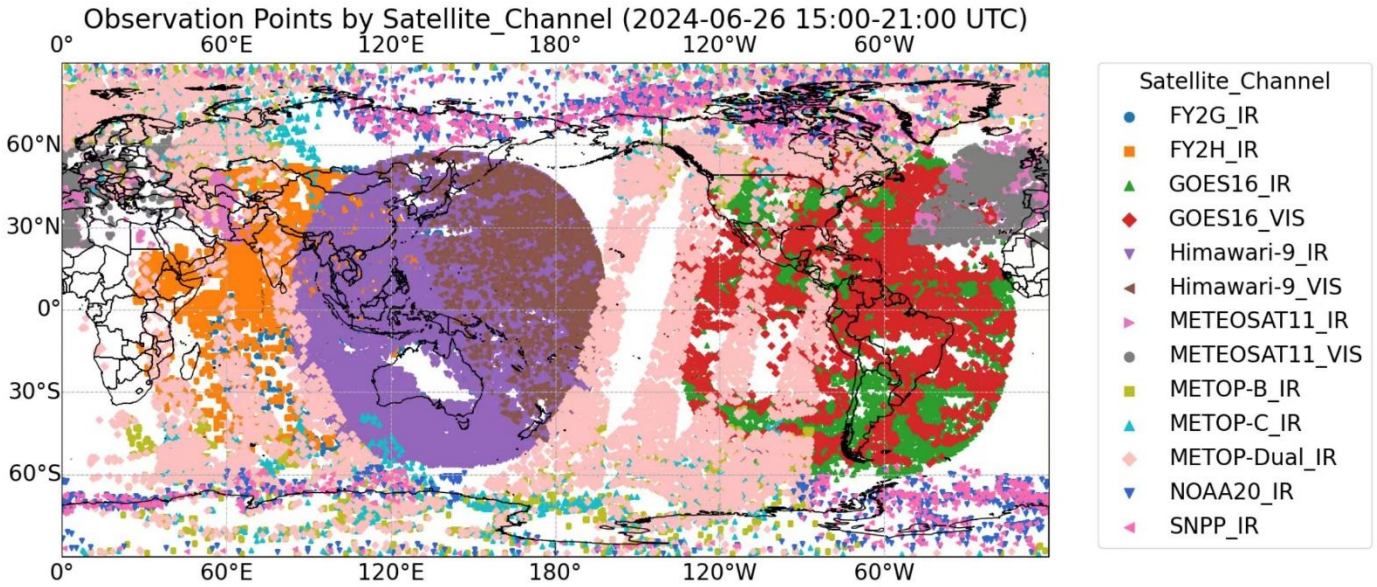


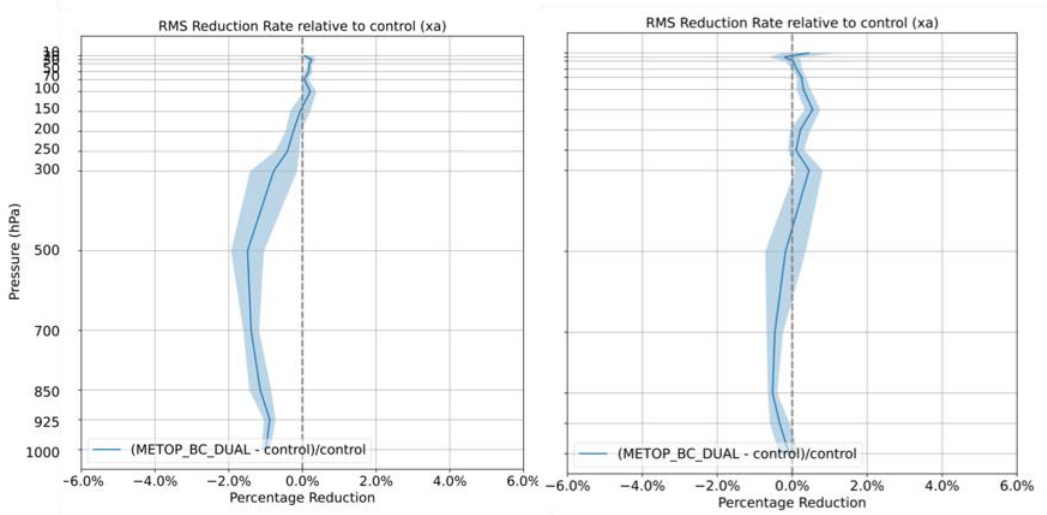
Morning/Afternoon/Early morning Orbits

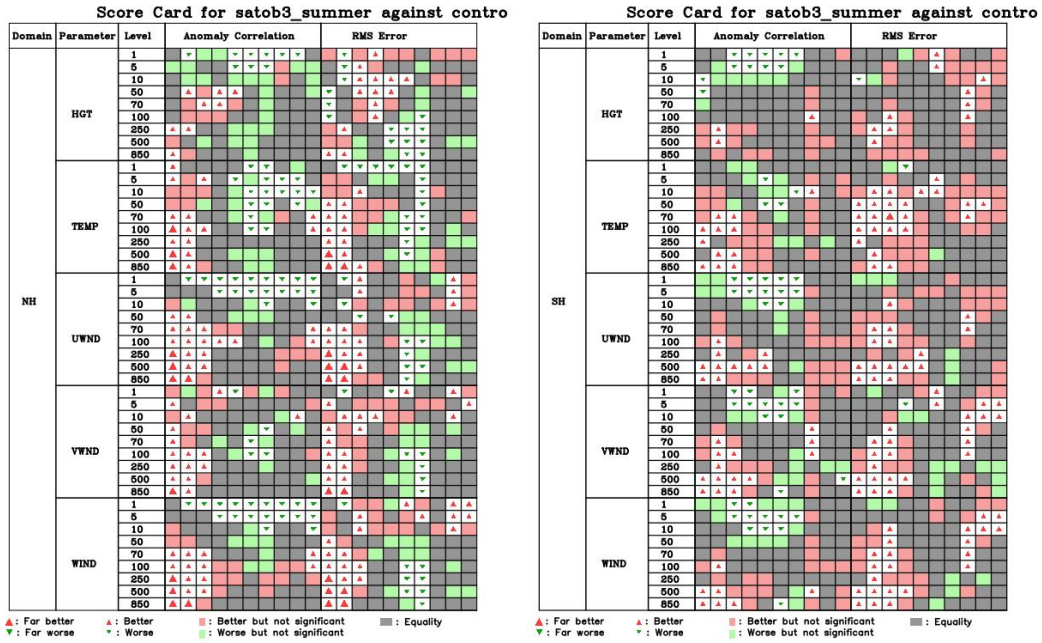


Forecast fields

Recent Upgrades: AMV



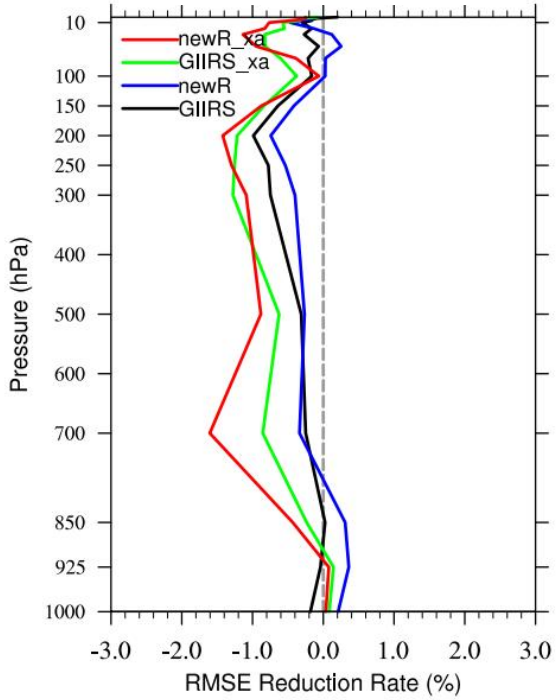


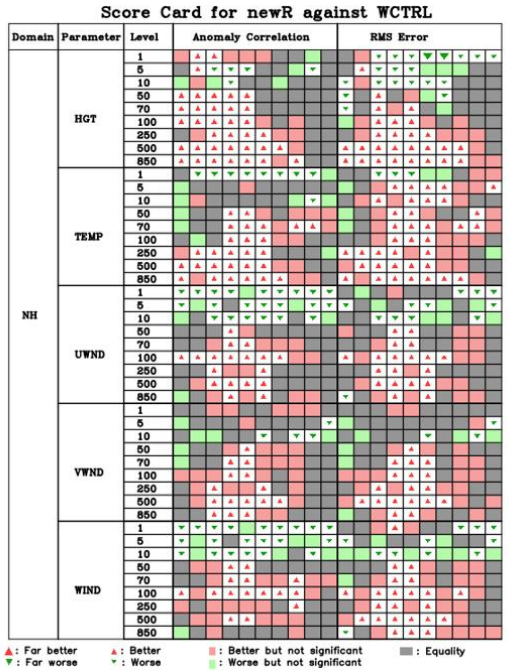


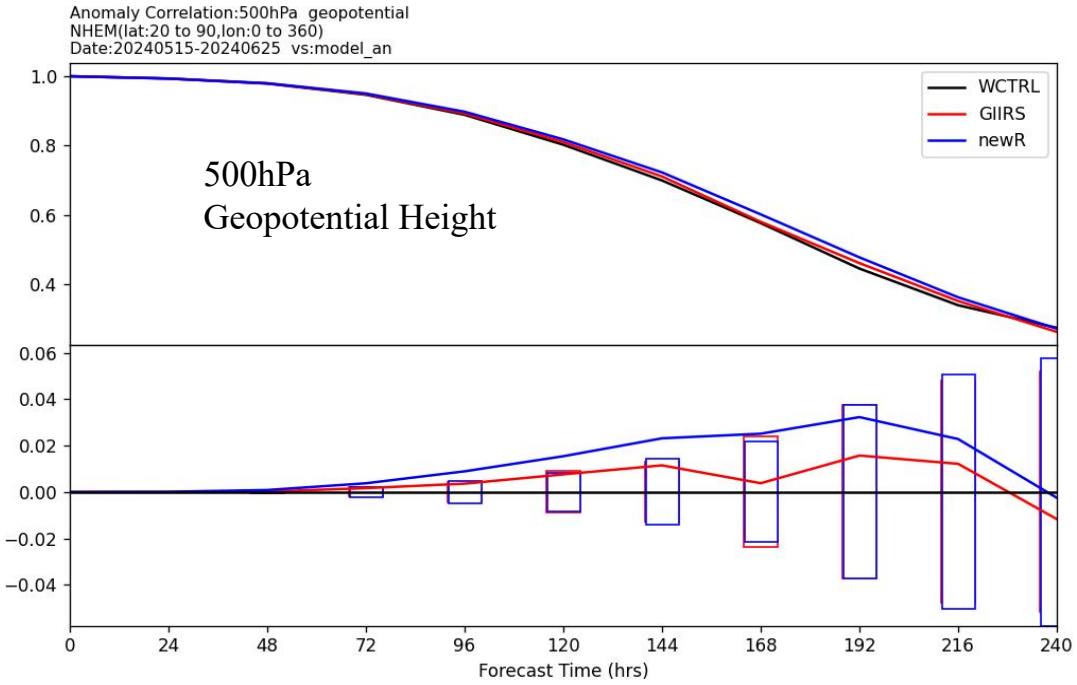
- Newly assimilated **dual-satellite AMVs** from METOP-B and C in 2025
- Provide **broader global coverage** than GEO and single polar-orbit AMVs
- Reduce wind analysis errors in the mid–lower troposphere
- Improve forecasts of tropospheric variables within 0-3 forecast days

Recent Upgrades: FY-4B GIIRS

potential height



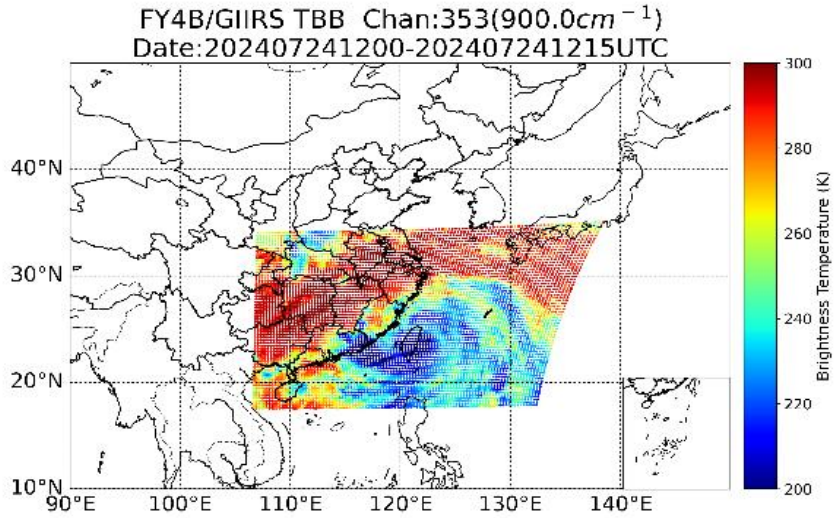




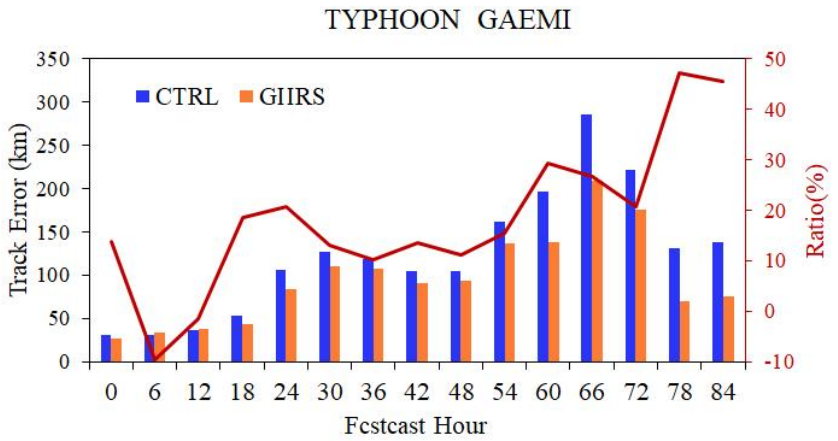
- The operational assimilation of FY-4B GIIRS (66 channels) has been realized in December 2024, improving the potential height analysis field and prediction field.
- The assimilation results is better when using the optimal inflation factor of observation error.

Targeted observetion for Typhoon using GIIRS

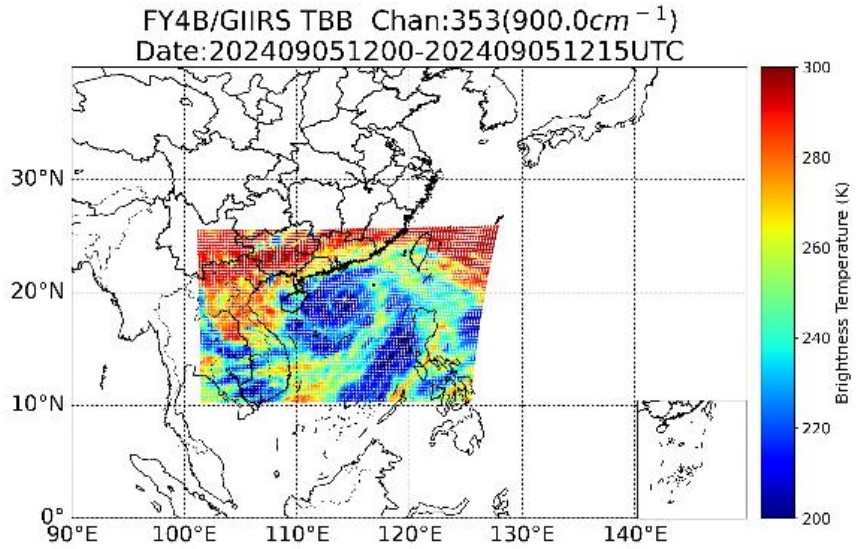
Gaemi



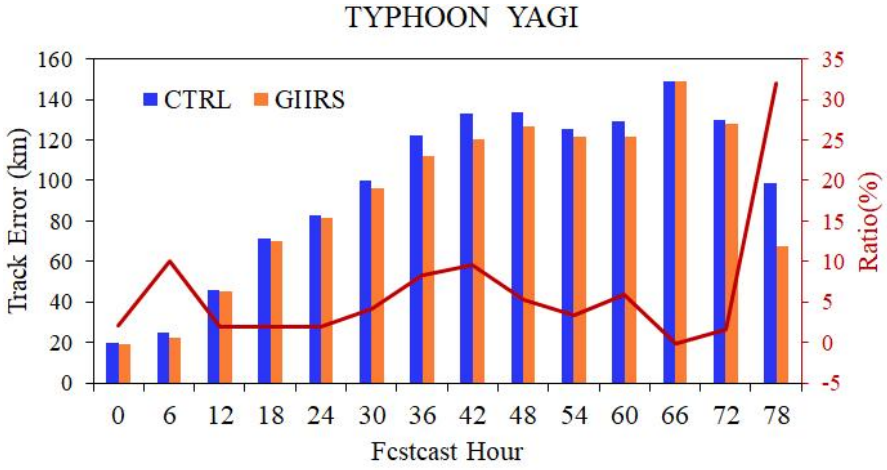
Track error was improved by **22.5%** through averaging four forecasts



Yagi



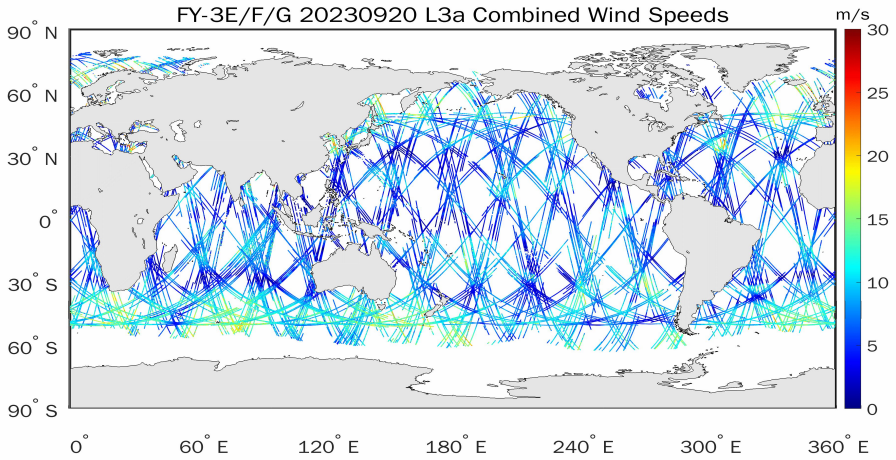
Track error was improved by **6.3%** through averaging five forecasts

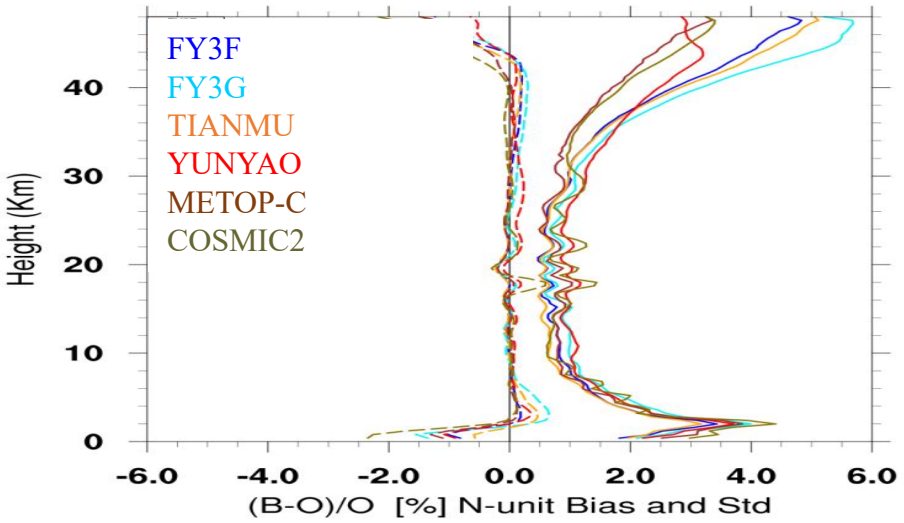


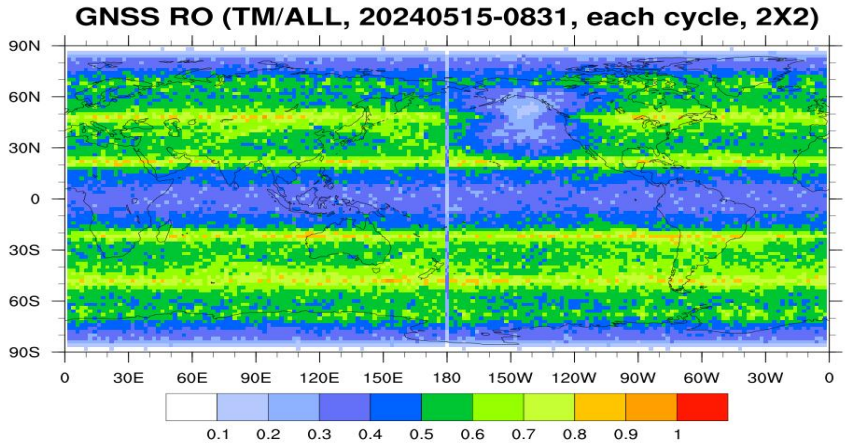
For two super typhoon cases in 2024, the assimilation of FY-4B GIIRS targeted observations improved track forecasts.

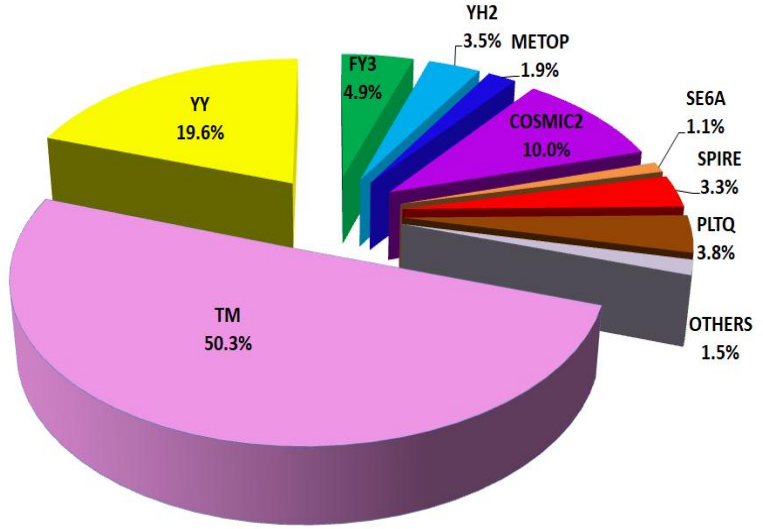
Recent Upgrades： RO

In CMA-GFS, the number of radio occultation profiles assimilated within each 6-hour time window exceeds 13,000, among which commercial RO account for more than 70%.

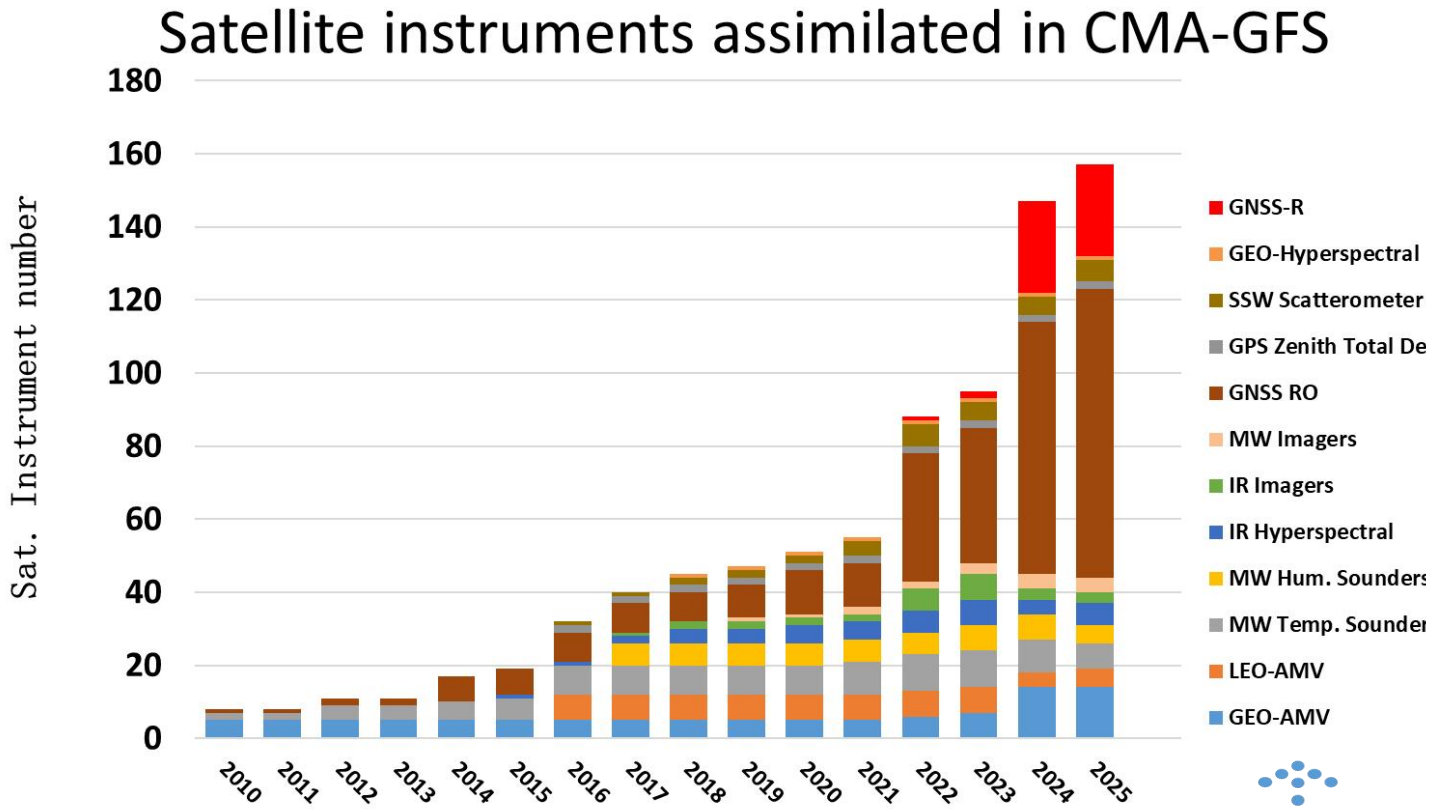


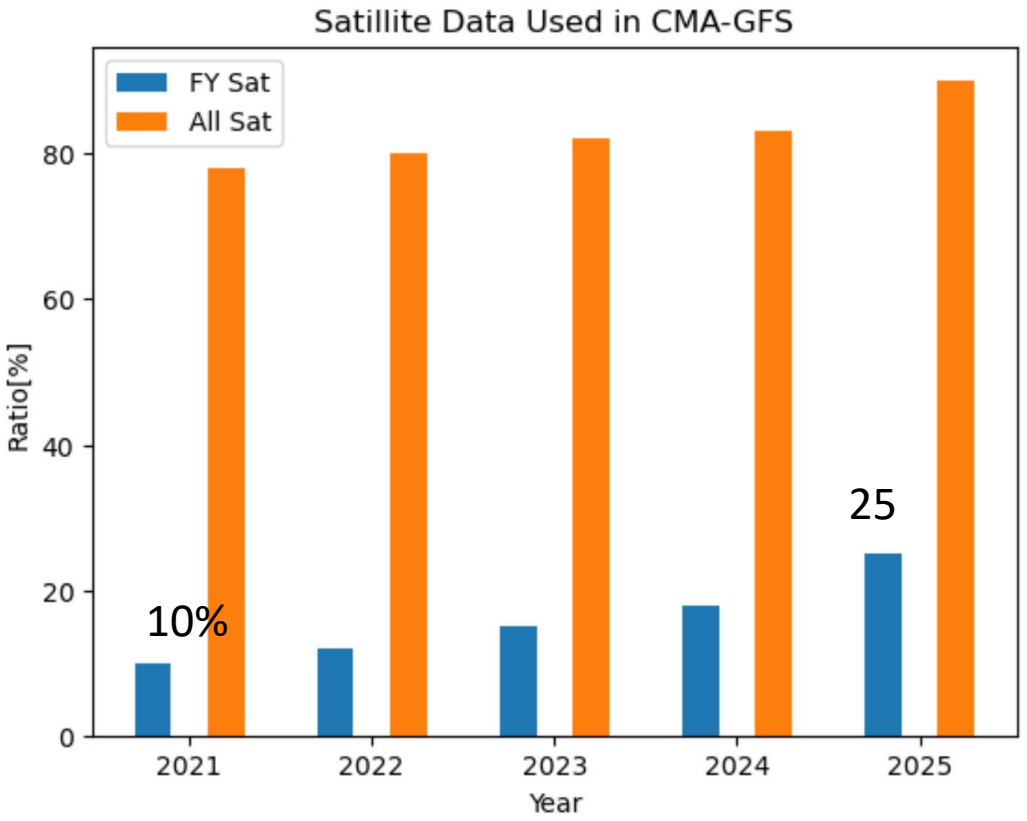


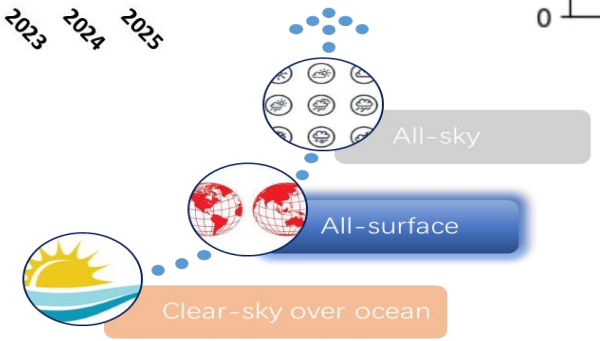




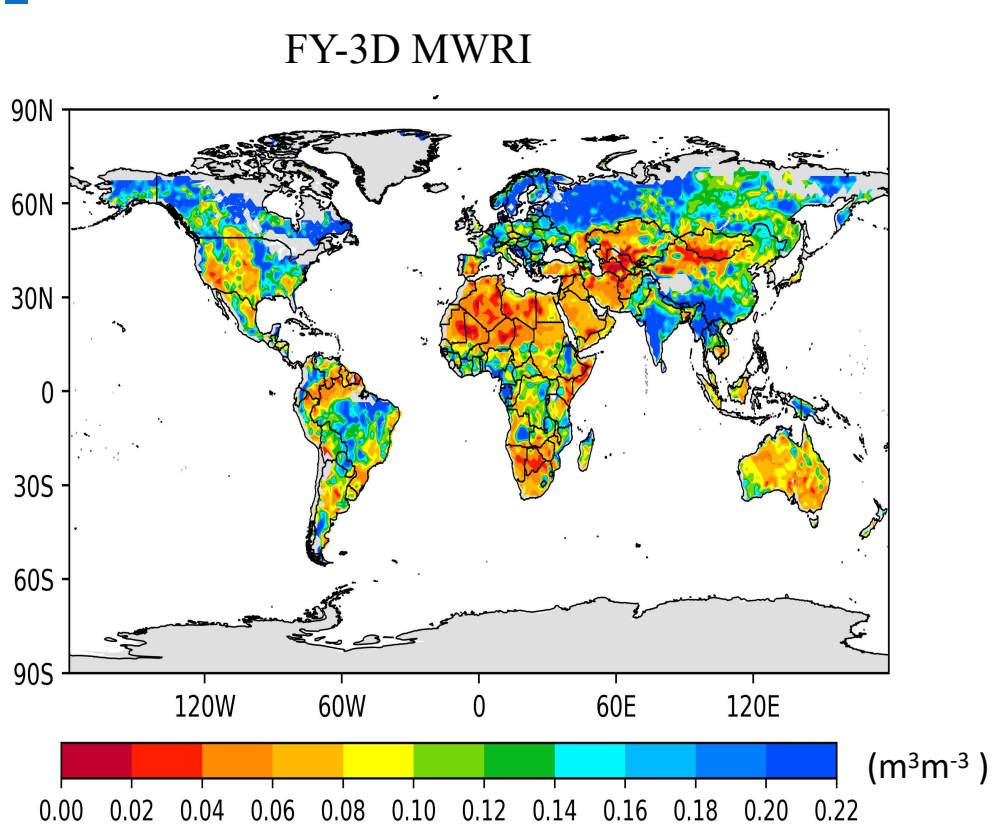
Recent Upgrades: Sats Used

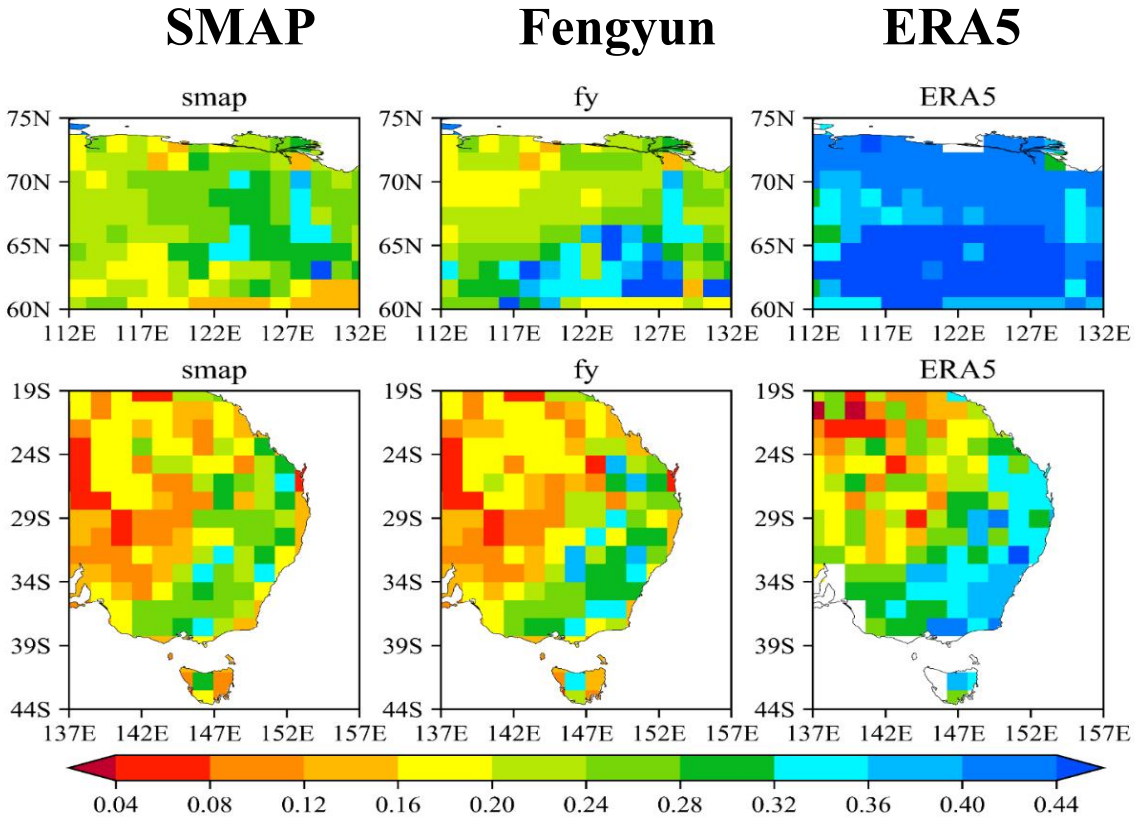






Assimilation of Fengyun soil moisture products

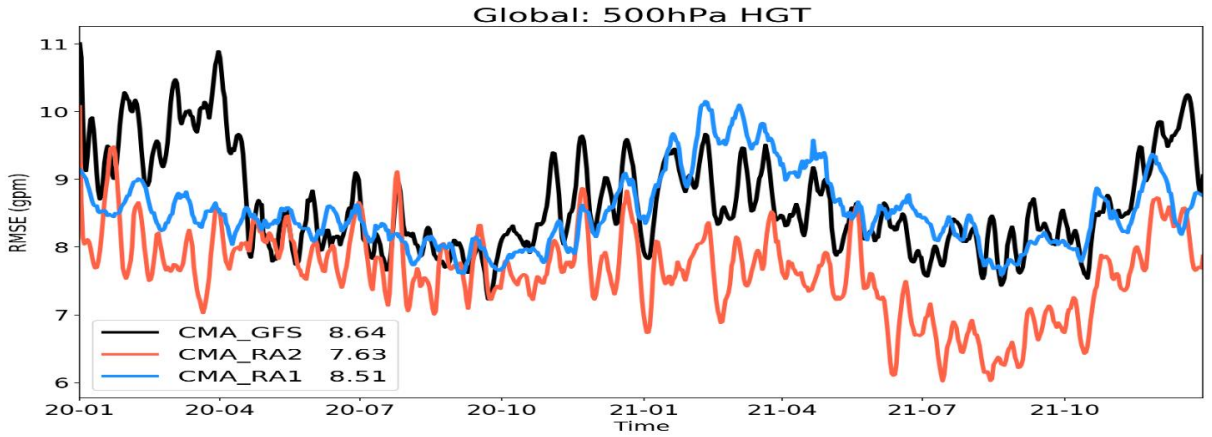




- The FY product assimilation prediction experiment can effectively predict high humidity areas that occur between 60-65°N.
- The FY product assimilation prediction experiment has a significantly better prediction effect on high soil moisture areas in eastern Australia than the SMAP product assimilation prediction experiment.

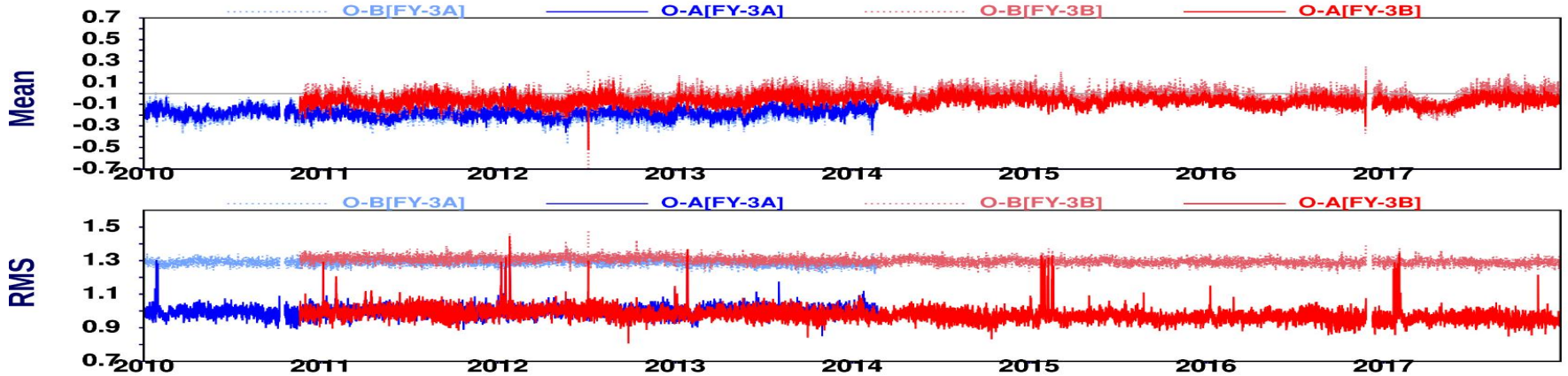
Satellite Data Assimilation in CMA-RA2

- Optimize the application of satellite observation data in reanalysis, develop a 2nd generation global reanalysis product with better quality than the 1st generation.



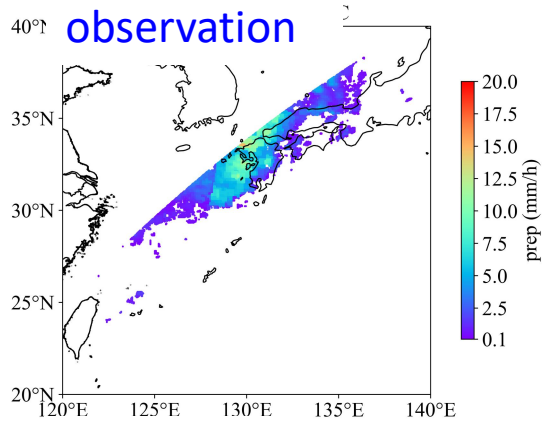
1ST generation (8.51)

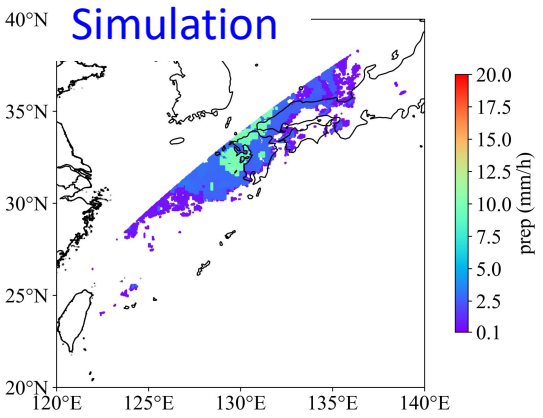
2nd generation (7.63)



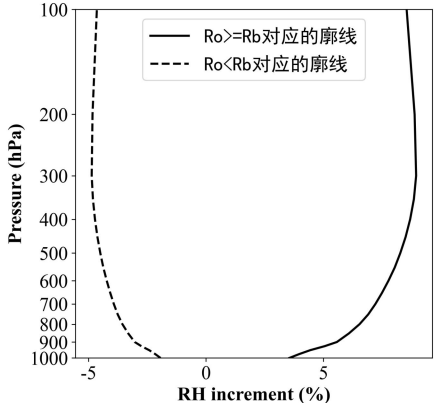
Future Developments: FY-3G Precipitation

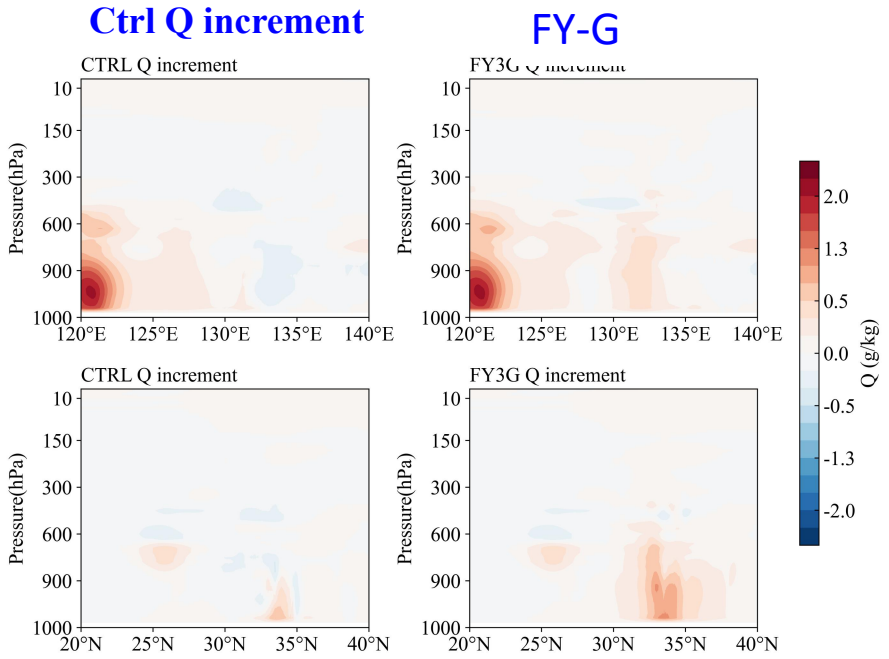
ML-based operator → 1DVar +3D Var assimilation → Forecast Validation

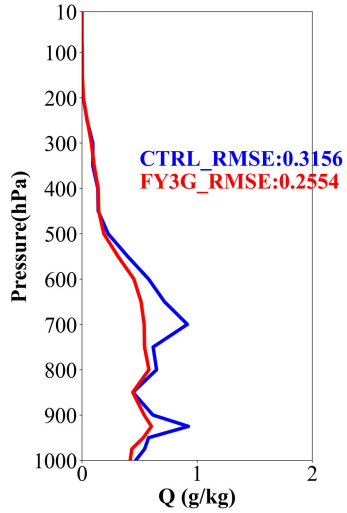


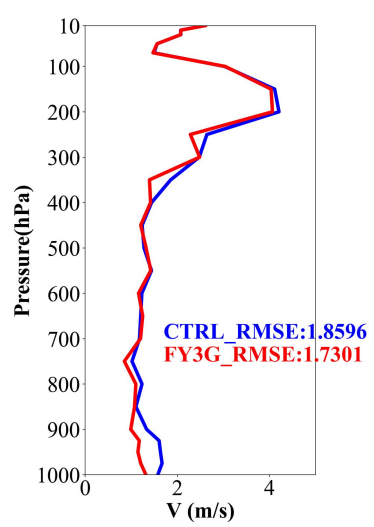


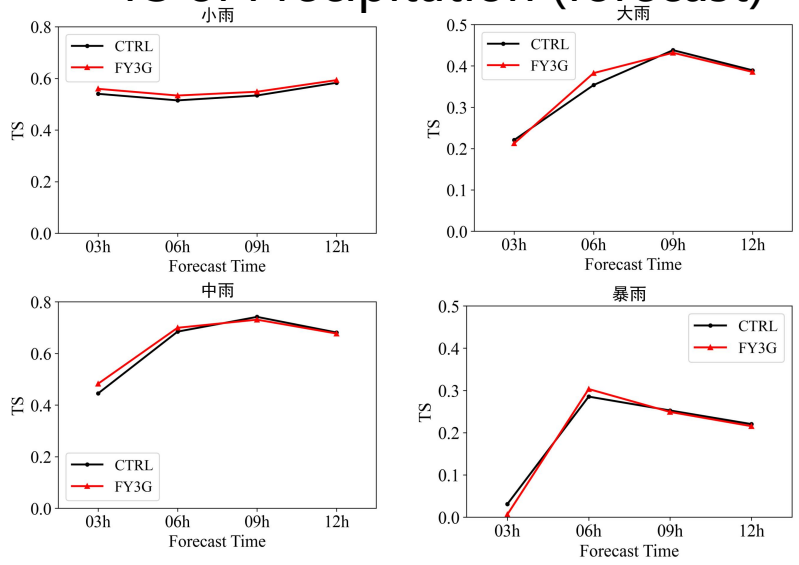
P range	MB	MAE	RMSE
<1.5	-0.05	0.3	0.37
1.5-7	0.48	1.12	1.54
7-15	0.44	1.8	2.2
>15	-2.31	7.42	9.29
all	-0.04	0.64	1.45





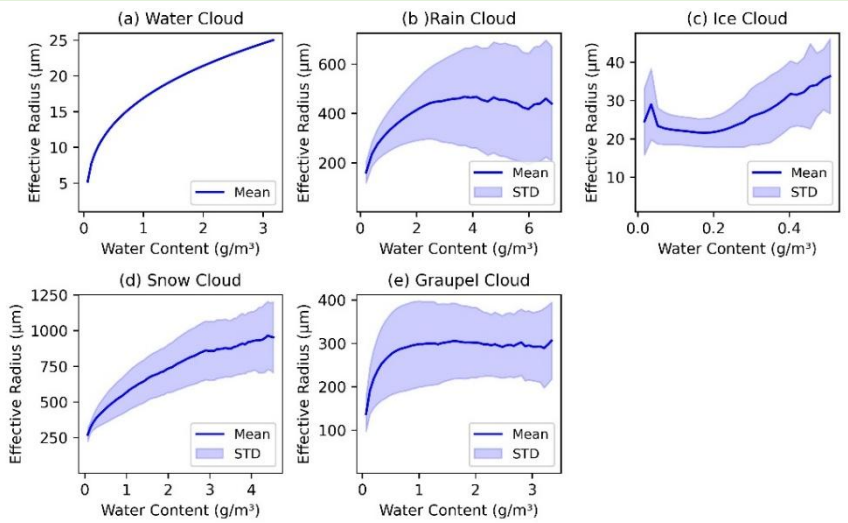


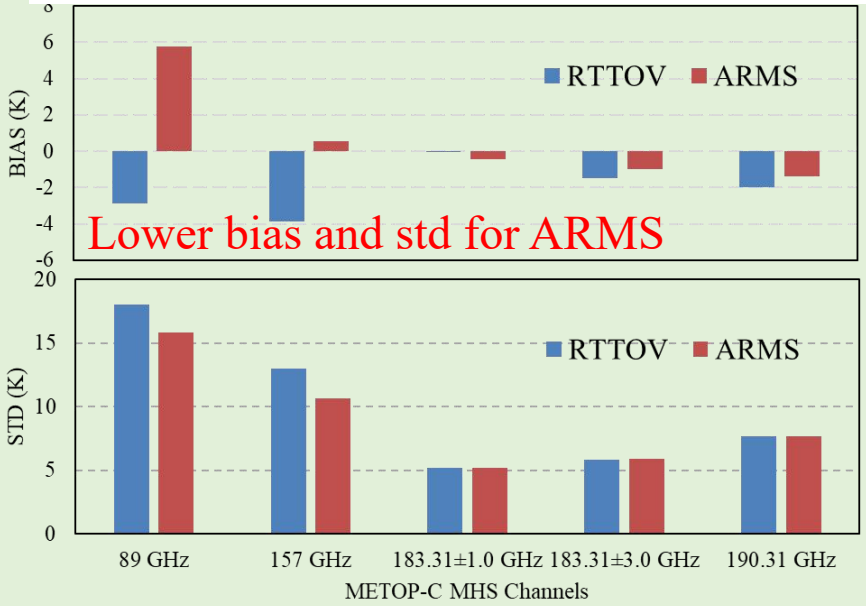




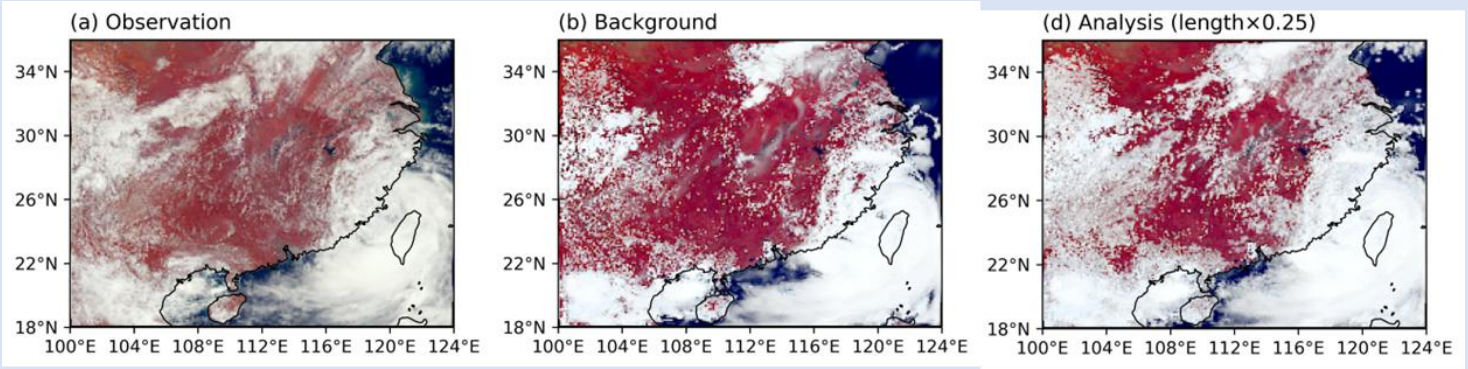
All Sky Assimilation

Consistency of cloud microphysics assumption between ARMS and NWP scheme.





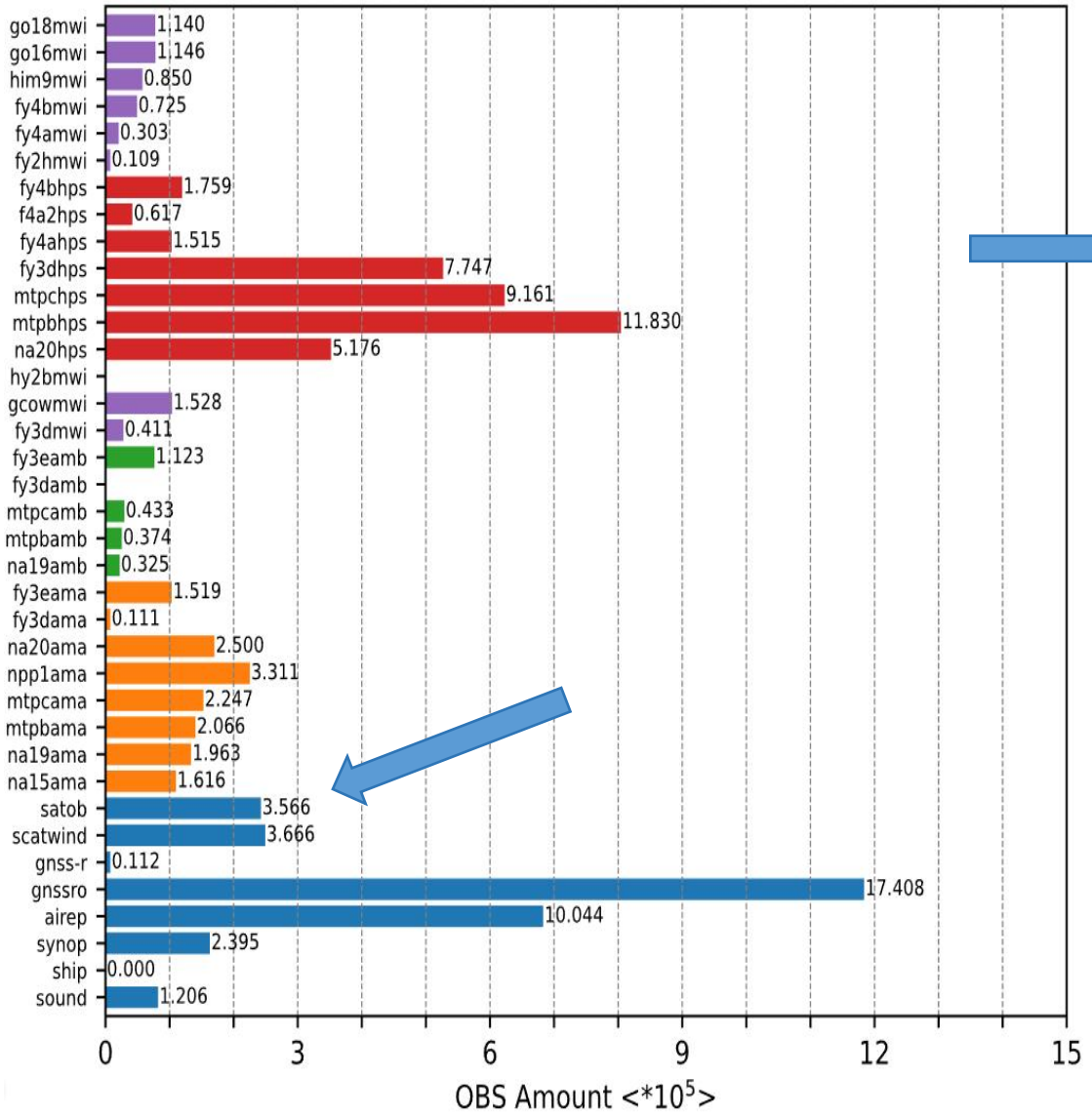
Good results were obtained from experiments using all-sky observations from the microwave and visible spectrum.



Future Plans:

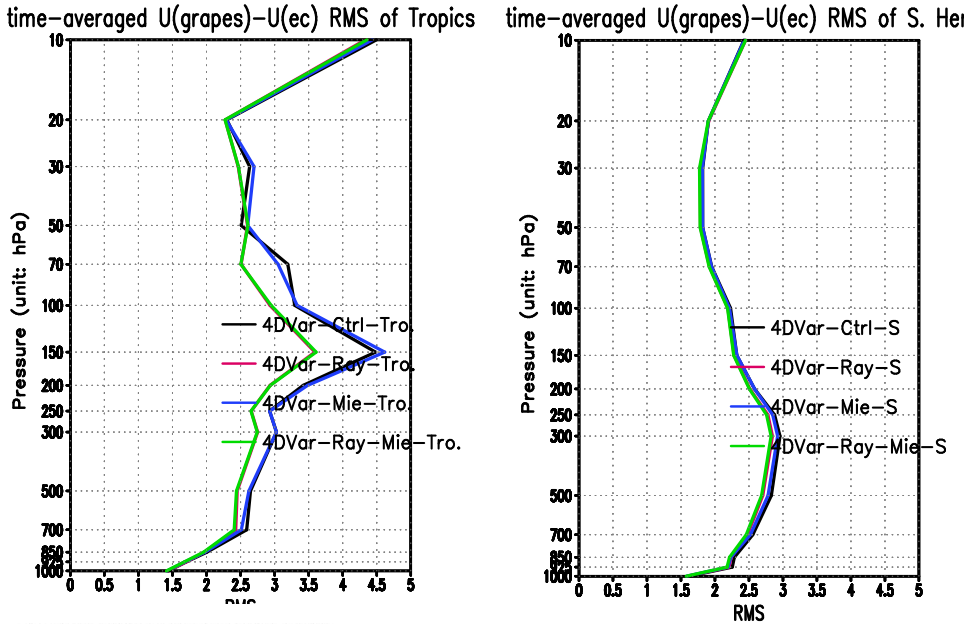
- Consider the impact of non-spherical particle scattering in radiation transfer models to further improve scattering simulation capabilities.
- Expand all-weather assimilation tests from regional models (1km spatial resolution & hydrometer control) to global models (12.5km spatial resolution & no hydrometer control).
- Further research is needed to address uncertainties in visible band assimilation.

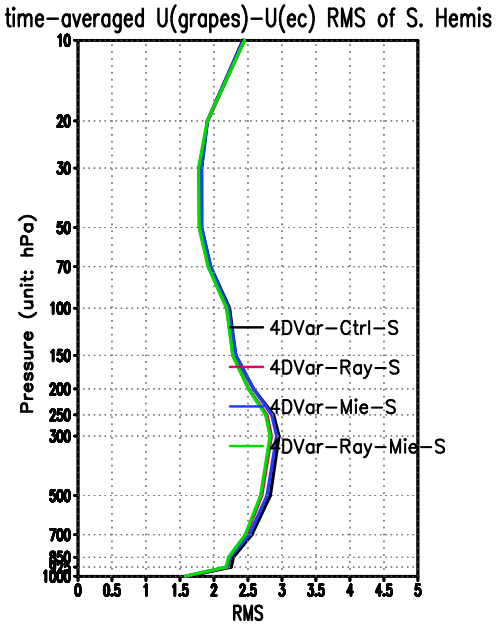
Satellite Data Used in CMA Model

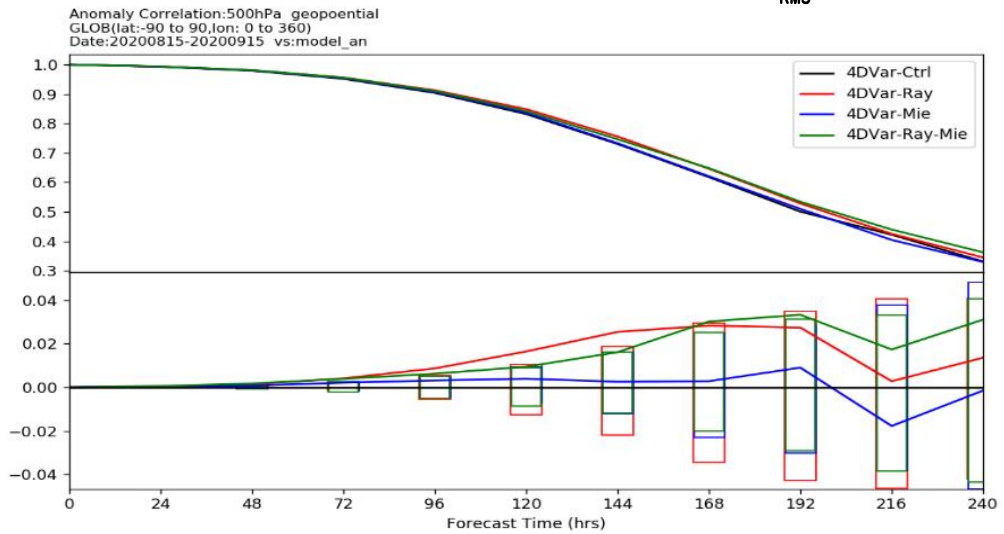


Requirement: Winds

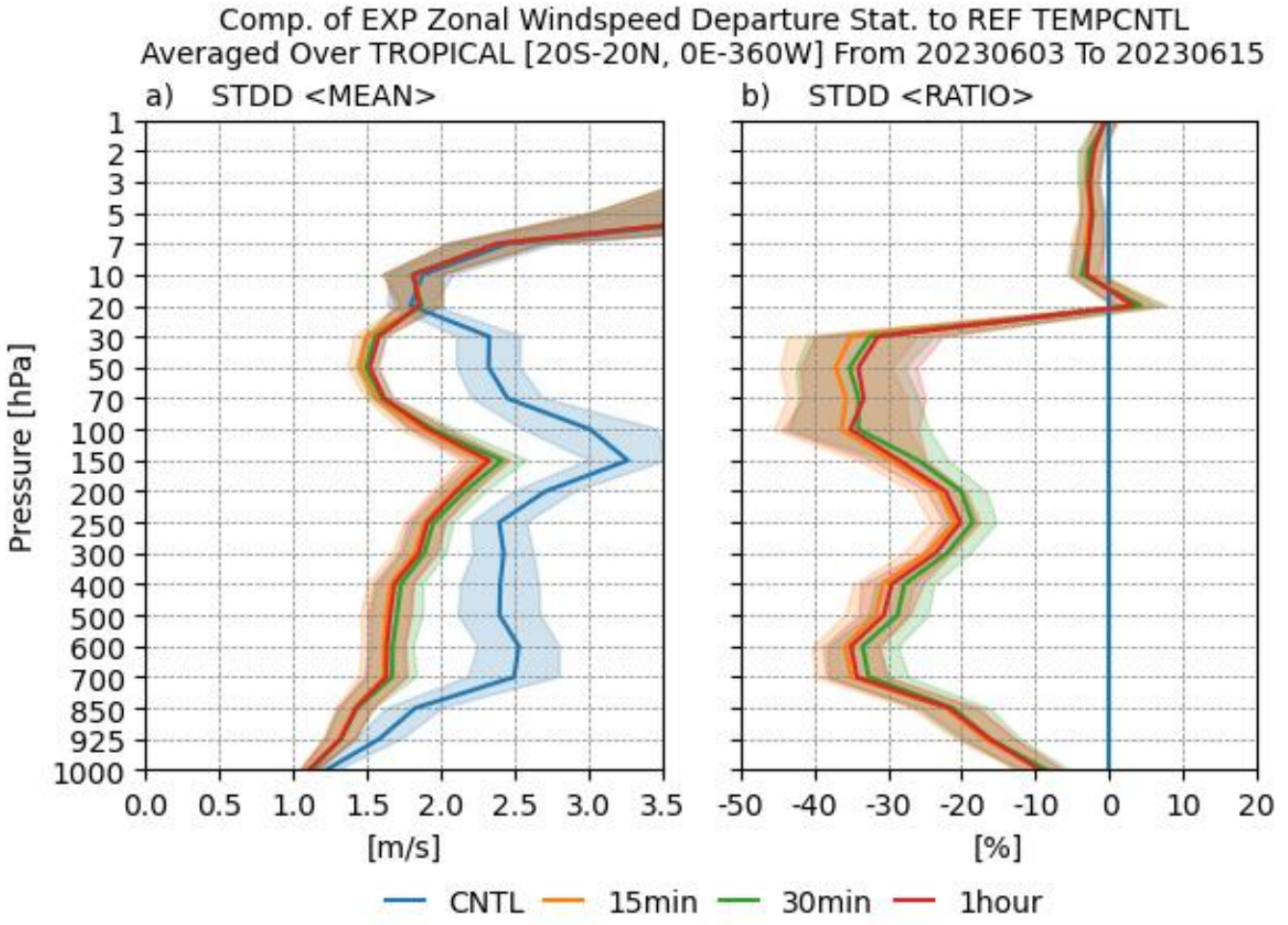
ALADIN Results







OSSE Results



Summaries

- **En4DVar** has the advantage of using the ensemble information to provide flow-dependent background error variances and has a better performance, which has replaced 4DVar in CMA-GFS.
- Benefit from the operational application of ARMS, **Fengyun satellites data assimilation** is becoming increasingly popular in CMA-GFS, the ratio FY data used to total data is increased from 10% to 25% in the past 5 years.
- In the CMA-GFS, some **new assimilation techniques** have been operationally applied, including resampling of the upper-level channels, anchoring of the upper-level errors, a smaller radius for satellite data thinning, assimilation of all-surface data, etc.
- The application of Fengyun satellites in Earth system models has gradually started, but the **coupling assimilation** of satellite data still **urgently requires** the development of available coupling assimilation observation operators.
- For CMA-GFS, the current satellite observation system is far from saturated, and the wind data is highly required.

Thanks For Your Attention!