The 40th annual meeting of the Working Group on Numerical Experimentation (WGNE)

WGNE40: Updates in the CMA NWP system and a unified MCV-based model system

Xingliang Li

CMA Earth System Modeling and Prediction Center (CEMC)

Beijing, China

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Contents

- Updates of operational NWP system
- Progresses in a unified next-generation MCV-based model
- Summary

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- Updates of operational NWP system
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CMA-GFS V4.2 update

- CMA-GFS V4.2 has been in operation since December 31, 2024.

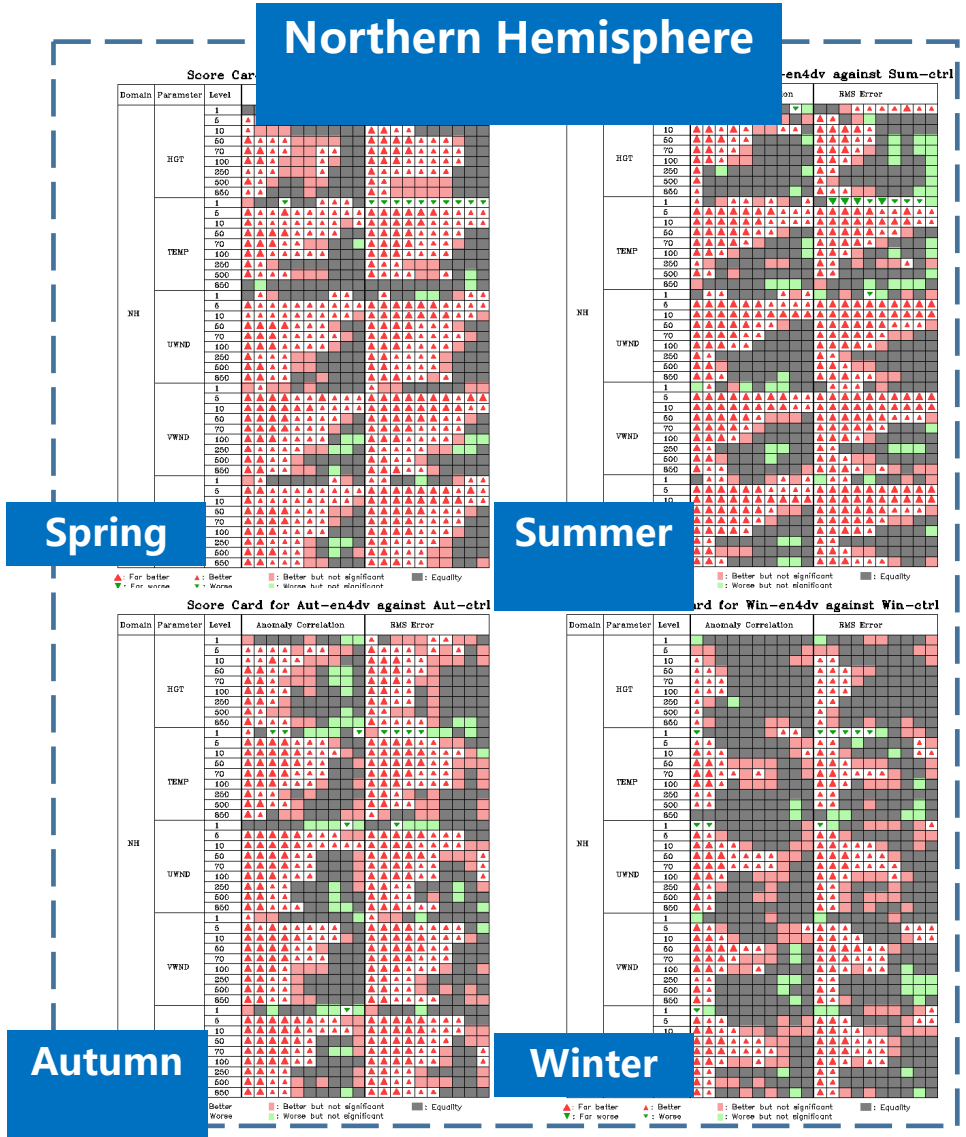
Upgrade CMA-GFS to V4.2

1. Upgraded 4DVar to Ensemble 4DVar (En4DVar), improving assimilation analysis quality.

2. Enhanced ARMS (Advanced Radiative transfer Modeling System) , enabling assimilation of over 10 types of domestic satellite data (including FY-3E/F/G and FY-4B)

3. Some improvements observed in extended-range heavy precipitation forecasts, with reduced temperature forecast errors during winter.

4. Enhancements achieved in global tropical cyclone track and intensity forecasts.



2025(1): Radiance bias correction method

◘ 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.

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

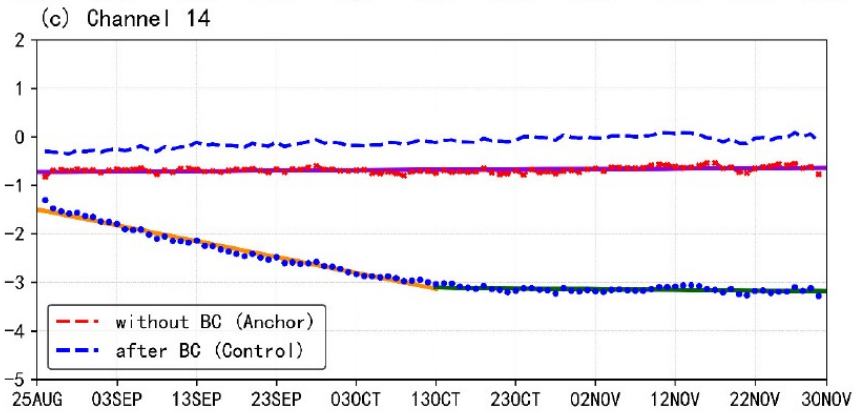


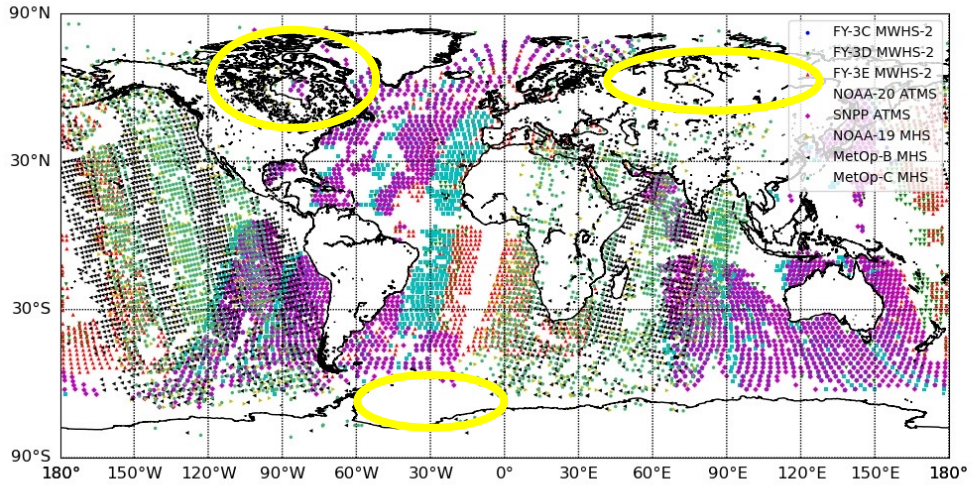
Fig. 6. The same as in Fig. 5 but for the results of the NOAA-19/AMSU-A tendency.

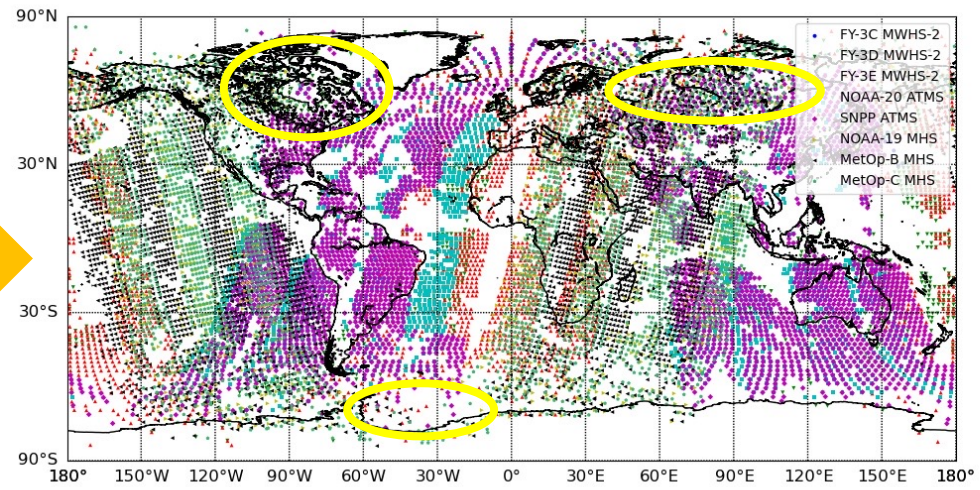
Variational bias correction (VARBC)

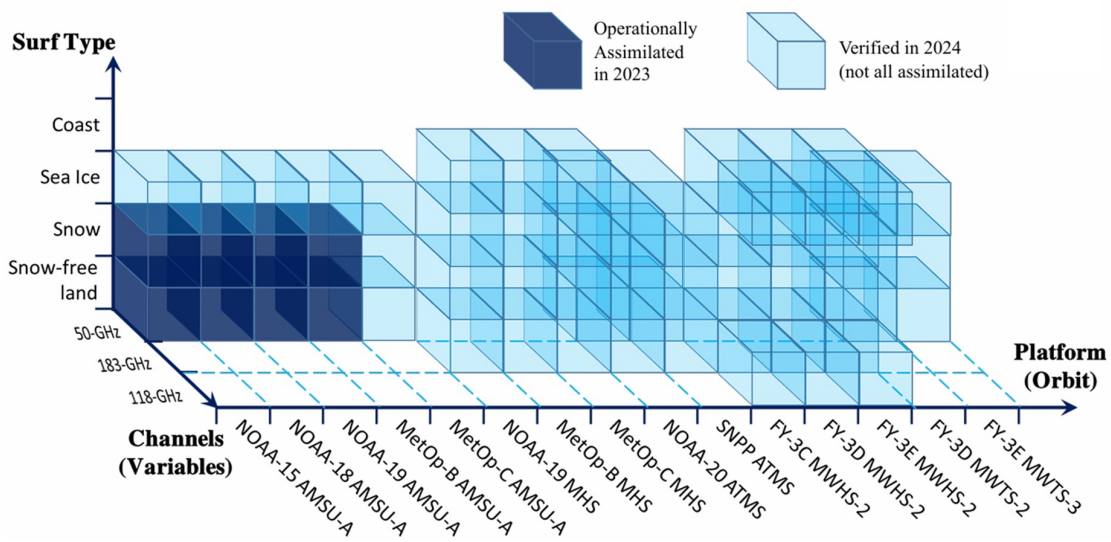
Bias correction terms are incorporated into the cost function minimization, enabling online bias correction within the variational assimilation framework.

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

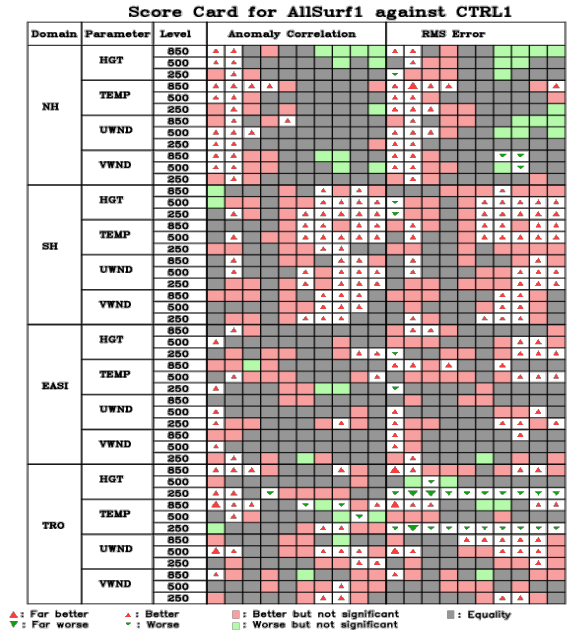
2025(2): Microwave Assimilation over Complex Terrain







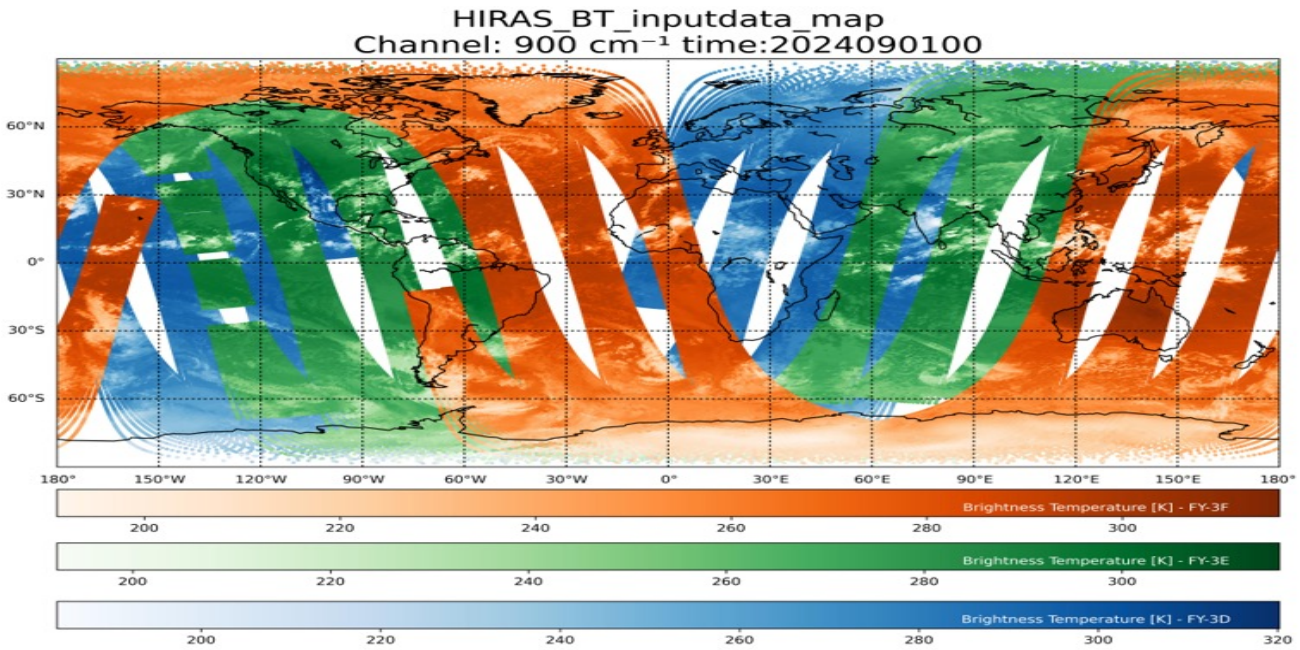
Achieved all-surface assimilation of near-surface microwave observations, improving forecast skill over **land-dominated regions** in the Northern Hemisphere.



2025(3): Newly assimilated satellite observations

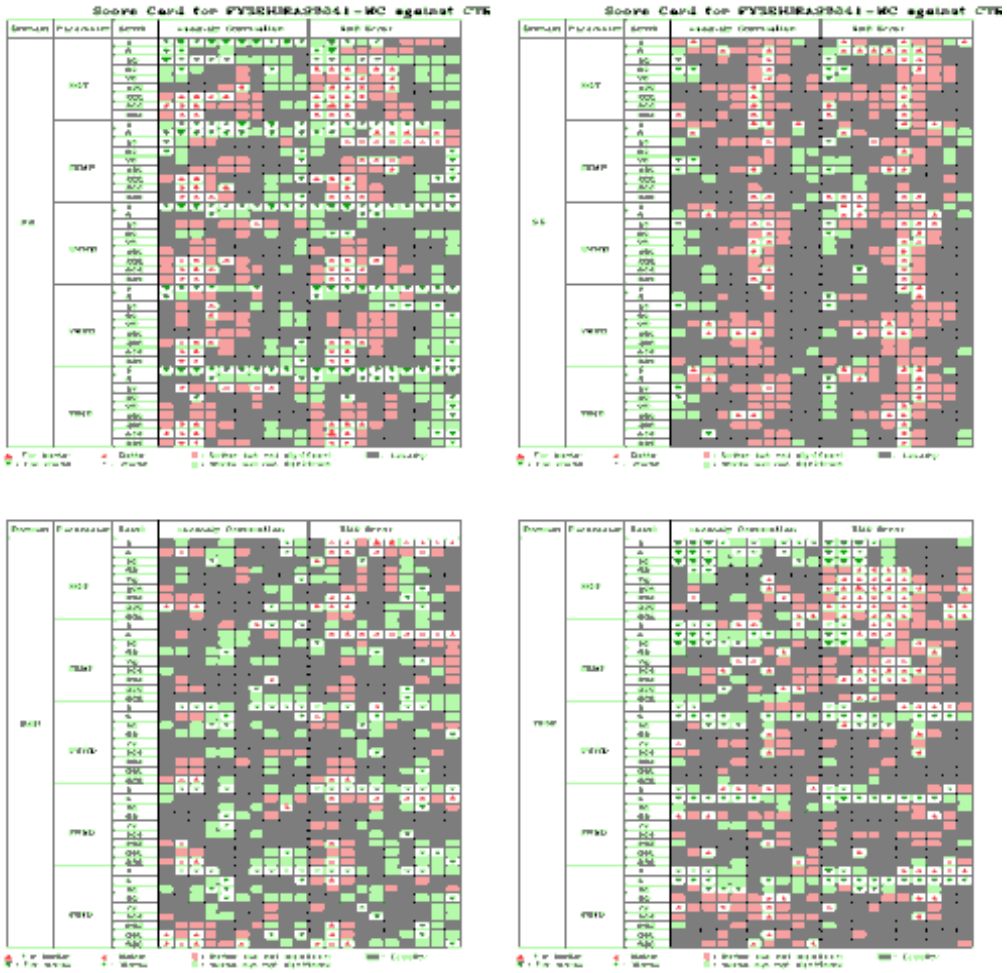
- Data from the three HIRAS instruments (FY-3D/3E/3F) have been operationally assimilated into the CMA-GFS, which **has a positive impact on the forecast fields**.

Morning/Afternoon/Early morning Orbits



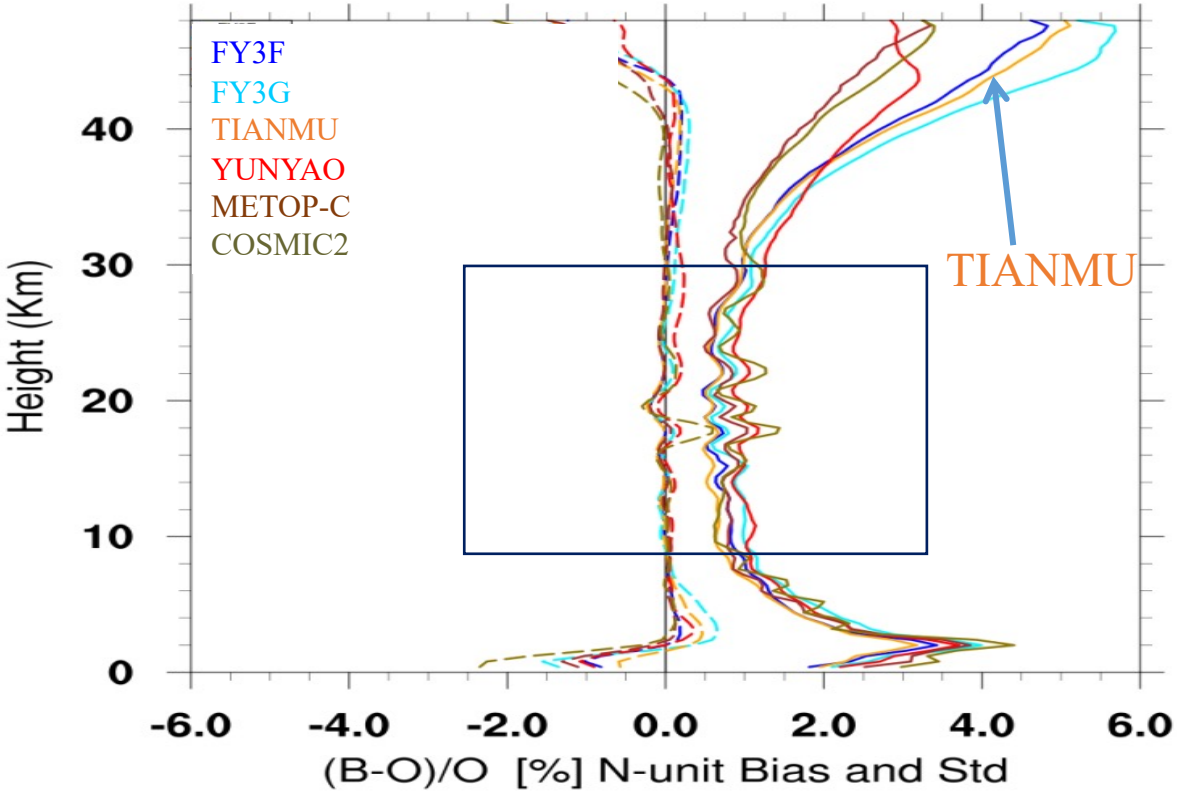
100% global coverage of polar-orbiting satellite data within a 6-hour assimilation window

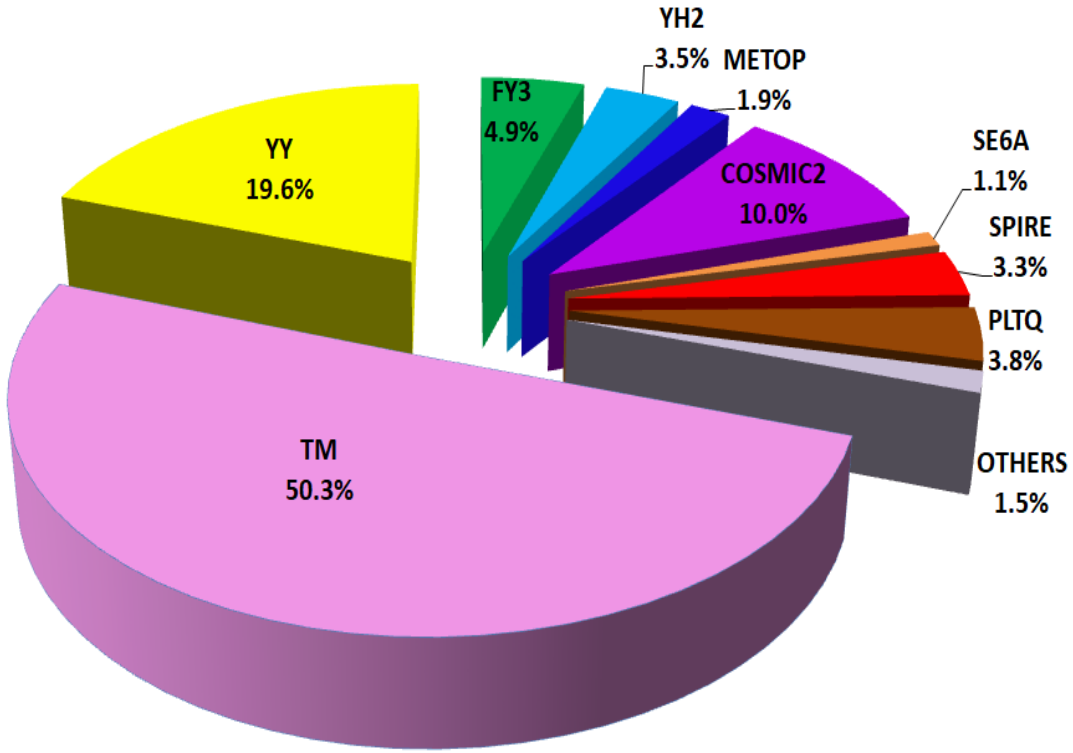
Score card



2025(4): Newly assimilated satellite observations

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%.



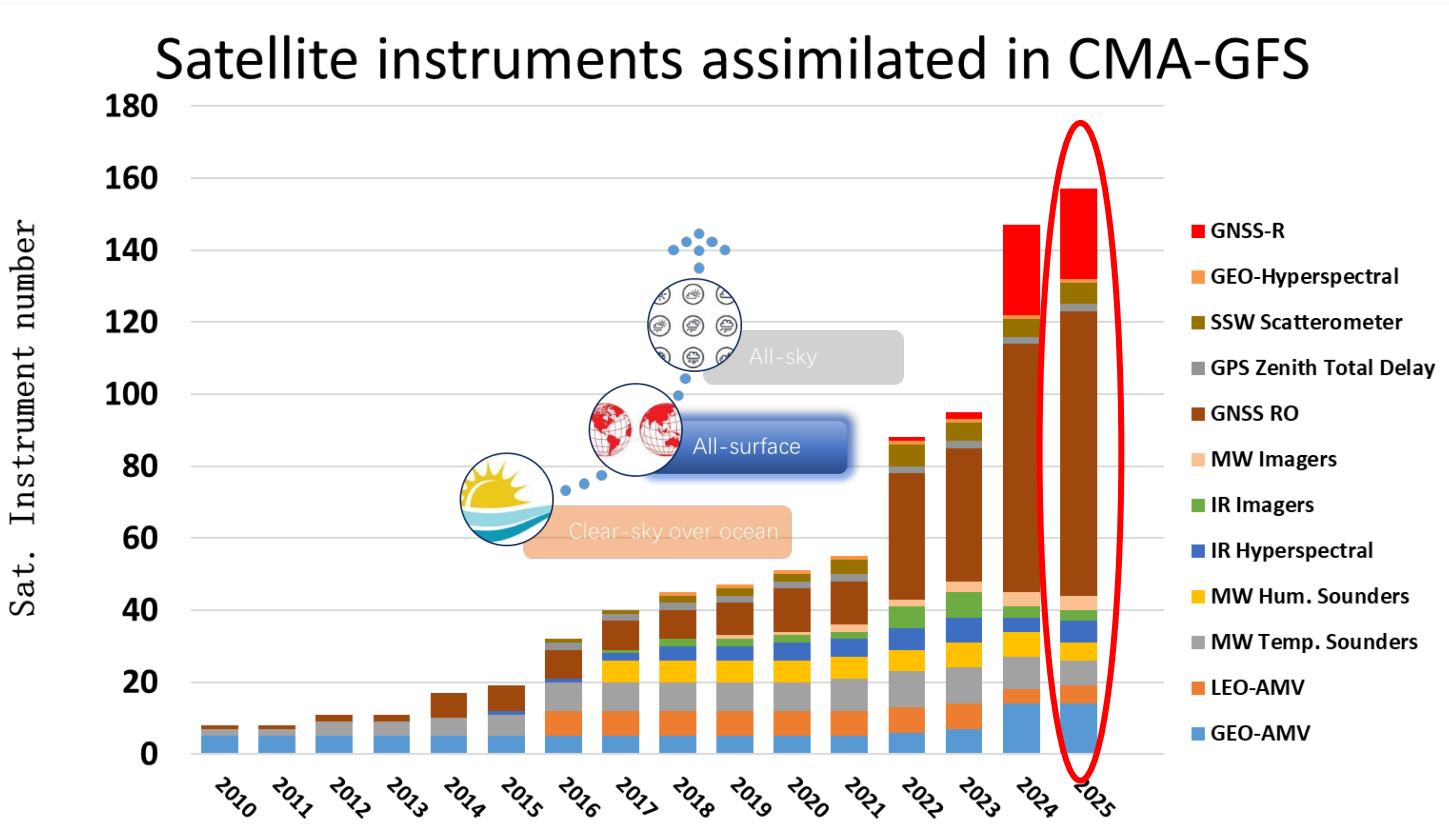


Radio occultation (RO) observations

2025(5): Newly Integrated Instruments

Newly Integrated Instruments

- **FY-3F**: MWTS, MWHS, HIRAS
- **FY-4B**: AGRI, GIIRS
- **FY-3E**: HIRAS
- **GPM**: GMI
- **GNSS-R/RO**: YUNYAO & TIANMU
- **NOAA-21**: CrIS
- **METOP**: AMV



Satellite information percentage from **83%** (2024) to **88%** (2025) in China (**94%** at ECMWF).

CMA-GFS V4.2.3 update

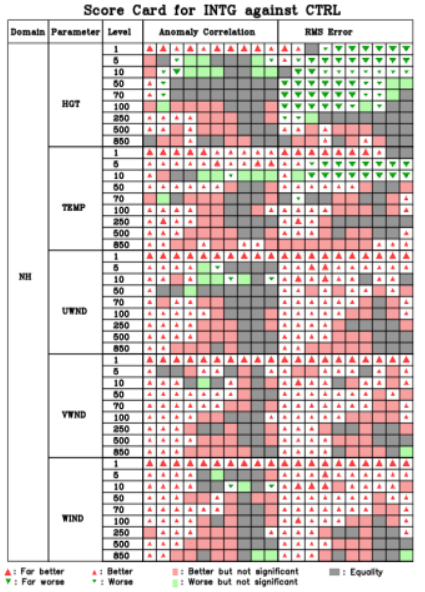
- CMA-GFS V4.2.3 has been in operation since August 13, 2025.

Northern Hemisphere: The RMSE of the height field increases, while other variables show positive effects.

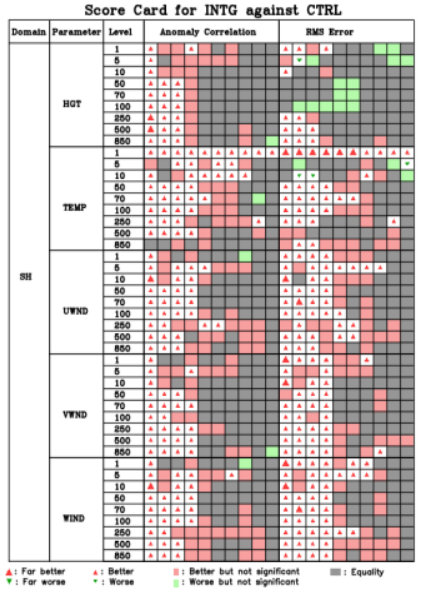
Southern Hemisphere: Forecasts for the first 4 days exhibit a neutral-to-positive contribution.

East Asia: The height field shows a neutral-to-negative trend, and other variables have a neutral impact.

Tropics: The ACC of the height field improves, but the RMSE increases. Other variables above 50hPa show a neutral-to-positive contribution.



NH



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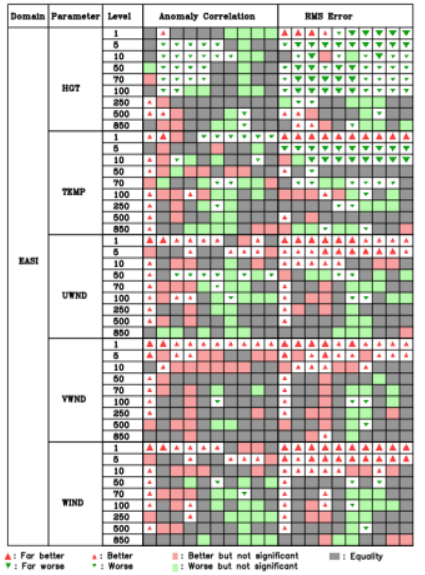
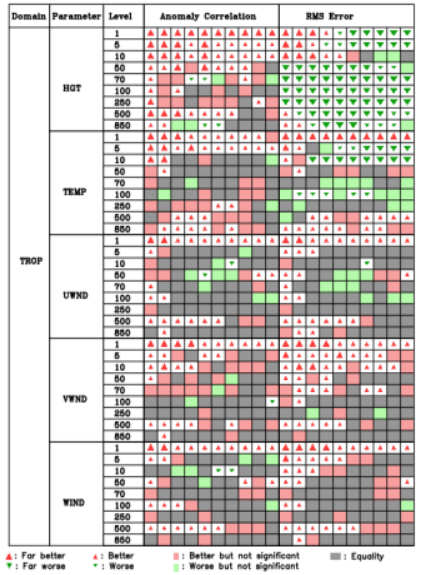


EA



Tropics

Updates of CMA-MESO

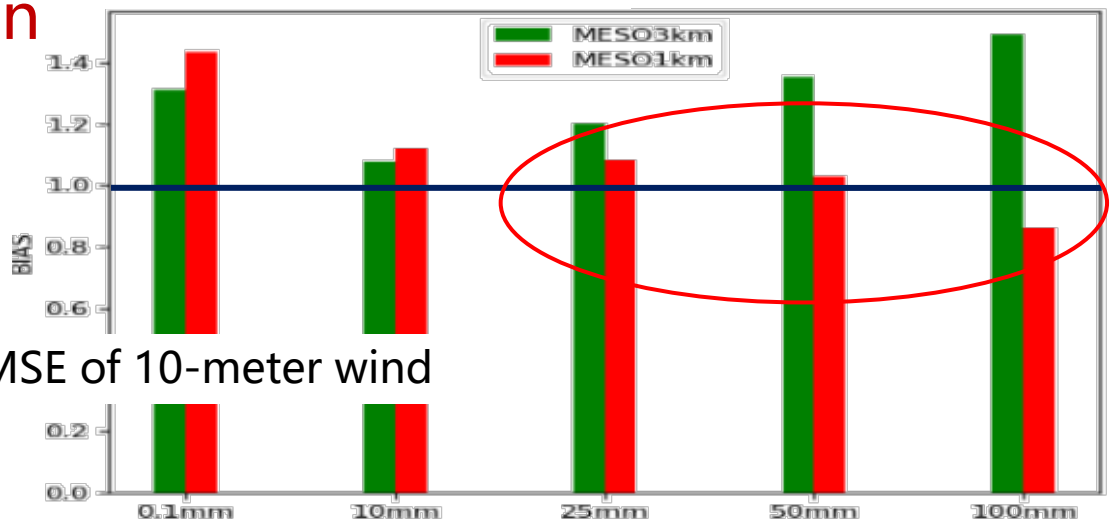
- CMA-MESO V6.0 has been in operation
  (October 19, 2024)

Upgrade CMA-MESO to V6.0

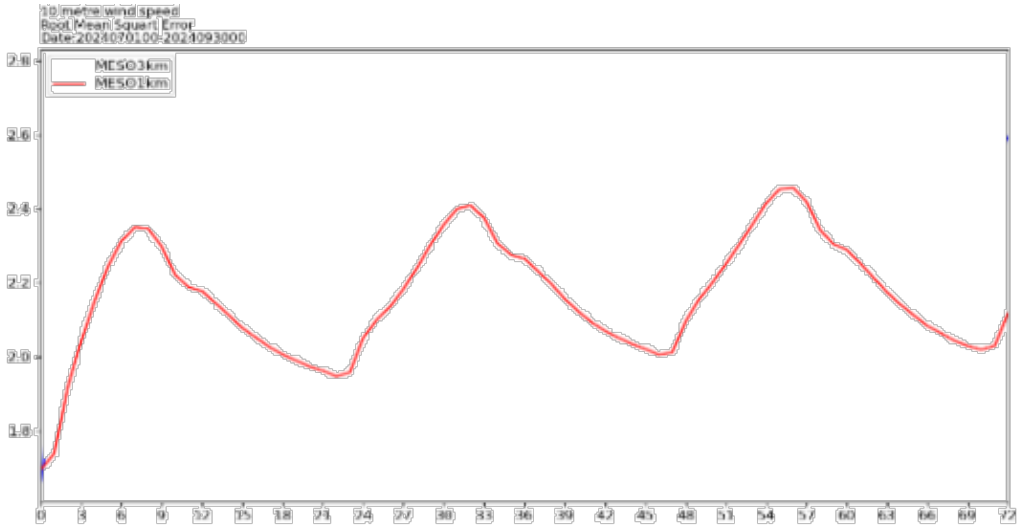
The proportion of radar data has reached 90%, and the computational efficiency has increased by more than double. The forecasts of precipitation, 2-meter temperature, and 10-meter wind have been improved.

CMA-MESO V6.0: 1km1h cycle

Precipitation Bias Score



RMSE of 10-meter wind



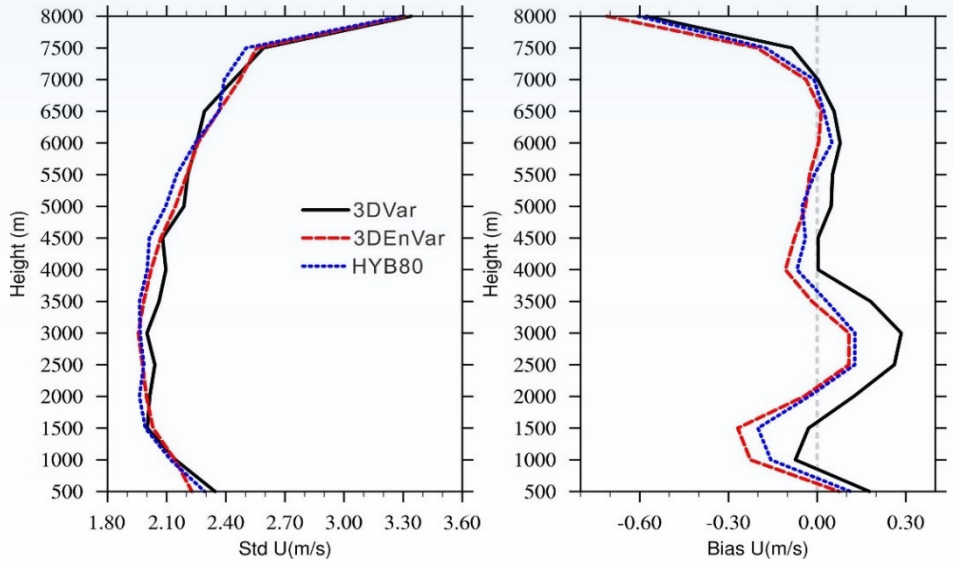
CMA-MESO 1km-EnVar System

1. **Developed EnVar and upgraded to 1km version:**
   - Based on CMA-MESO V6.0
2. **Tests with ensemble samples from different sources:**
   - including downscaled global EDA and regional ensemble forecasts
   - comparable performance
3. **Conducted one-month assimilation cycle test:**
   - EnVar outperformed the 3DVar approach

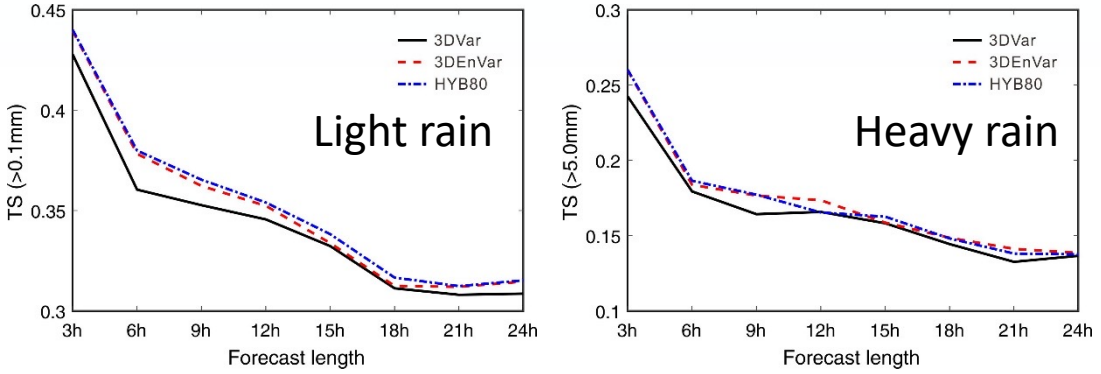
One-month DA cycle test (using global EDA samples)

test name	B_{static}	B_{ens}
3DVar	100%	0
3DEnVar	0	100%
HYB80	20%	80%

3h wind forecast against Wind Profile Radar Obs



TS Scores for 3h cumulative rainfall forecasts



Updates in CMA-GEPS

Component	Operational GEPS V1.3	Integrated 25km- GEPS
model Version	CMA-GFS V3.3	CMA-GFS V4.0
Initial analysis	GRAPES-4DVar (0.125°x0.125°; 87 levels)	GRAPES-4DVar (0.125°x0.125°; 87 levels)
Initial perturbations	Singular Vector-based perturbation	Combination of SVs-based perturbation and EDA perturbation
Model uncertainty	SPPT and SKEB	mSPPT
Horizontal Resolution	0.5°x0.5°	0.25°x0.25°
Vertical resolution	L87	L87
Daily frequency	00 and 12UTC	12UTC
Forecast length of EPS	15 days	15 days
Ensemble size	31 (30 perturbed members + control)	20 (20 perturbed members + control)

1. Extend targeted area of the computation of SVs over the tropical cyclones(TCSVs)

- Current targeted area: Northwest Pacific Ocean and Northern Indian Ocean
- Extended targeted area: globally up to 6 optimization regions

2. Improvements on initial perturbations by combining two scale SV-based perturbation and EDA-based perturbations

- ☐ Singular vectors components : two scales (2.5 degree and 1.5 degree) over Northern and Southern Hemisphere
- ☐ EDA components: from GFS-En4Dvar members

3 . Upgrade the model uncertainty by using multi-scale SPPT

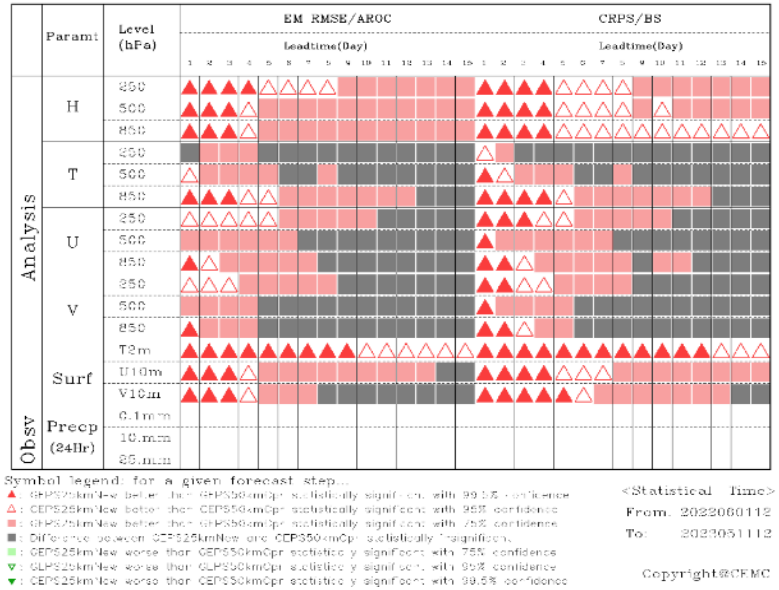
Updates in CMA-REPS

System name	CMA-REPS V3.2 (old system)	CMA-REPS V4.0 (operational system)
Model version	CMA-MESO 4.3	CMA_MESO 5.1
Horizontal Res.	0.1° (10km) , 51layers	0.03°(3km) /51 layers
Forecast domain	10-60° N, 70-145° E	10-60.1°N, 70-145°E
Grid numbers	751*501	2561*1671
Background data	GFS+GEPS	GFS+GEPS
Assimilation analysis	Cloudy analysis	3dvar, Cloud analysis
Initial perturbation	ETKF	Multi-SVs + Observation perturbation
Model perturbation	SPPT	SPPT
Boundary condition perturbation	GFS Background+GEPS Perts. : fixed coefficient	GFS Background+GEPS Perts. : dynamically coefficient
Ensemble members	1 control +14 ensemble members	1 control + 14 ensemble members
Lead time	84 h(00/12 UTC)、6h(06/18UTC)	72h (06/18 UTC)

1. **Improvements on ensemble perturbations**
   - Upgrade initial perturbation by using Hybrid initial perturbations combining multi scale SV-based and obs. Perturbations
   - Upgrade Lateral Boundary perturbations by using Hybrid Lateral Boundary Dynamic Perturbation Technique
2. **Improvements on post-processing procedures to improved the stability of the operational system**
3. **Upgrade resolution from 10km to 3km, use CMA-MESO V5.1 to replace the previous CMA-MESO V4.3**
4. **The CMA-REPS V4.0 system has been operational since January 2025.**

CMA-GEPS Scorecard (May. 2022-May. 2023)

NH



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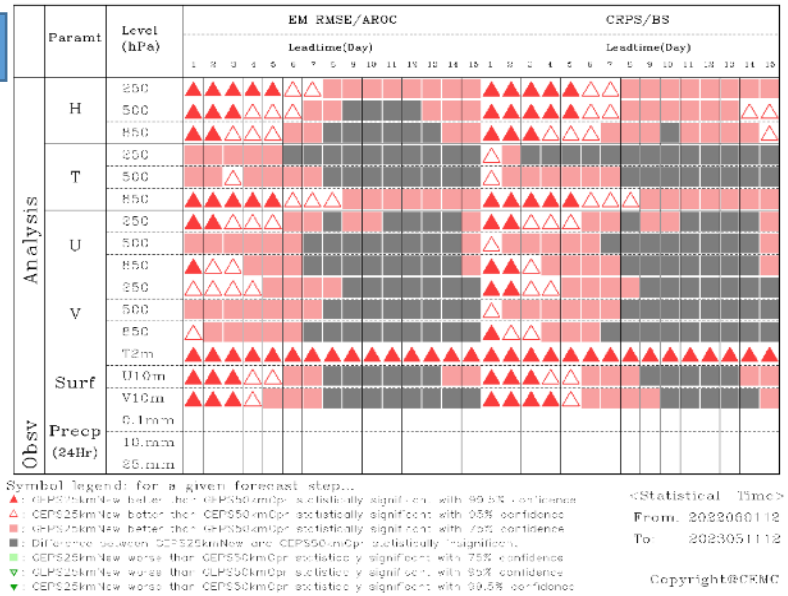
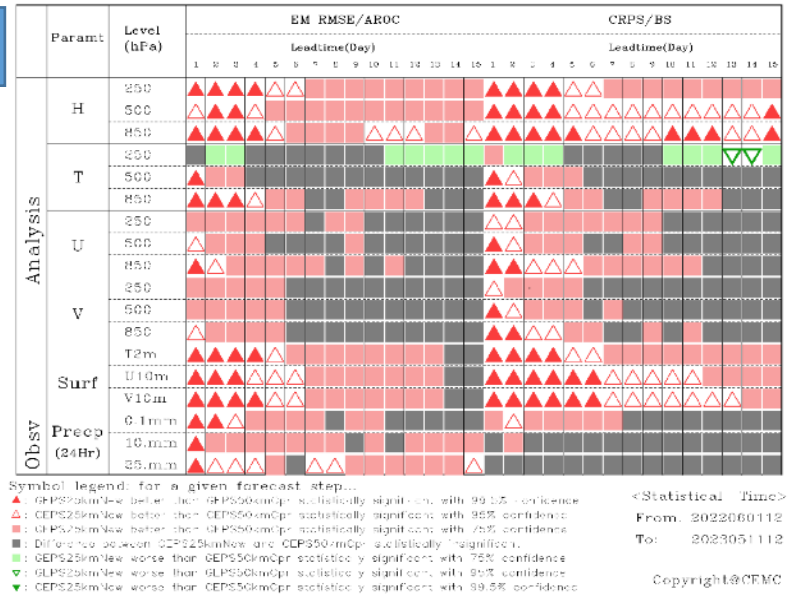
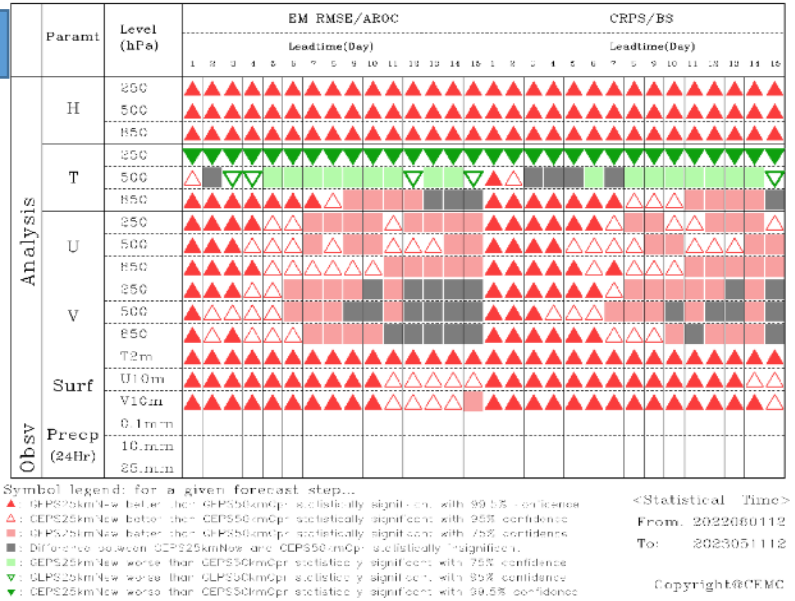


E-Asia



Tropics



25km-GEPS is better

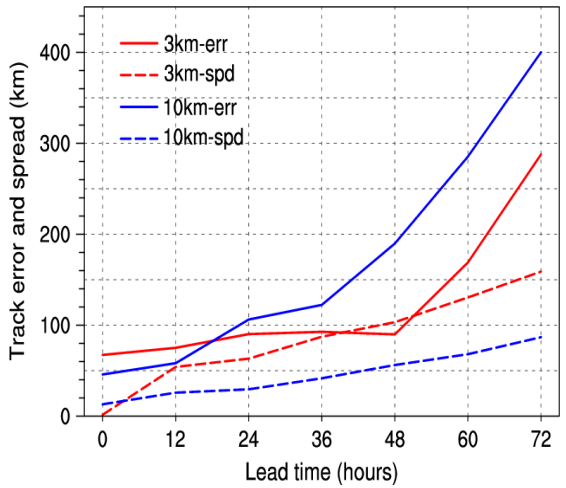
50km-GEPS is better

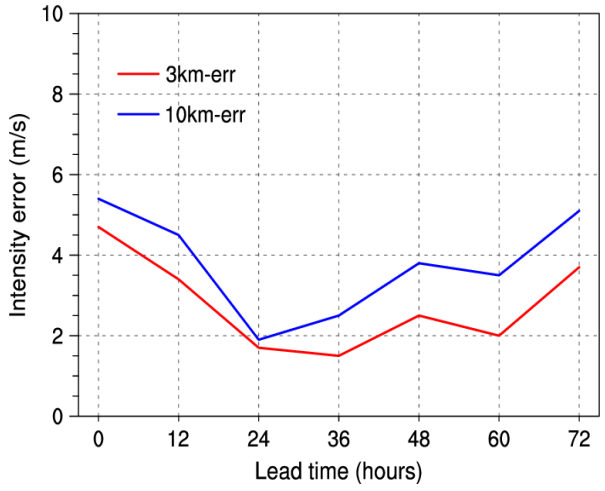
CMA-REPS Quasi-operational experiment performance

Precipitation FSS Score increased by more than 8%

预报时间	CMA_REPS V4.0				CMA_REPS V3.2				暴雨提高率（%）
	>=0.1mm	>=10mm	>=25mm	>=50mm	>=0.1mm	>=10mm	>=25mm	>=50mm	
24	0.6774399	0.543296	0.5267286	0.486969	0.67145	0.526494	0.483701	0.450892	8.0
48	0.6842212	0.539759	0.5130285	0.472489	0.67471	0.488391	0.432807	0.395086	19.6
72	0.665376	0.501741	0.4730214	0.433457	0.654577	0.458937	0.39685	0.353198	22.7

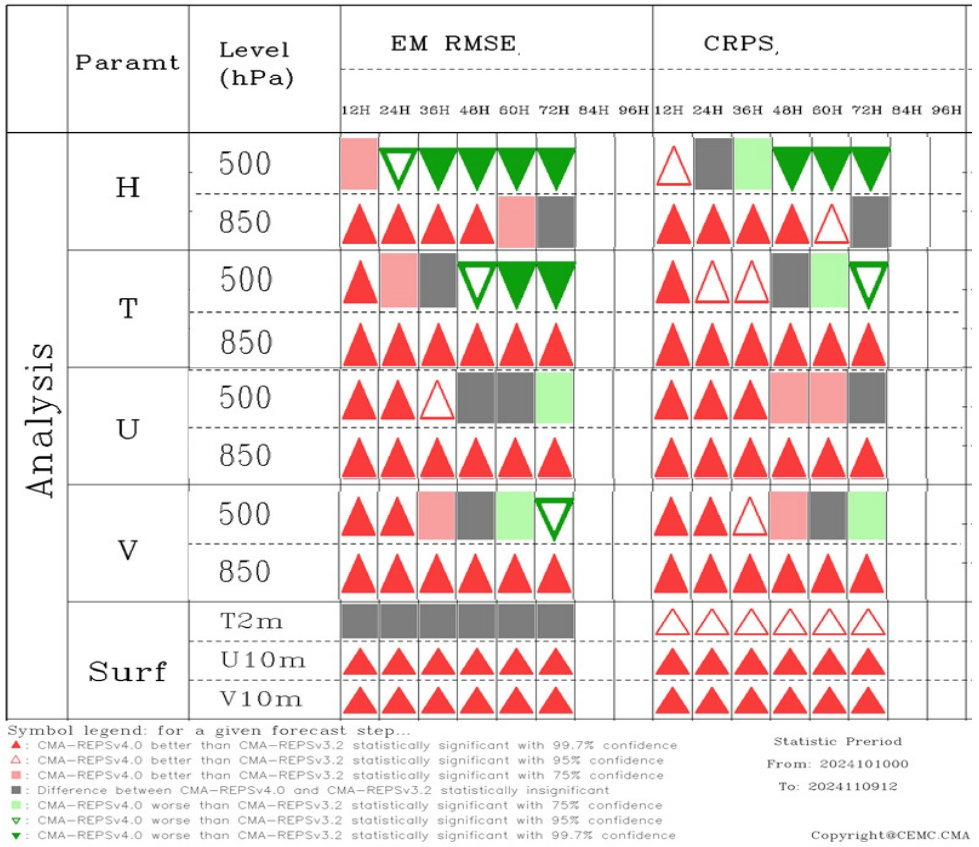
The track error and intensity error of Typhoon Trami have both shown significant improvement.





Scorecard (v.s. 10km REPS)

Quasi-operational experiment



3km-REPS is better

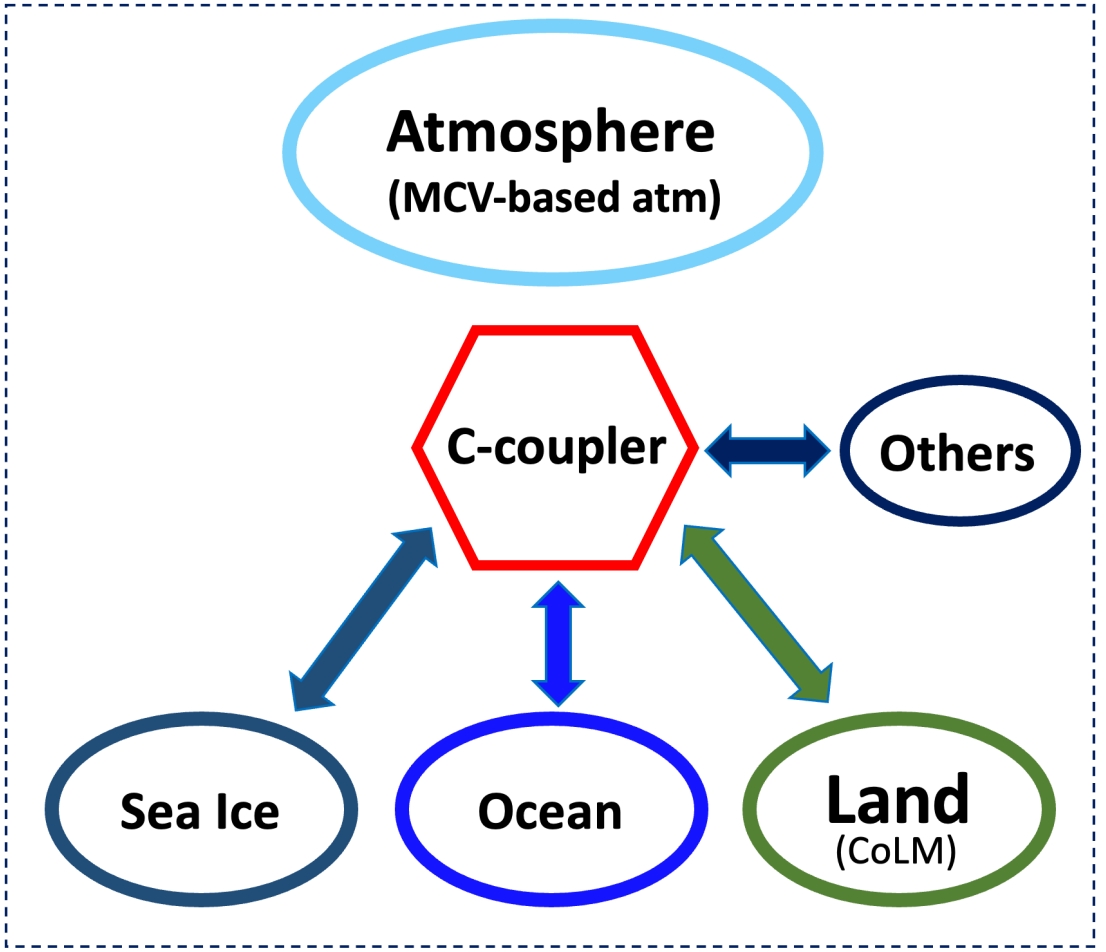
10km-REPS is better

Contents

An MCV-based unified weather and climate model

A unified weather and climate model system based on the cubed-sphere MCV-based GCM has been preliminarily built.

Weather and Climate Unified Model	Multi-moment Constrained Finite Volume Method
High order: Accurately simulating multi-scale atmospheric motions	- Local Reconstruction - Grid Adaptivity - High Precision
Global kilometer / local hundred-meter resolution	
High Scalability: Heterogeneous many-core exascale computing	- Local Algorithm - Less Parallel Communication - High Scalability
Ensuring Numerical conservation	- Multi-moment Constraint - Model Conservation



C-Coupler supports a unified weather and climate model

Sun, Liu et al. , GMD, 2021; Yu, Liu et al., GMD, 2022; Liu, Sun et al., GMD, 2023

C-Coupler3 supporting model parallel framework, software module integration framework, assimilation framework, and data input/output framework.

C-coupler functions

- Global Kilometer-Scale High-Efficiency Coupling Technology
- General-Purpose Parallel Framework for Models
- General Software Module Integration Framework
- General Ensemble Coupling Assimilation Framework
- General Data Input/Output Framework

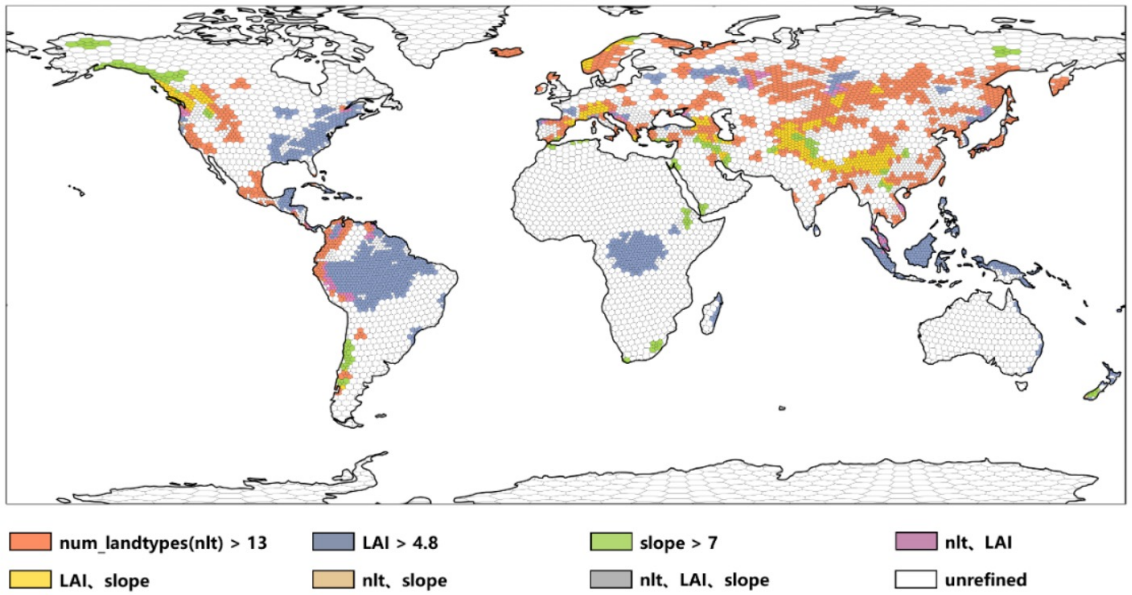
Atmospheric Horizontal Grid Points (10,000)	Atmospheric Processes	Ocean Horizontal Grid Points (10,000)	Ocean Processes	C-Coupler3 Startup Time (seconds)	OASIS3-MCT5.0 Startup Time (seconds)
3000	300	5000	300	23.7	84.3
3000	900	5000	900	16.0	79.4
3000	1200	5000	1200	12.8	80.0
3000	1600	5000	1600	15.1	83.3
3000	3200	5000	3200	10.8	100.8
3000	6000	5000	6000	9.9	145.5
3000	10000	5000	10000	11.4	153.7
3000	12000	5000	12000	14.2	167.5

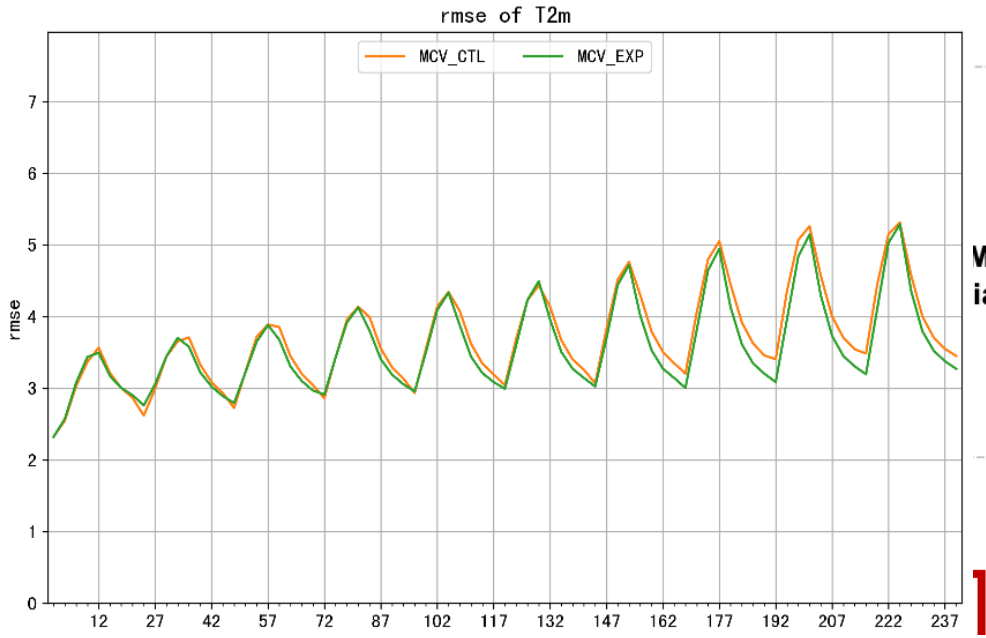
MCV-Common Land Model (CoLM)

Dai et al., 2004

Noah Land Surface Model

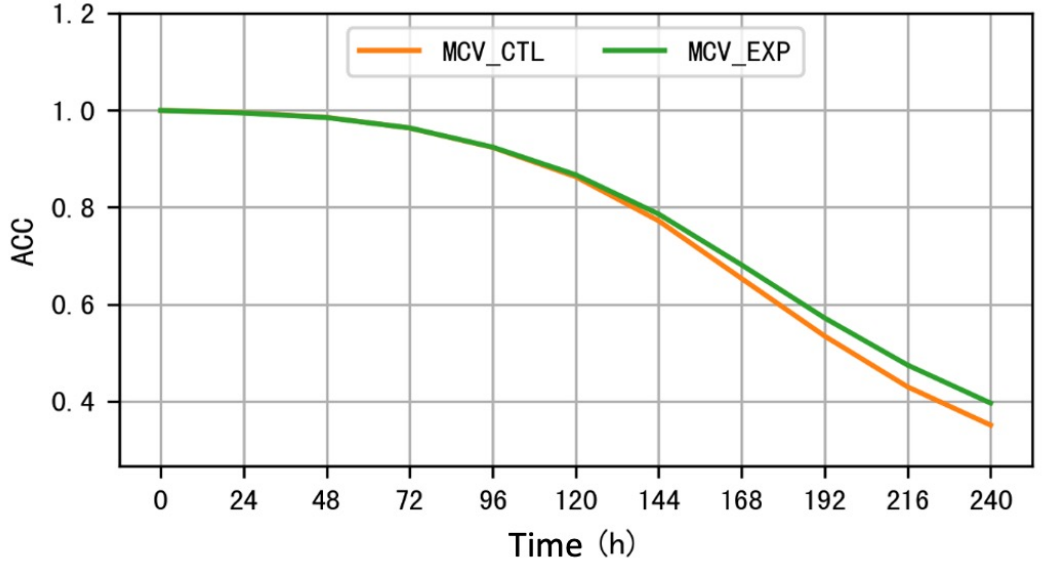
The Common Land Model (CoLM)





Model ialization

ACC N.H. 500hPa



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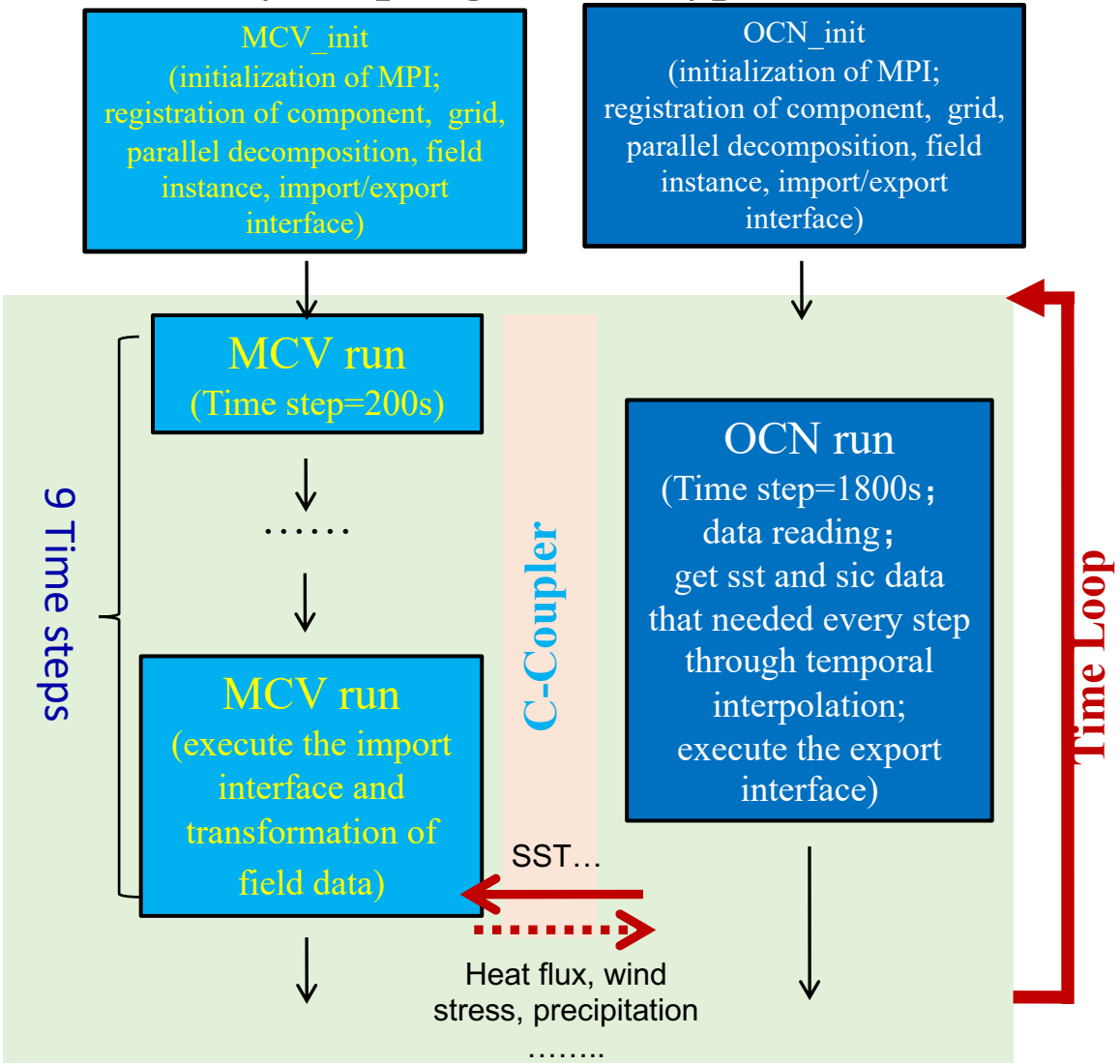
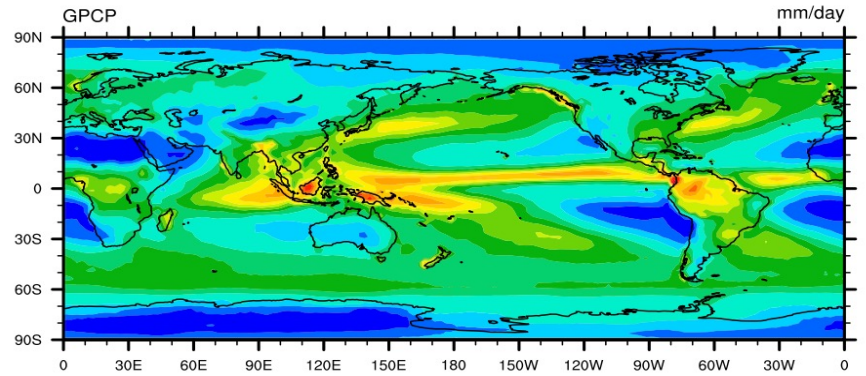
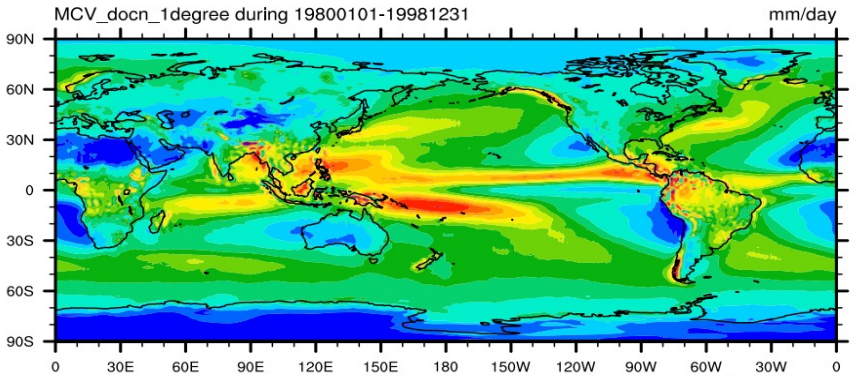
MCV-AMIP type simulation (20 years)

The flow diagram of MCV-docn
(one-way coupling; AMIP-type simulation)

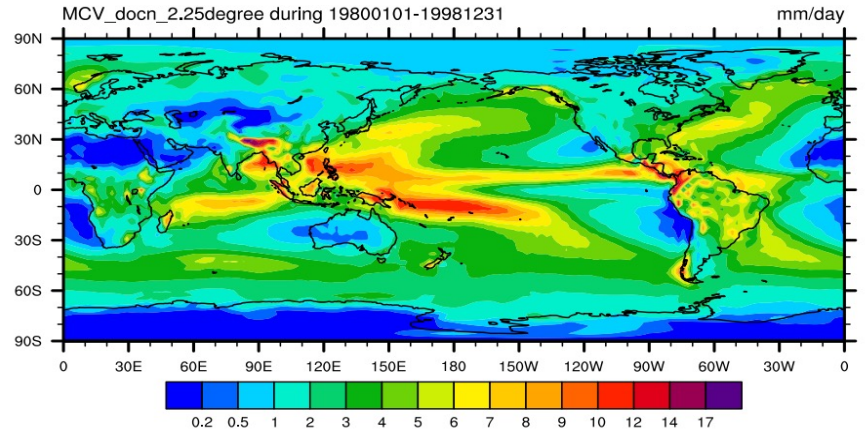




Obs.



1° resolution

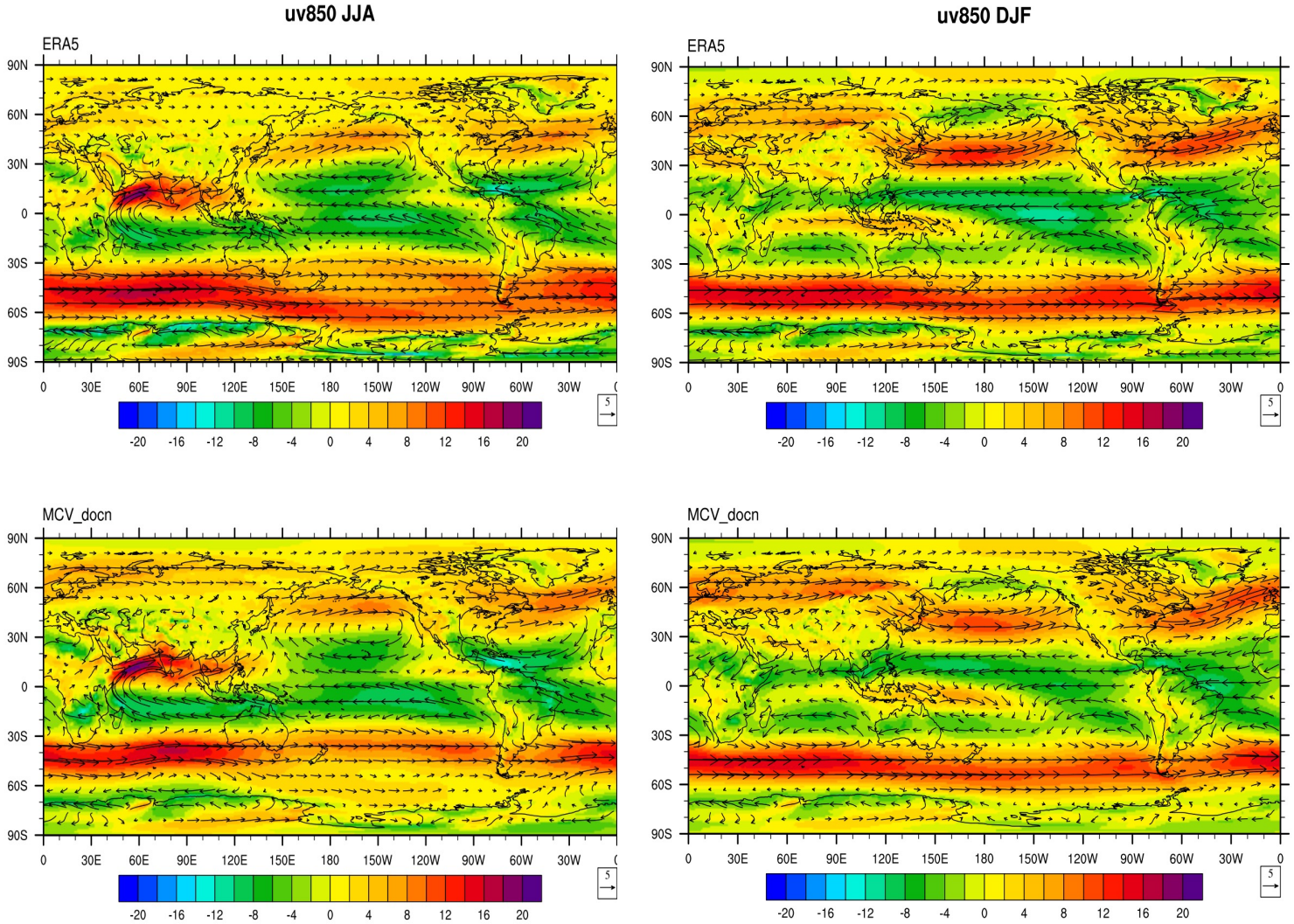


2.25° resolution

MCV-AMIP type simulation (20 years)

❑ **Climatological Large-scale Circulation (850 hPa wind fields):**

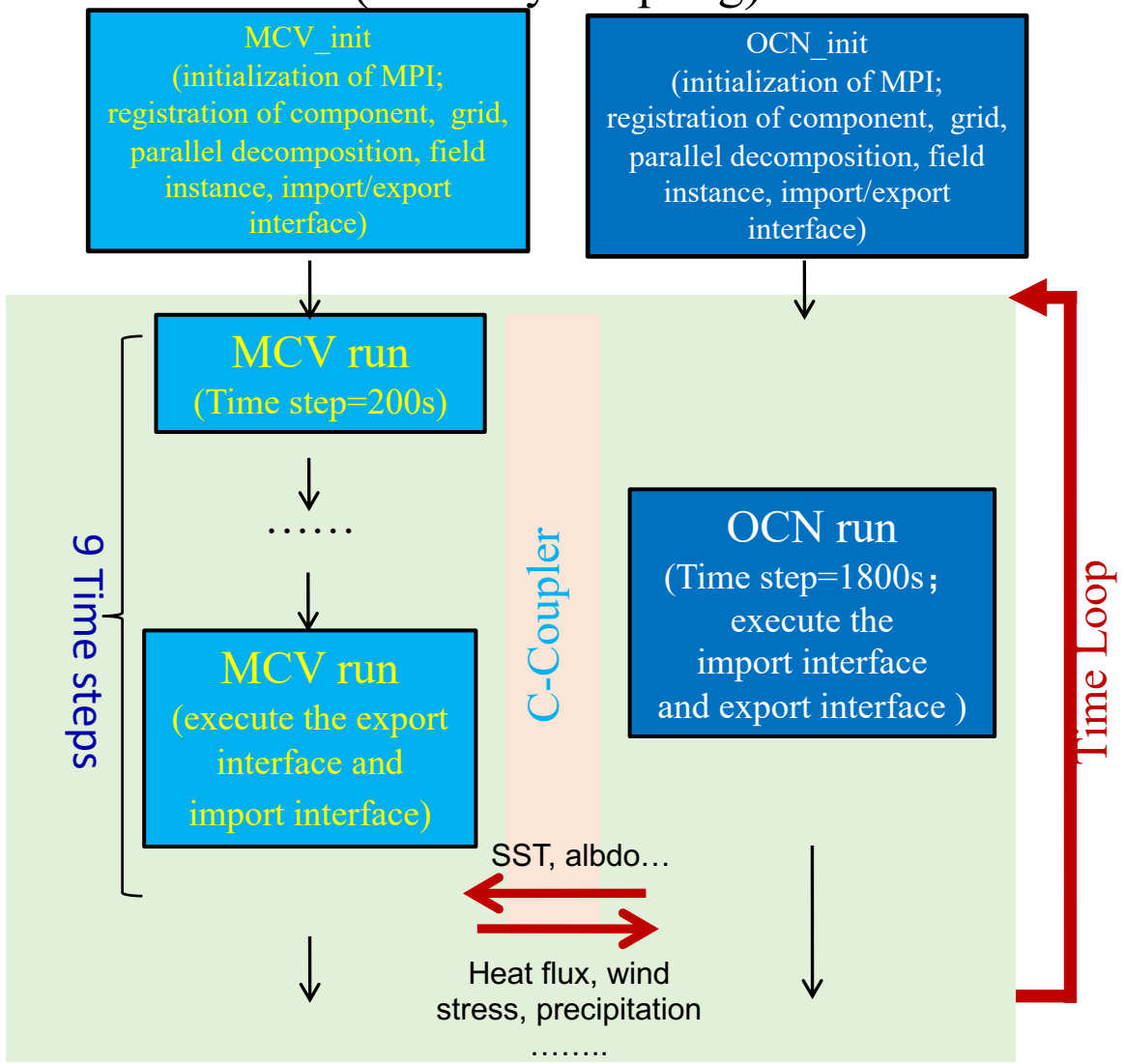
- **Major circulation systems captured:**
  - Tropical trade wind
  - North Pacific and North Atlantic subtropical highs
  - Asian monsoonal flow
  - Mid- and high-latitude westerly jets
- **Agreement with ERA5:**
  - Realistic strength and spatial patterns
- **Overall:**
  - MCV–docn system robustly simulates the large-scale circulation of the climate system

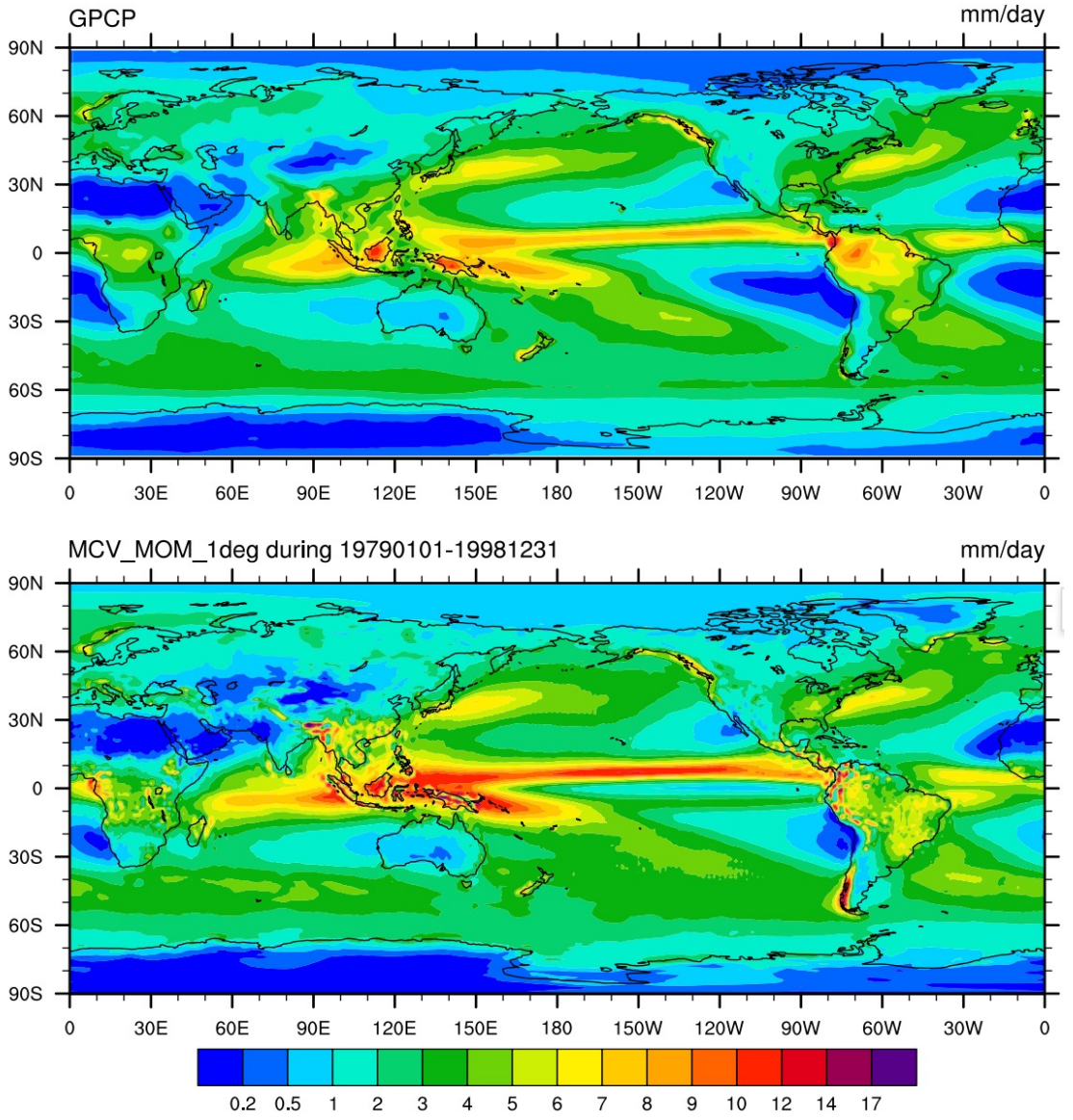


Climatological (JJA and DJF) 850 hPa wind fields

MCV-MOM coupled simulation (20 years)

The flow diagram of MCV-MOM (two-way coupling)

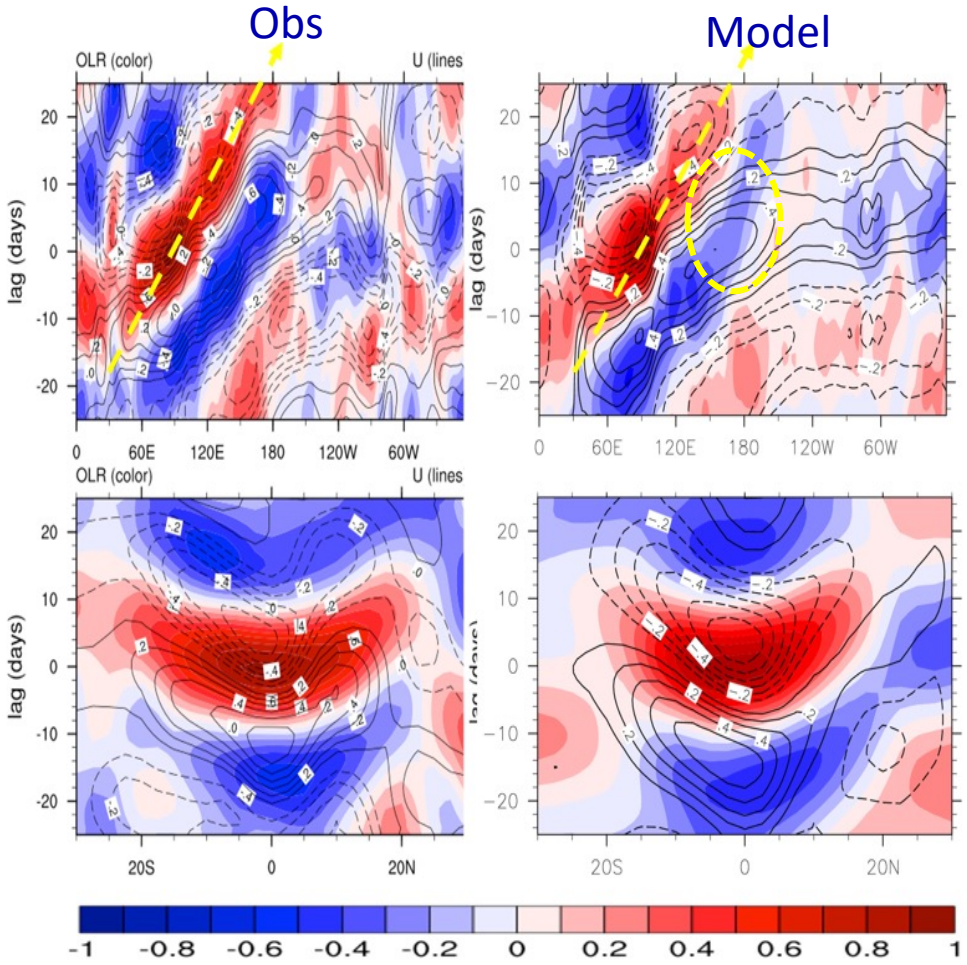




MCV-MOM coupled simulation – MJO (20 years)

MJO Propagation

- **ERA5:**
  - Eastward propagation (~5 m·s^{-1}) from Indian Ocean → Maritime Continent → western Pacific → weakening in eastern Pacific
- **Model:**
  - Realistically captures propagation path & meridional symmetry
  - Phase speed consistent with observations
  - Bias: weaker convection over western Pacific (linked to cold SST bias)
- **Overall:**
  - Model robustly represents MJO propagation despite regional weakness



The longitude–time evolution of lagged correlation coefficients for the 20–100d band-pass-filtered anomalies (OLR and U850, averaged over 10°S–10°N) against itself averaged over the equatorial eastern Indian Ocean (75–85°E; 5°S–5°N; upper panel), and the meridional propagation of lagged correlation coefficient for anomalies (averaged over 80–100°E) against the anomalies averaged over the same region of the equatorial eastern Indian Ocean (lower panel). Yellow dashed lines denote a 5 m·s^{-1} eastward propagation speed reference.

Summary

- CMA-GFS V4.2.3 has been in operation, more satellite data are assimilated and its percentage from 83% (2024) to 88% (2025) in CMA-GFS DA system.
- CMA-GEPS version upgrades from 3.3 to 4.0, and the model uncertainty by using multi-scale SPPT, improvements on initial perturbations by combining two scale SV-based perturbation and EDA-based perturbations.
- CMA-REPS V4.0 are upgraded and has been operational since January 2025.
- 1km-EnVar DA is implemented into CMA-MESO 1km1h cycle system.
- A unified weather and climate model system based on the cubed-sphere MCV-based GCM has been preliminarily built, and shows good performances in AMIP simulation and MCV-Ocean coupled model.
- C-Coupler supports a unified weather and climate model

Thanks for your attention!

Many thanks for my colleague’s contributions at CEMC!