The annual joint meeting of the Working Group on Numerical Experimentation (WGNE) and the Working Group on Subseasonal to Interdecadal Prediction (WGSIP)

WGNE39: Updates in the CMA NWP system and a unified next-generation MCV model

Xingliang Li

CMA Earth System Modeling and Prediction Center (CEMC), Beijing 100081, China

Toulouse, France

5/11/2024

Contents

Overview of current CMA NWP system

GFS：12.5km

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

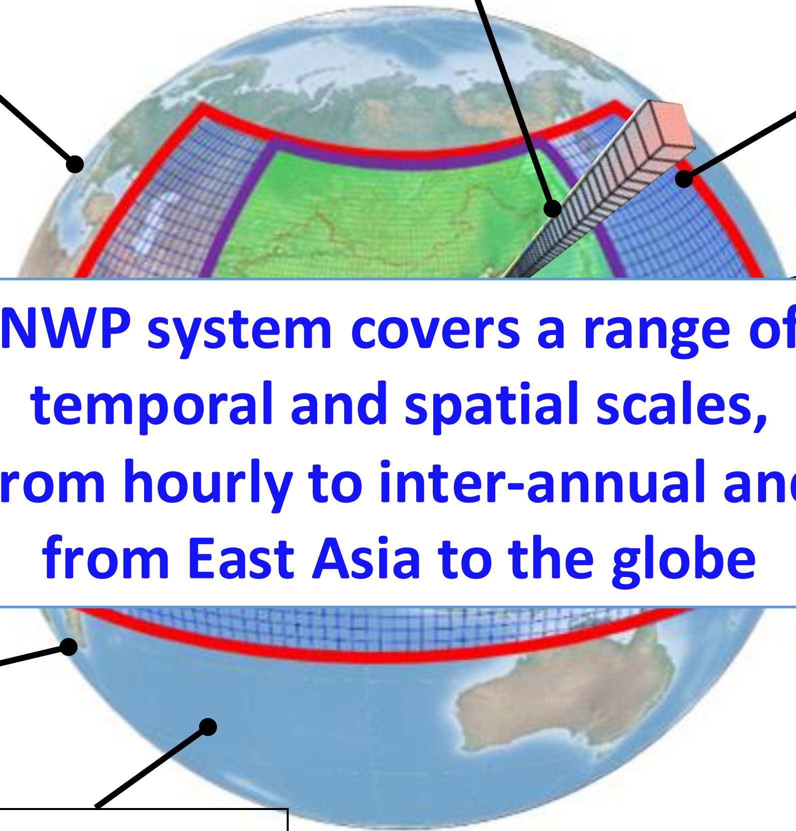
GEPS：50km/25km

CMA-GEPS：
- 87 layers, top to 0.1hPa
- 50km operation, 25km on test
- 1 control + 30 members
- 15 day forecast（00,12UTC）

CPS：45km

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

87 layers, 63km



NWP system covers a range of temporal and spatial scales, from hourly to inter-annual and from East Asia to the globe

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 per day, 5day forecast

MESO：3km/1km

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

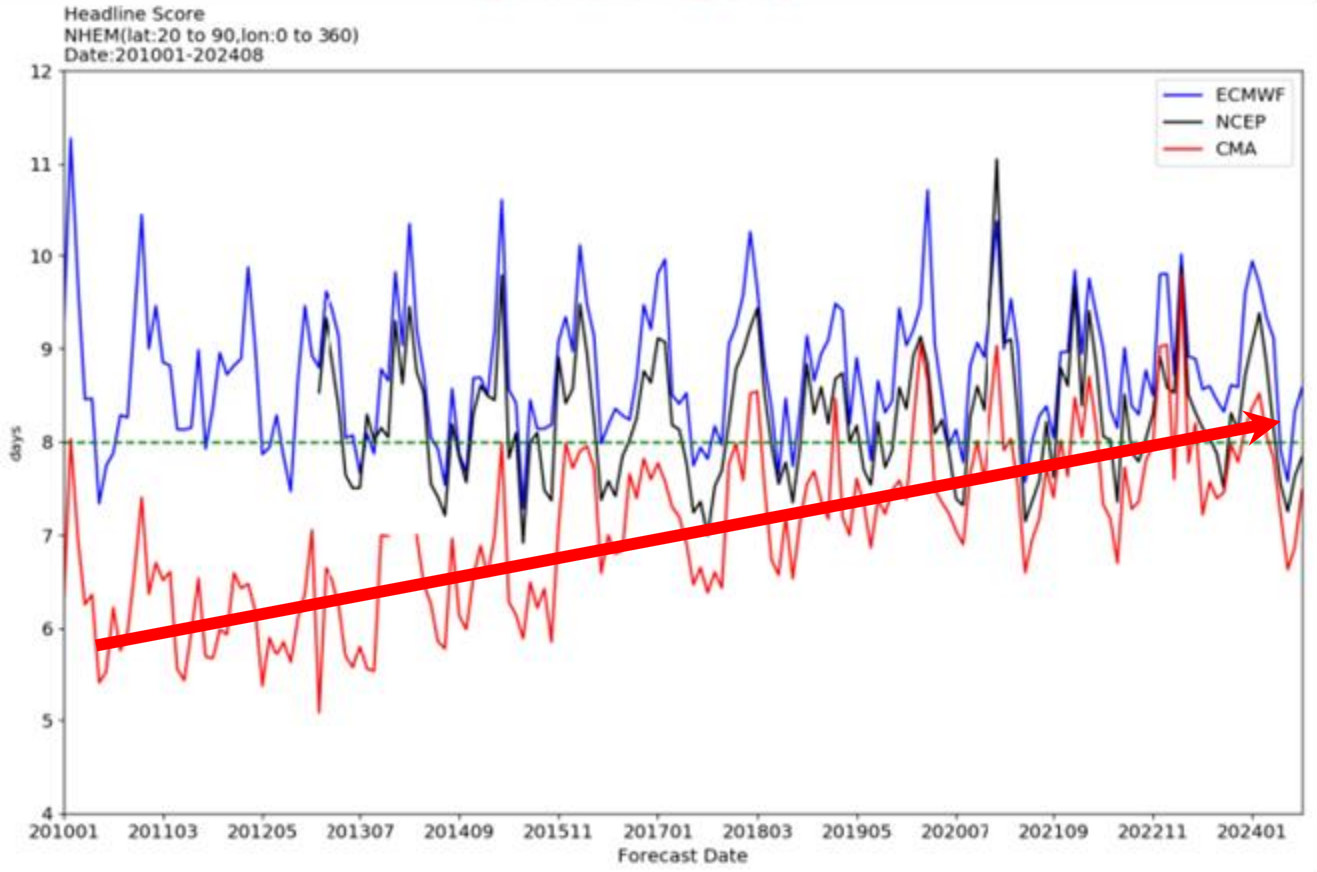
REPS：10km/3km

CMA-REPS：
- China domain, 10km operation, 3km on testing
- 1control +15member
- 3.5day forecast（00,12UTC）

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

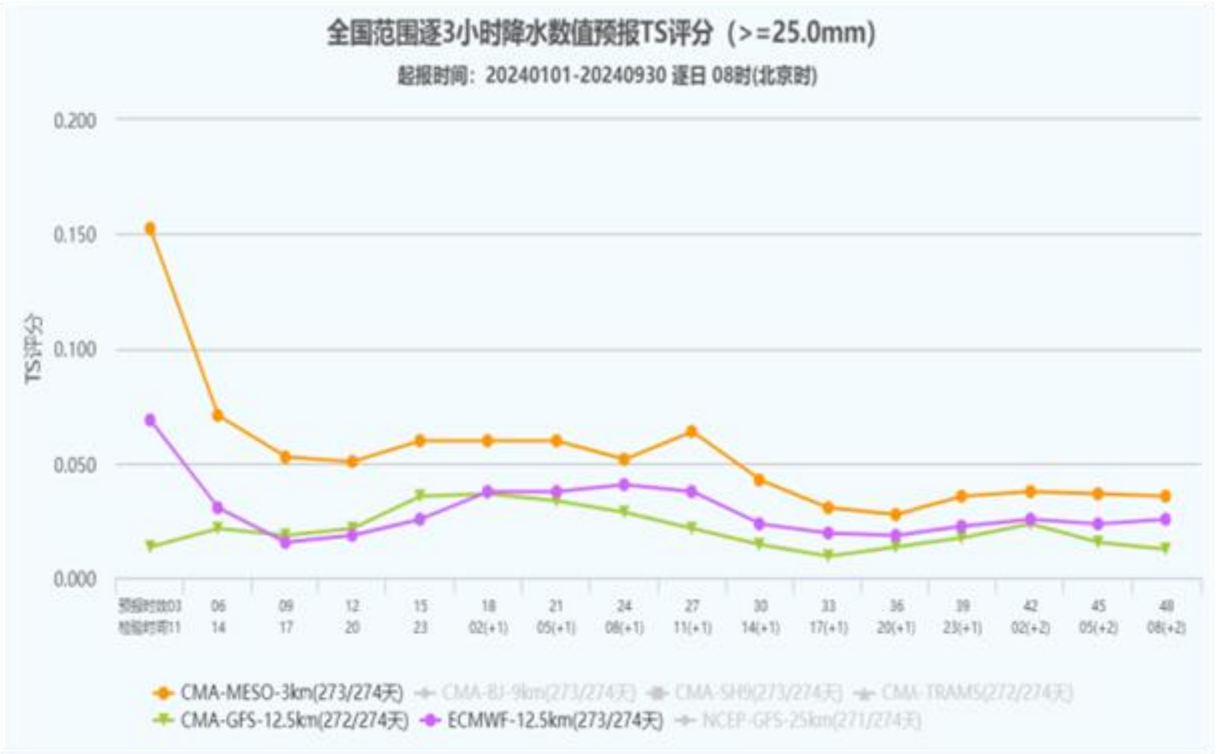
Overall performance of operational CMA NWP model (2024)

CMA-GFS



ACC in northern Hemisphere

CMA-Meso



Heavy rainfall in China's regions

2024(1): CMA-MESO V6.0 – 1km/1hr

- Applications of radar and vertical sounding data

- Assimilation of weather radar echoes and polarization quantities
- Vertical detection data assimilation
- Wind profilers, microwave radiometers

-Improvements in small- and meso-scale assimilation methods

- Developing non-Gaussian, non-hydrostatic assimilation algorithms: ensemble variational hybrid assimilation
- Reconstructing humidity variables: non-equilibrium proposed relative humidity

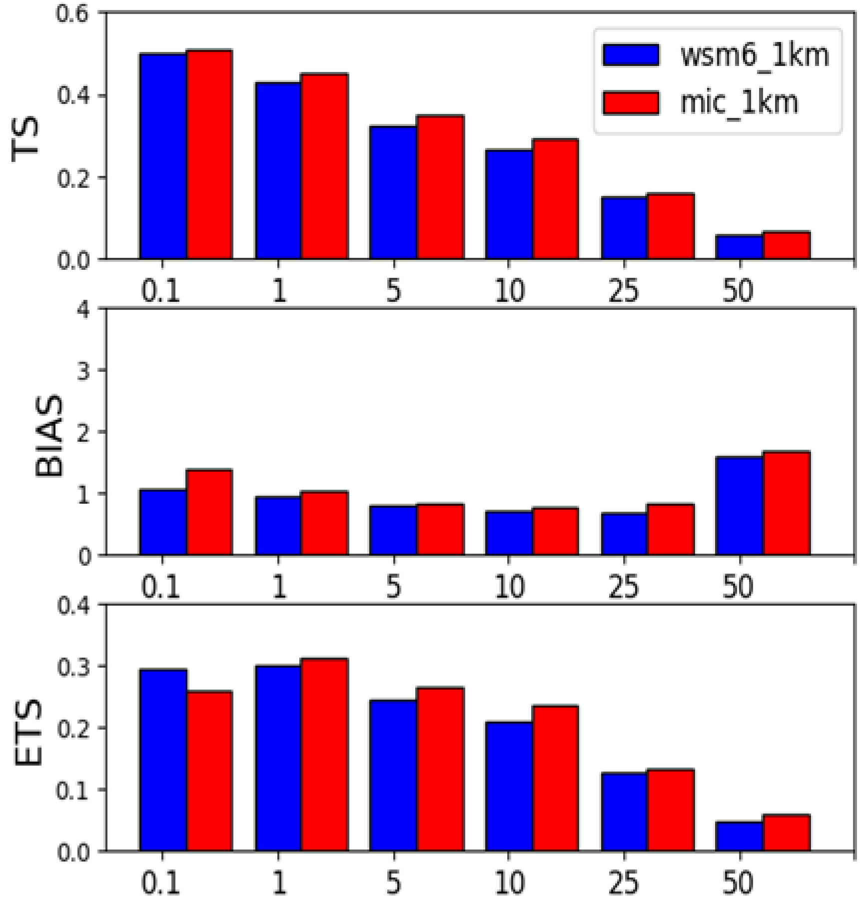
-Physical process refinement

- Mixed-phase two-moment cloud physics
- Introduction of lateral turbulent diffusion and improvement of PBL
- Effects of non-uniform surface: subgrid topography

-Improved harmonization between data assimilation and numerical models

- Noise control during rapid cycling –IAU
- Consideration of model physics schemes in the assimilation process

East China 1km Aug. and Sept.

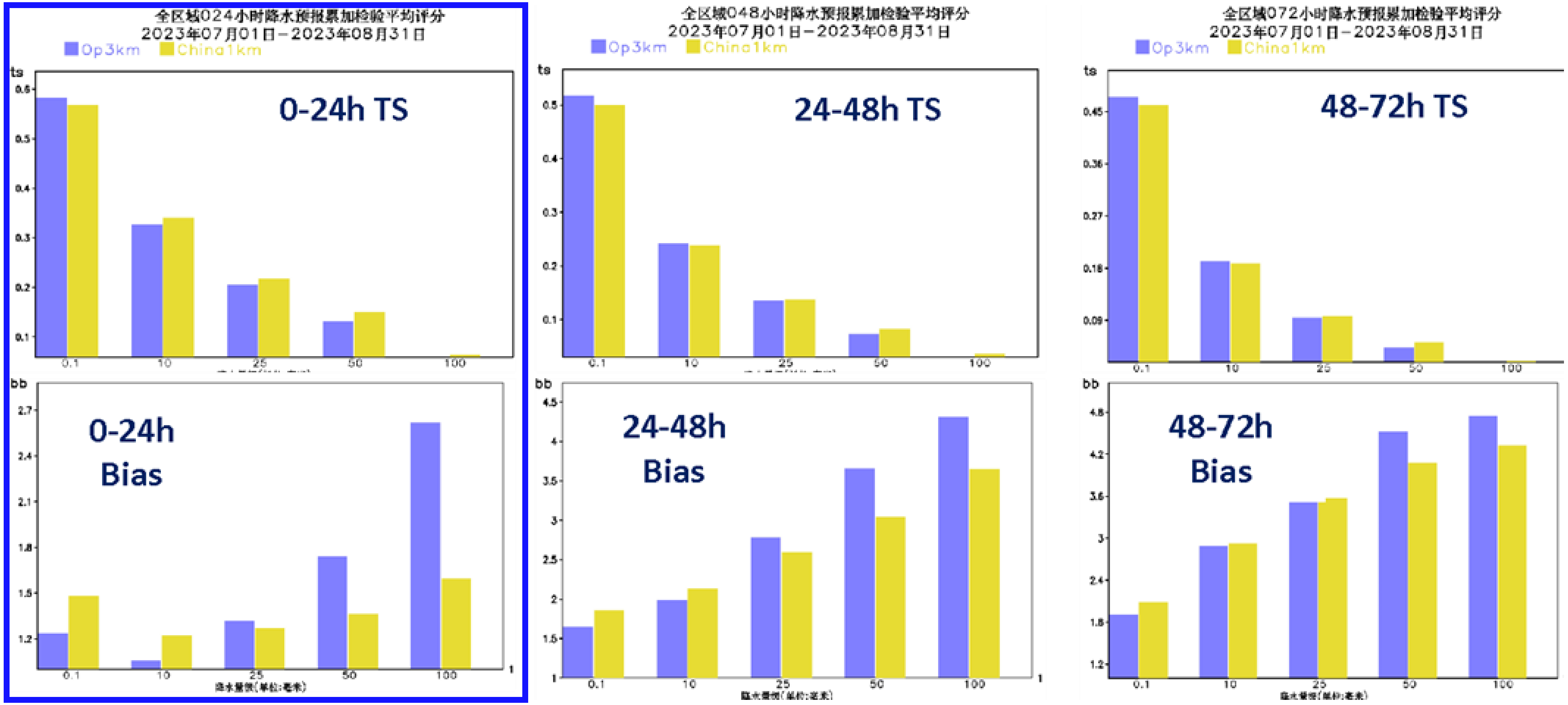


The two-moment scheme for regional precipitation in China.

Especially the moderate and heavy precipitation forecasts are improved

CMA-MESO 1km/1hr V.S. 3km/3hr

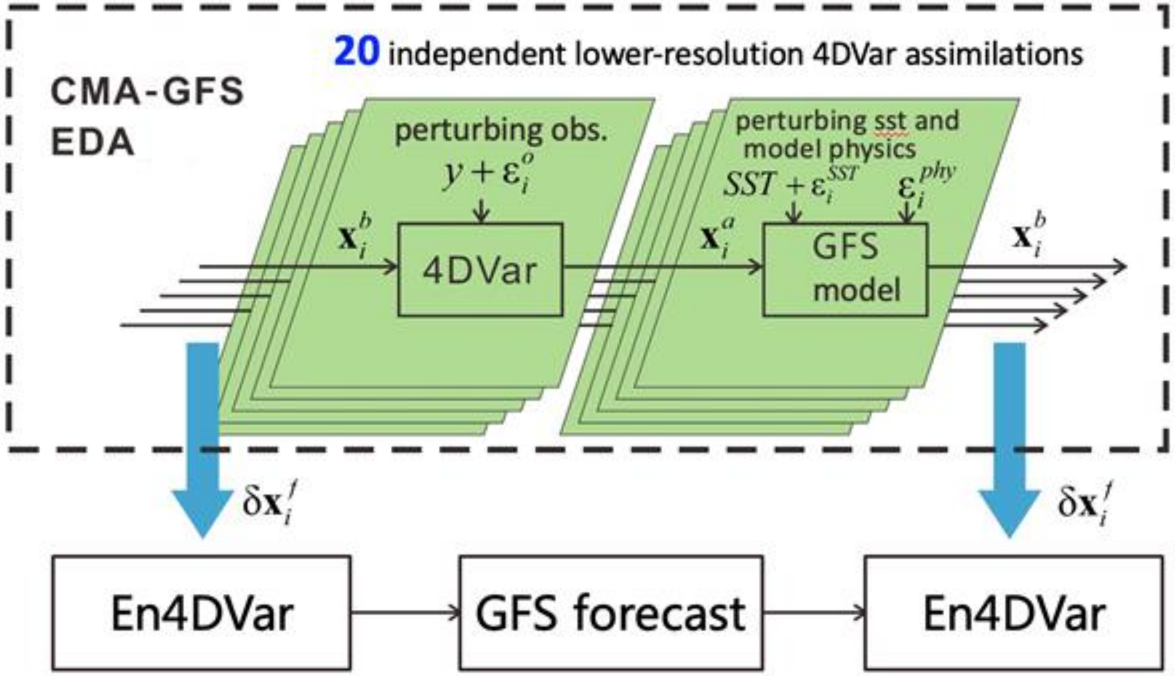
Precipitation, 2-meter surface temperature and 10-meter wind forecasts were significantly better than the existing CMA-MESO 3km operational system



24h Precipitation: 1km/1hr cycle heavy precipitation is better than that of 3km/3hr cycle, Bias is reduced significantly for precipitation above moderate rainfall.

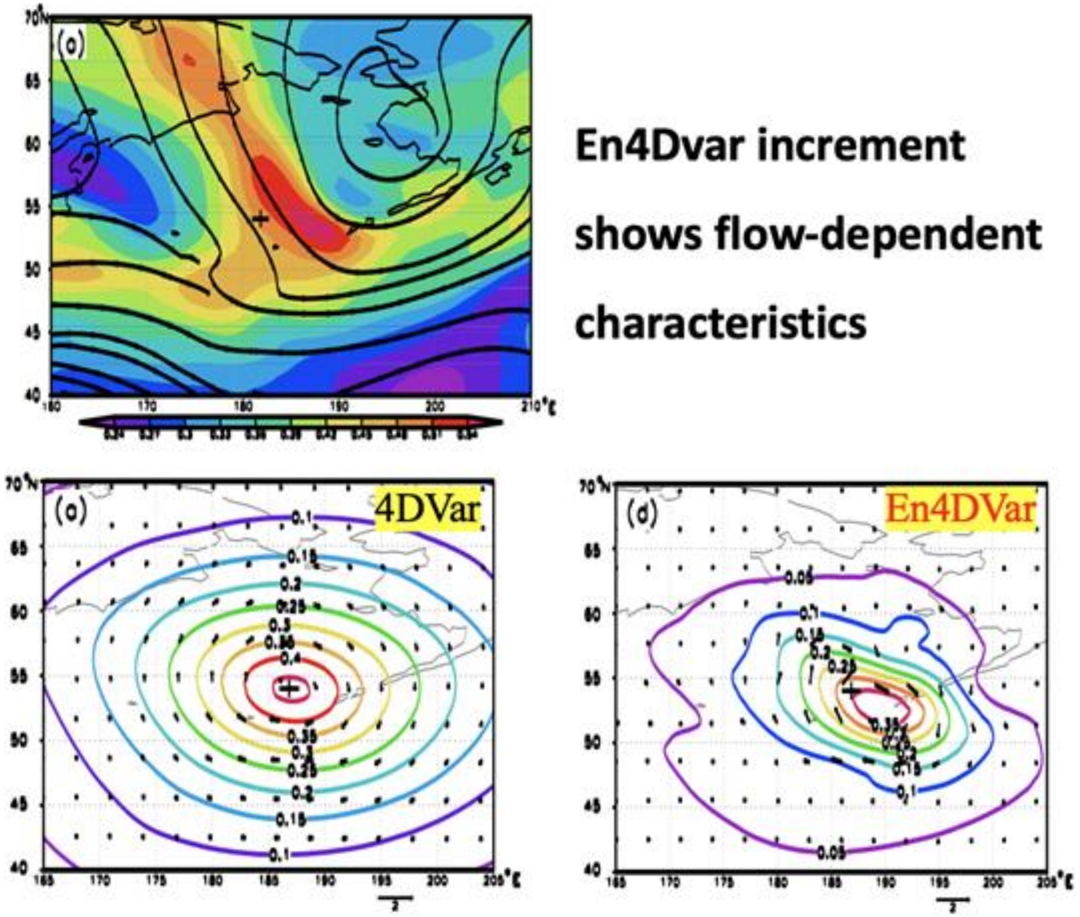
2024(2): CMA-GFS V4.2 En4DVar

En4DVar is a new technological step



CMA-GFS 12.5km analysis and forecast cycle

background situation

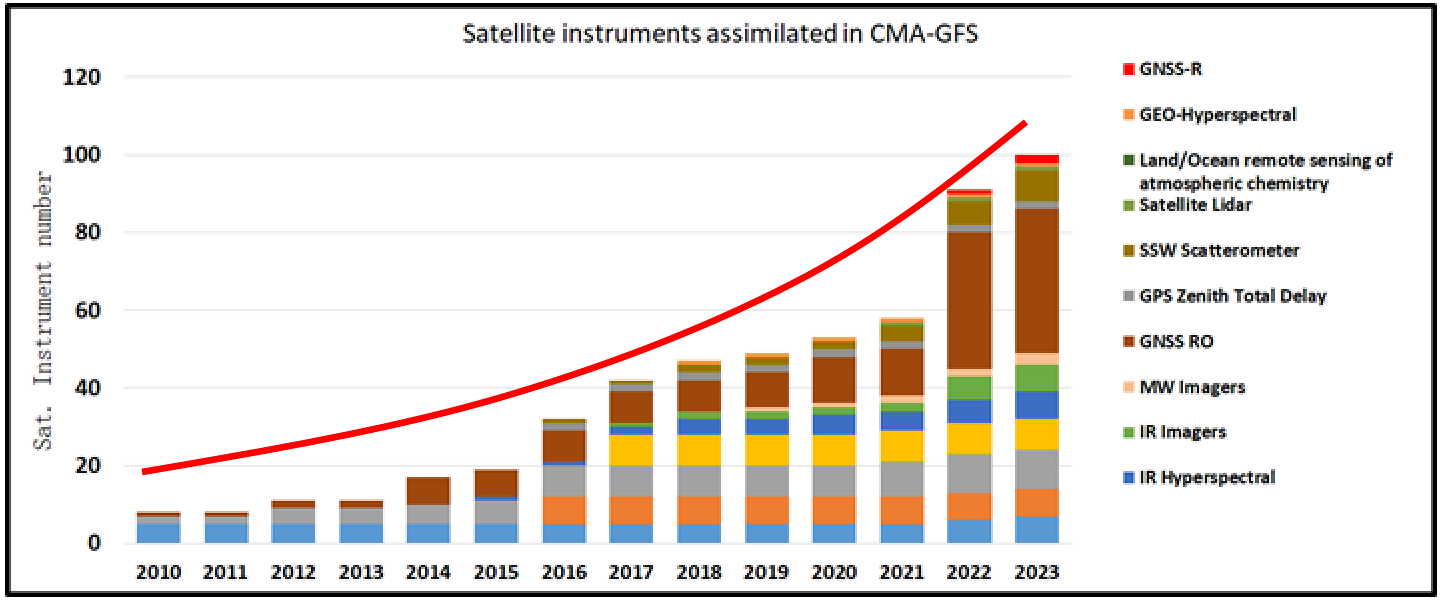


En4Dvar increment shows flow-dependent characteristics

2024(3): More satellite data in CMA-GFS V4.2

<u>More data:</u>

1. FY-4B AGRI/GIIRS
2. FY-3E MWHS 183GHz vapor channal
3. FY-3E WindRAD scatterometer wind
4. HY-2B SMR imager
5. HY2D scatterometer wind
6. NPP/NA20 ATMS 13\14 channel
7. GOES18 ABI / Himawari9 AHI
8. GOES18 AMV



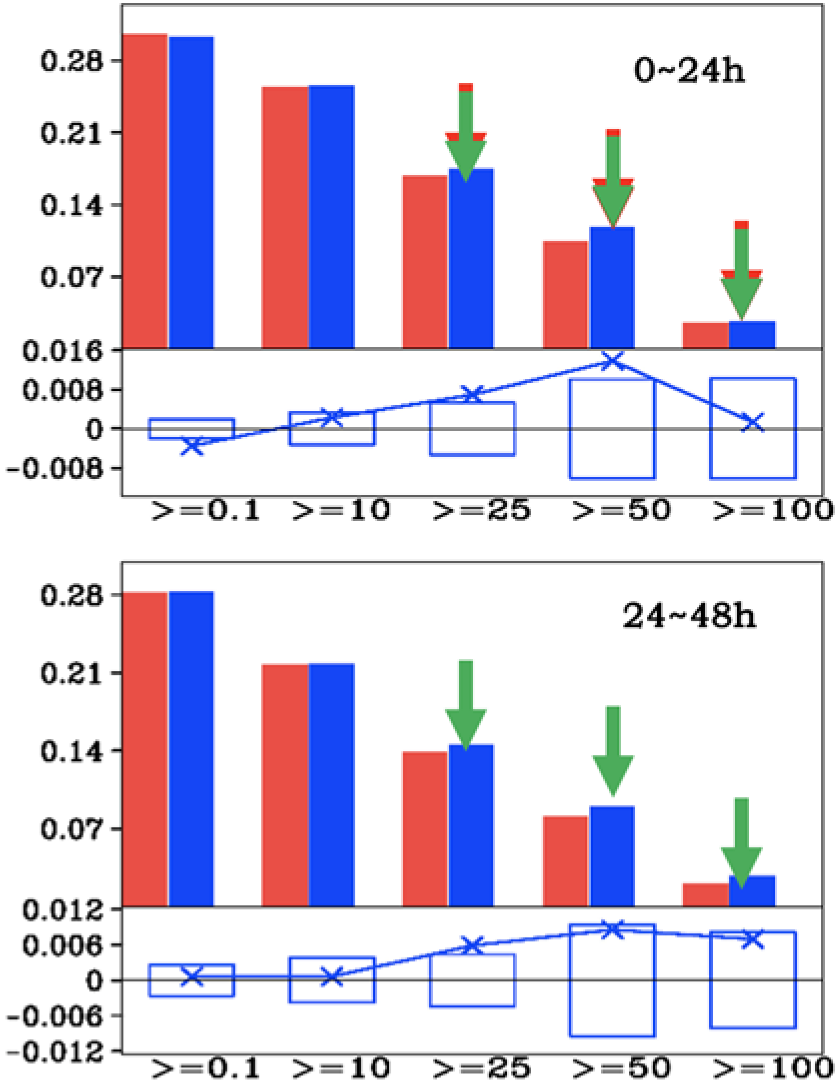
Satellite information accounted for: more than **82.9%** in China (**94%** at ECMWF).

- Of the satellite data assimilated in China: 14.9% for Feng Yun, 26.7% for European satellites, 16.7% for American satellites, 2.4% for Japanese satellites; 17.4% for occultation and 3.7% for scatterometer winds.
- Conventional observations **17.1%**

2024(4): CMA-GFS V4.2 physical package improvement

Addressing underestimation of cloudiness and low precipitation level

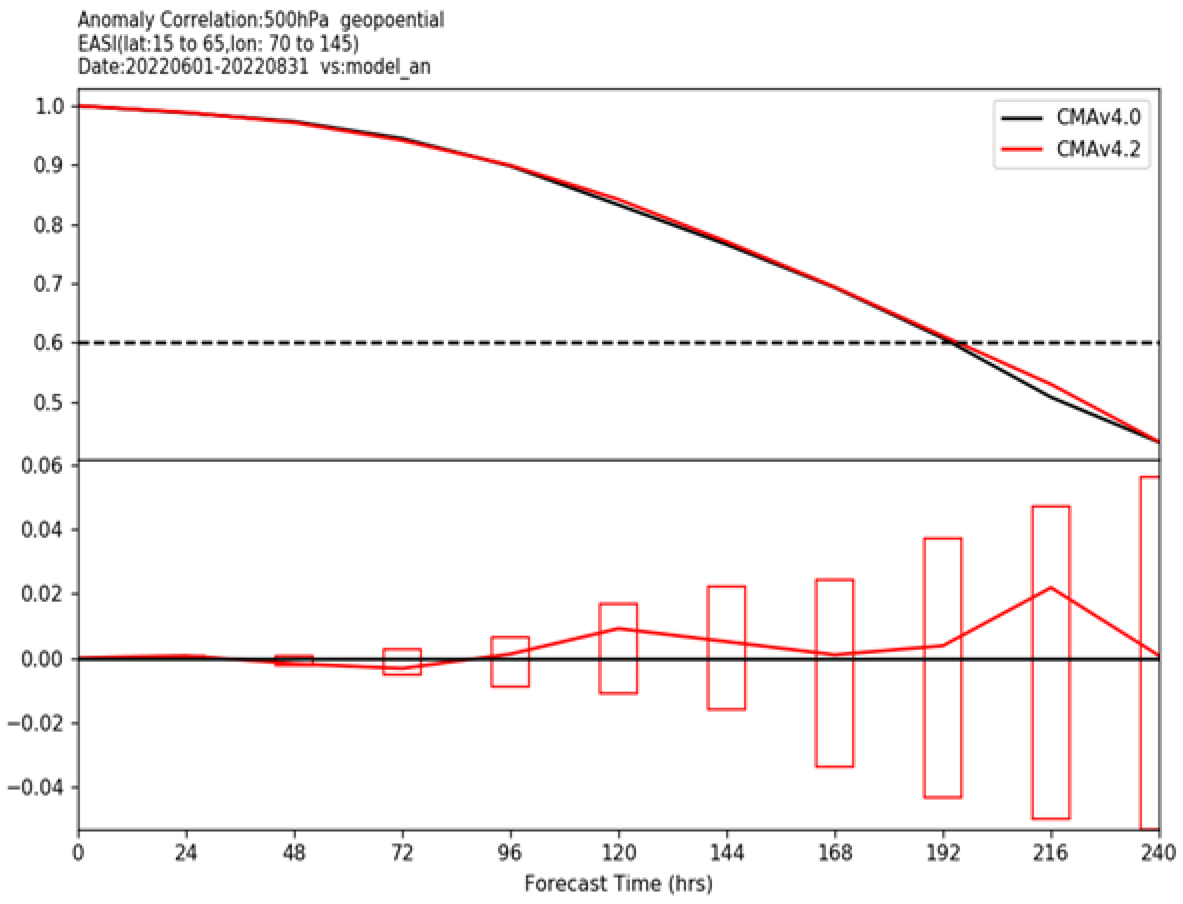
- Add cloud rollout and compensation subsidence terms to supplement subgrid convective cloud feedback (deep and shallow convection)
- Correct the convective trigger function to reduce the frequency of subgrid convective triggers (deep convection)
- Optimize cloud bottom mass flux diagnostics to enhance the intensity of (triggered) subgrid convection (deep convection)
- Adjust rain conversion rate coefficients to reduce the conversion of convective precipitation and increase the roll-out of high clouds (deep convection).
- Improvement of cloud volume and number concentration advection scheme
- Optimization of ice cloud optical effective radius calculation scheme



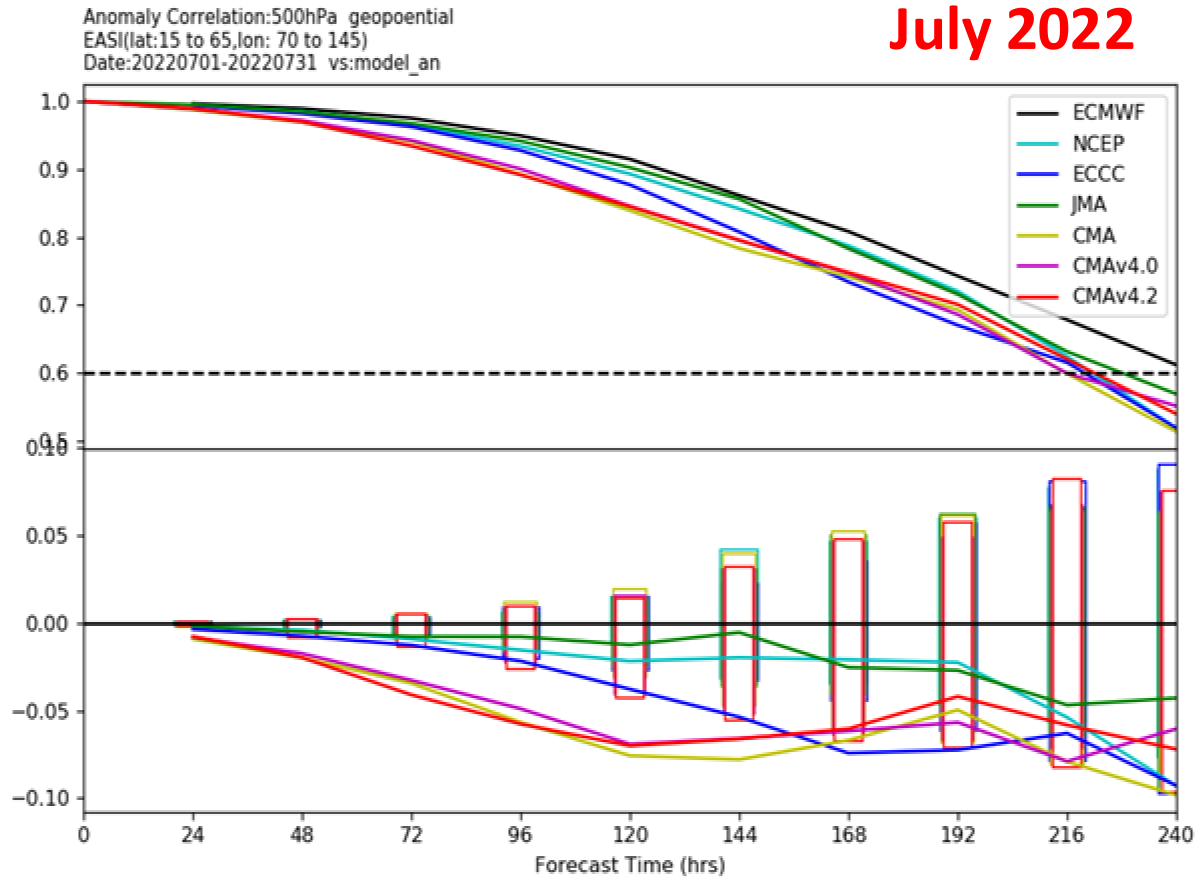
Performance of the coming CMA-GFS V4.2

East Asia: ECMWF (10.18)、 NCEP (9.23)、 ECCC (9.16)、 JMA (9.50) CMA V4.0(8.99)、 CMA V4.2(9.25)

Increased by **3%**

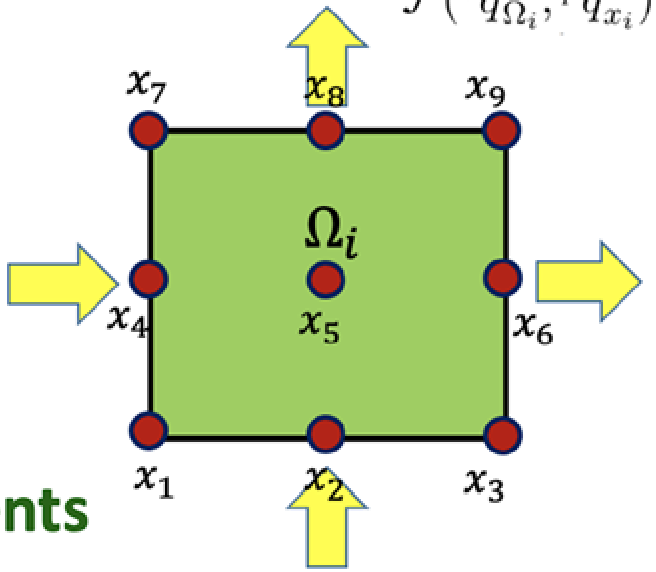


July 2022

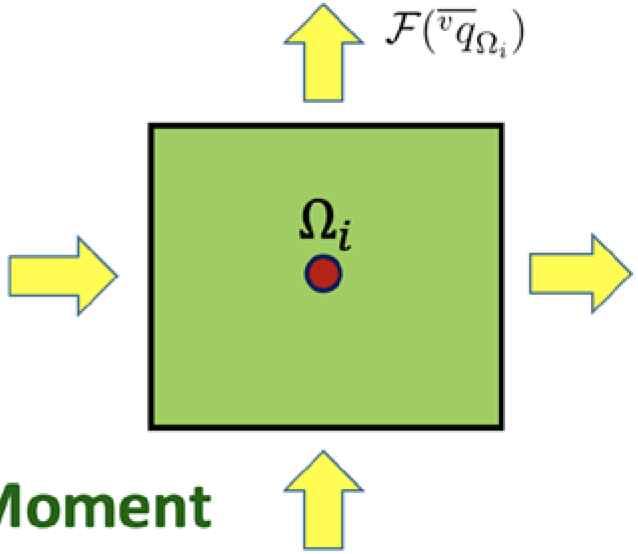


The Multi-moment Constrained finite Volume method
(Ii and Xiao, JCP, 2009; Xiao et al, AMM, 2014)

Multi-moment FVM



Conventional FVM



Moments

Volume integrated average **(VIA)**	Point value **(PV)** / Derivative value **(DV)**
$\overline{^v q}_{V_i}(t) = \frac{1}{\lvert V_i \rvert} \int_{V_i} q(x,t)dV$	Point value **(PV)**: $\overline{^p q}_{x_j}(t) = q(x_j, t)$ Derivative value **(DV)**: $\overline{^{D_k} q}_{x_j}(t) = \frac{\partial^{[k]}}{\partial x^{[k]}} q(x_j, t)$

Multi-moment method uses two or more kinds of moments

Moment

Volume integrated average(VIA)

$$\overline{^v q}_{V_i}(t) = \frac{1}{\lvert V_i \rvert} \int_{V_i} q(x,t)dV$$

Conventional FVM only uses one moment

A multi-moment FVM distinguishes, memorizes and updates all of the moments.

A regional/global unified MCV prototype model

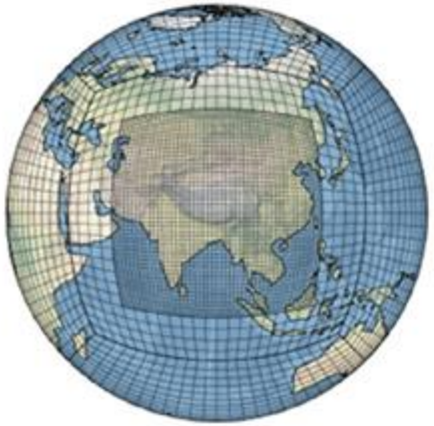
(Li et al., MWR, 2013; Chen et al., JCP, 2014; Qin et al., AAS, 2019; Li et al., QJRMS, 2020; Tang et al., QJRMS, 2022; Chen et al., JCP, 2023)

MCV Dyncore

- ☐ Multi-moment algorithm
- ☐ Horizontal 4th order accuracy
- ☐ Mass conservation

Model aspect	MCV DynCore
Equation system	fully compressible flux-form
Prognostic variables	$(\rho_d', u^\xi, u^\eta, w, \rho_d\theta', \rho_d r_x)$
Horizontal discretization	structured MMFV(4th order)
Vertical discretization	structured MMFV/FD(2nd or 3rd)
Time-stepping scheme	3rd RK-IMEX (HEVI)
Horizontal grid	Cubed-sphere grid
Horizontal coordinates	$(\alpha,\beta) \in [-\pi/4, \pi/4]$
Vertical coordinate	generalized height-based terrain following
Horizontal staggering	co-located
Vertical staggering	co-located
Advection scheme	conservative MCV3_BGS-PRM (FCT)

Global/Regional unified model



- Global: Cubed sphere grid
- Regional: Lat-Lon grid

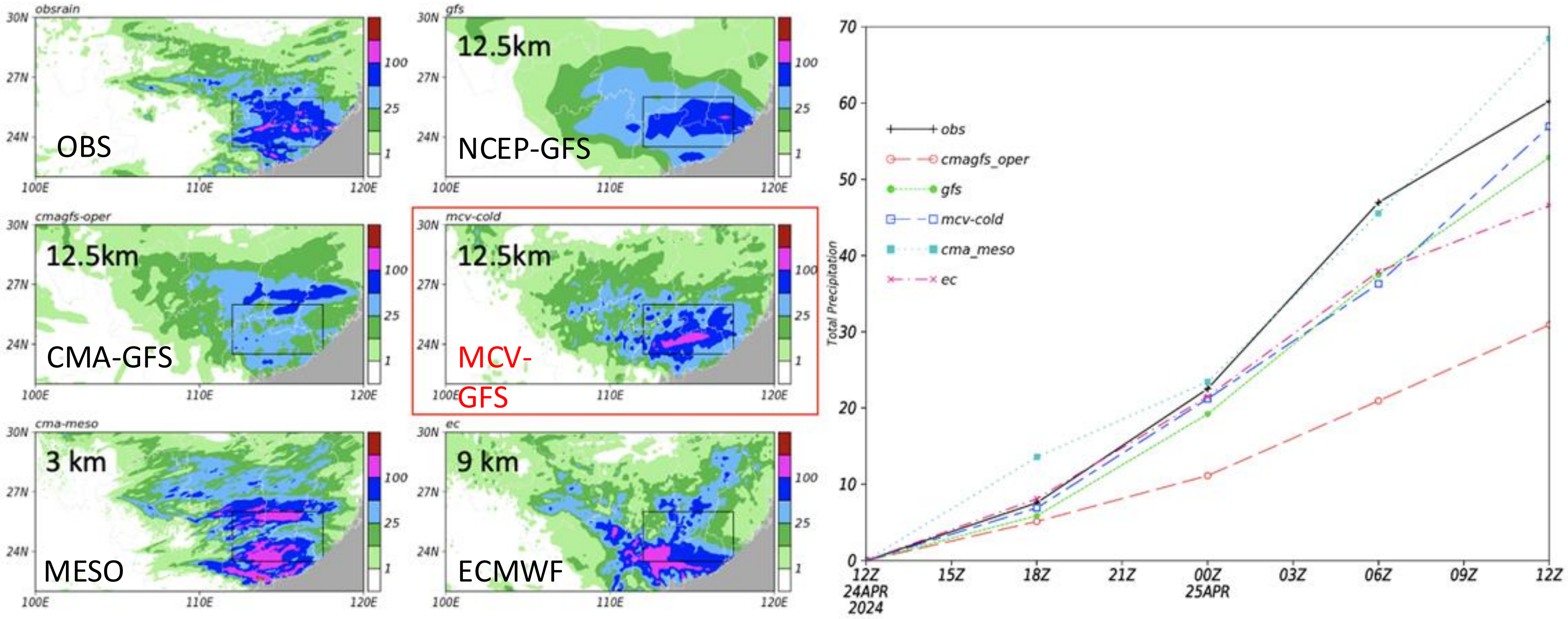
Physical package

- ☐ Scale-aware physical processes
- ☐ C-coupler supports interface between dynamics and physics

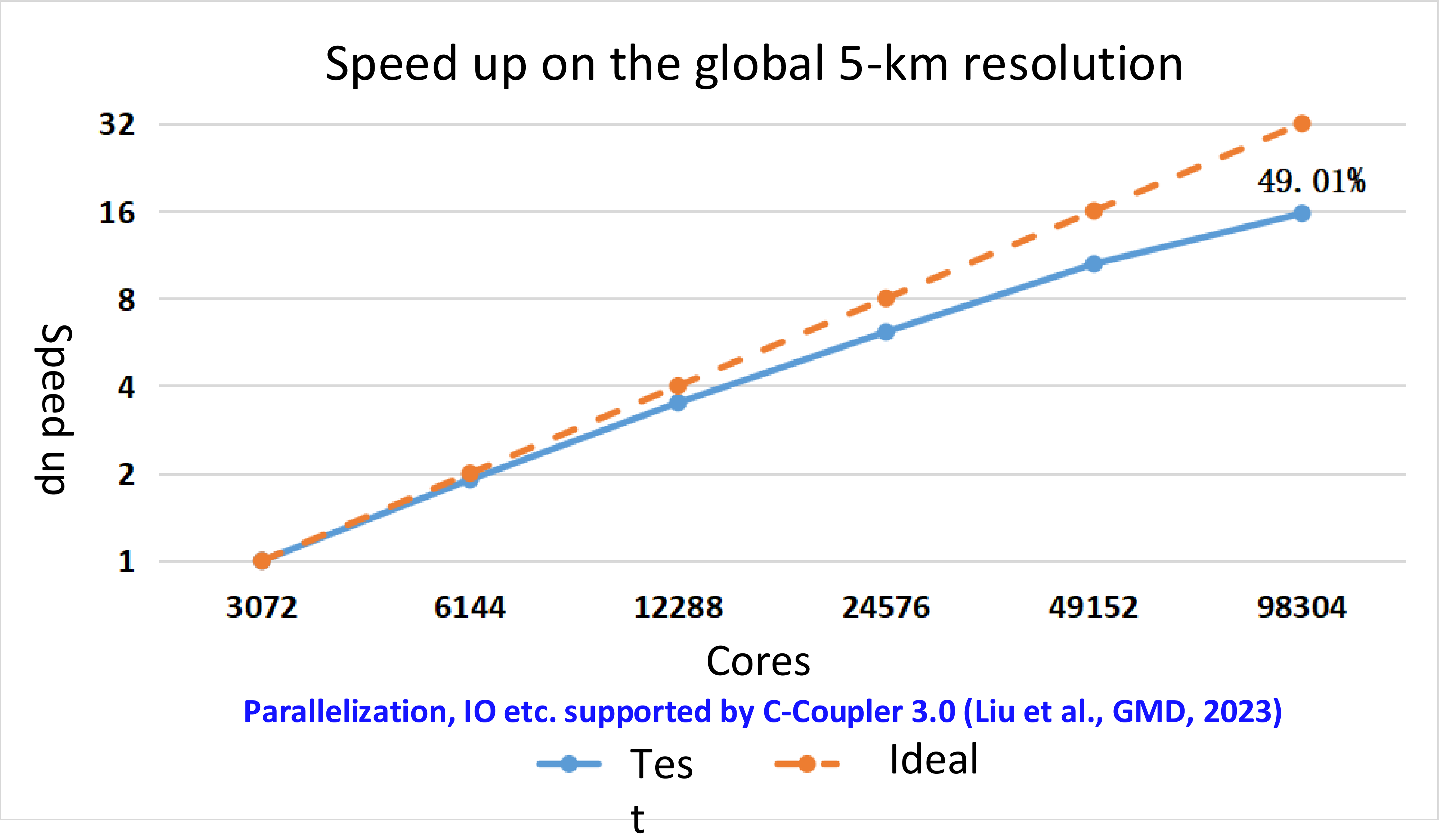
Physical processes	Parameterized scheme
Cumulus convection(shallow, deep)	Scale-aware SAS
Microphysics	2-moments/GFDL MP
Radiation(short, long)	RRTMG
Orographic gravity drag	Kim-Arakawa
Non-Orographic gravity drag	uGWP v0
Land surface	Noah LSM
PBL	Scale-aware TKE EDMF
Surface layer	Monin-Obukhov
Aerosol	OPAC（Category 5，5°×5°）
Stratosphere Ozone and water vapor	NRL

Heavy rain case in south China (12.5km)

☐MCV model 20240424 case



Scalability of MCV model



Parallelization, IO etc. supported by C-Coupler 3.0 (Liu et al., GMD, 2023)

Roadmap of CEMC

CMA Operational Model (GRAPES & CPS based) improvement

(More satellite data, raise model top, model improvement)

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 specific area
- CMA-CPSv4 quasi-operational running

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

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 development

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

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

Thanks for your attention!

Many thanks for my colleague’s contributions!