National Meteorological Center,CMA
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JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2018

CHINA

NMC and NCC

China Meteorological Administration

July, 2019

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JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2018

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1. Summary of highlights

- The GRAPES data assimilation analysis system switched successfully to four-dimensional variational assimilation.

The operation system GRAPES-GFS_4DVAR was completed and parallel test was started on May 8th, 2018. On June 28, this system passed the business evaluation, and the GRAPES-GFS_4DVAR system was put into operation run on July 1st, 2018. The new system was added 06, 18 UTC products issued, and the decoding program was upgraded. Compared with GRAPES-GFS_3DVAR, the system has not only greatly improved the performance of data assimilation and prediction technology, but also upgraded the data retrieval mode, running environment and operation technology. The data retrieval mode is switched from real-time library retrieval to CIMISS retrieval, the running environment is changed from IBM high-performance computer to Sugon high-performance computer, and the running technology is upgraded from SMS technology to ECFLOW technology.

- The GRAPES global ensemble prediction business work has made phased progress.

The key technologies of integration of singular vector initial value perturbation SVs, the random perturbation SPPT of model physical process, the random kinetic energy backscatter compensation scheme and northwest Pacific typhoon SVs initial value perturbation are established. Through system operation stability test and forecasting effect evaluation, the unified post-processing of ensemble forecasting and conventional ensemble forecasting products were developed, and the extreme weather ensemble forecasting products, the track, intensity and attack probability of typhoons in the Northwest Pacific and South China Sea were developed. On December 26, 2018, the GRAPES global ensemble prediction system was put into operation run. The operation environment was switched from IBM high-performance computer to Sugon high-performance computer. The operation technology was upgraded from SMS technology to ECFLOW technology.

- Operation system was migrated from IBM to Sugon high-performance computer.

In 2018, the development of CIMISS-based retrieval technology for observation data has been completed, and the migration of GRAPES global model observation data retrieval system has been completed. The regional observation data retrieval system OBS_REG, OBS_RAFS, radar data assimilation application pre-processing system RAPS, GRAPES_3KM prediction system and its post-processing system were switched from IBM to PI. The GRAPES_MESO_v4.3, GRAPES_MEPS, GRAPES_TYM and the data products system of the Ministry of Environmental Protection were also migrated from IBM to PI and have the business ability. All the procedures needed for migration were recompiled. The operation system, data and graphic products manufacturing system were established.

2. Equipment in use at the Centre

There are two major high-performance computer systems in CMA. The total peak performance of IBM Flex System P460 is 1759 TFlops and the total storage capacity is about 6925TB. Two sets of subsystems of this HPC were installed in Beijing in 2013, in which the peak performance was more than 1PFlops. More details are showed in Table 2.1.

Table 2.1 Details of sub-systems of CMA IBM Flex System and/or P460 HPC Systems

Subsystem	SS1	SS2	SS3	SS4	SS5	SS6	SS7
Site	Beijing		Guangzhou	Shenyang	Shanghai	Wuhan	Chengdu
Peak Performance (TFlops)	527.10	527.10	391.69	77.24	51.80	77.24	26.35
Storage (TB)	2109.38	2109.38	949.22	210.94	140.63	210.94	70.31
CPU Cores （Include I/O nodes）	18560	18560	13792	2720	1824	2720	928
Memory (GB)	81792	81792	57856	10752	7168	10752	3584

The total peak performance of Sugon HPC system is 8189.5 TFlops and the total storage capacity is about 23PB. Two sets of subsystems of this HPC were installed in Beijing in 2018， More details are showed in Table 2.2.

Table 2.2 Details of sub-systems of CMA Sugon HPC Systems

Subsystem	SS1	SS2
Site	Beijing	
Peak Performance (TFlops)	4094.77	4094.77
Storage (TB)	10488	12600
CPU Cores	49216	49216
Memory (GB)	345216	345216

3. Data and Products from GTS in use

Data from the database of NMIC in use are showed in table 3.1 according to one day data used by GRAPES-GFS in December 2018.

Table3.1 Observation data for assimilation system

Data type	Mean	Data type	Mean	Data type	Mean
SYNOP	124201	AIREP/AMDAR	426109	NOAA15_AMSUA	71160
SHIP/BUOY	8385	SATOB (WIND)	200046	NOAA18_AMSUA	53863
TEMP	1546	AIRS	81352	METOP2_AMSUA	111337
GNSS(including	87789	NOAA19-AMSUA	77251	METOP1_AMSUA	75472

COSMIC)					
ASCAT	11963	FY3C-AMSUB	5526	NPP-ATMS	165891
FY4A-HPS	71739				

4. Forecasting system

4.1 System run schedule and forecast ranges

In the new IBM Flex Power P460 and PI-Sugon,, the operational schedule was showed in table 4.1.

Table 4.1 Operational Schedule of NWP system in CMA

Systems	Cut-off time (UTC)	Run time (UTC)	Computer used
Global Forecasting System (GRAPES_GFS2.3)	03:40 (00Z_ASSIM+240HR_FCST)	03:40～04:50	PI-Sugon
	07:10 (00Z_ASSIM. +6HR_.FCST)	07:10～07:50	PI-Sugon
	13:10(06Z_ ASSIM +6HR_.FCST)	13:10～14:00	PI-Sugon
	15:40(12Z_ASSIM.+240HR_FCST)	15:40～16:50	PI-Sugon
	19:10(12Z_ASSIM.+ 6HR_.FCST)	19:10～19:50	PI-Sugon
	01:10(18Z_ASSIM.+ 6HR_.FCST)	01:10～02:00	PI-Sugon
Regional Forecasting System (GRAPES_MESO4.3)	03:20 (00Z_ ASSIM +84HR_.FCST)	03:20 ~ 04:30	IBM Flex P460
	05:00 (03Z_ ASSIM +30HR_.FCST)	05:00 ~ 05:40	IBM Flex P460
	08:00 (06Z_ ASSIM +30HR_.FCST)	08:00 ~ 08:40	IBM Flex P460
	11:00 (09Z_ ASSIM +30HR_.FCST)	11:00 ~ 11:40	IBM Flex P460
	15:20 (12Z_ ASSIM +84HR_.FCST)	15:20 ~ 16:30	IBM Flex P460
	17:00 (15Z_ ASSIM +30HR_.FCST)	17:00 ~ 17:40	IBM Flex P460
	20:00 (18Z_ ASSIM +30HR_.FCST)	20:00 ~ 20:40	IBM Flex P460
	23:00 (21Z_ ASSIM +30HR_.FCST)	23:00 ~ 23:40	IBM Flex P460
Ensemble Forecasts With 31 members (GRAPES-GEPS)	04:40 (00Z_ASSIM+360HR_FCST)	04:40 ~ 07:10	PI-Sugon
	16:40 (12Z_ASSIM+360HR_FCST)	16:40 ~ 19:10	PI-Sugon
Regional Typhoon Forecasting System (GRAPES-TYM 2.1)	04:20 (00Z_120HR_FCST)	04:20 ~ 06:10	IBM Flex P460
	11:00 (06Z_120HR_FCST)	11:00 ~ 12:50	IBM Flex P460
	17:00 (12Z_120HR_FCST)	17:00 ~ 18:50	IBM Flex P460
	23:00 (18Z_120HR_FCST)	23:00 ~ 00:50	IBM Flex P460
Regional Ensemble Forecasting system with 15 members (GRAPES-REPS)	04:55(00Z_96HR_FCST)	04:55~08:00	IBM Flex P460
	16:55(12Z_96HR_FCST)	16:55~20:00	IBM Flex P460
Sand/dust Forecasting system (T639)	05:30 (00Z_72HR_FCST)	05:30 ~ 06:50	IBM Flex P460
	18:30 (12Z_72HR_FCST)	18:30 ~ 19:50	IBM Flex P460
Sea Wave Forecasting System (WW3)	07:20 (00Z_120HR_FCST)	07:20 ~ 07:40	IBM Flex P460
	19:20 (12Z_120HR_FCST)	19:20 ~ 19:40	IBM Flex P460
HAZE Forecast System	00:10 (00Z_120HR_FCST)	00:10~05:40	IBM Flex P460

(T639)	12:00 (12Z_120HR_FCST)	12:00~17:40	IBM Flex P460
GRAPES_MESO(HR 3KM) Forecast System	04:10 (00Z+48HR_FCST)	04:10～05:40	PI-Sugon
	10:10 (06Z+48HR_FCST)	10:10～11:40	PI-Sugon
	16:10 (12Z+48HR_FCST)	16:10～17:40	PI-Sugon
	22:10 (18Z+48HR_FCST)	22:10～23:40	PI-Sugon

4.2 Medium range forecasting system (4-10 days)

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation

The production service of T639-GSI global forecast system was terminated in 2018. The GRAPES global 4D-var system was built to run on Sugon HPCs for the first time on July 1st 2018. By using more CPUs, the run time of 240hrs forecast can be shortly limited in 55 minutes.

4.2.1.2 Research performed in this field

In 2018, many research was performed in this field. The preconditioning of Lanczos-CG algorithm has been validated through the 1-month 4D-Var cycles. The approximated eigenpairs of Hessian matrix are calculated during the 4D-Var minimization at the first DA cycle and provided to conduct the preconditioning operator in the 4D-Var minimization at eh subsequent times in 1 month. The averaged 4D-Var minimization iteration number is reduced significantly after the use of this preconditioning scheme.

The new linear deep convection and large-scale condensation schemes based on NSAS (Han and Pan, 2006) and Tompkins schemes (Tompkins and Janiskova, 2004) have been improved further and are ready for the operational run.

The bias correction factors for AMSUA observation have been changed to the thickness between 194 and 882 hPa, between 56 and 194 hPa, and between 7 and 35 hPa. The old bias correction scheme uses the thickness between 358 and 1005 hPa, between 56 and 194 hPa as the correction factor. This modification has a positive impact on the 4D-Var analysis.

The assimilation of METOP-A/B IASI observation has been developed which focus on the channel selection and adaptive bias correction. The preliminary results show that the 4D-Var analysis has been improved in the middle and upper troposphere.

The assimilation of Chinese FY satellite observation has been put more and more efforts. The impact of FY-4A GIIRS observations on the 4D-Var analysis and global forecast is slightly positive which have been used in the operational 4D-Var system from the end of 2018. The FY-3D MWHS2 observation is ready for the operational use. The assimilation of FY-4A AGRI is also evaluated in the global 4D-Var. The preliminary results show that the impact is neutral.

4.2.2 Model

4.2.2.1 In operation

Medium-range system GRAPES GFS has been upgraded on 25 December 2018, with Improvements including implementation of the planetary boundary layer scheme and cloud scheme on the CP grid, improved surface layer defined as between the surface and the first full layer rather than first half-level for heat diffusion in previous operational model, calling of radiation, and so on.

4.2.2.2 Research performed in this field

In GRAPES global model, Predictor-Corrector SISL scheme and 3D reference profile continued to be improved: completed idealized test, ameliorated the initial reference profile and orography, cut down different artificial fixers. In order to reduce wet biases, deep convection and shallow convection and cloud schemes are modified in many details, including introducing organized entrainment, separation of water vapour and cloud water in convective cloud model in deep convection, optimization of entrainment and detrainment and modification of trigger mechanisms of shallow convection, improvement of condensation and evaporation of cloud, macro cloud, consistency of cloud cover and condensate.

Based on the multi-moment finite volume (MMFV) framework, a scalable high-order nonhydrostatic multi-moment finite volume dynamical core on the cubed sphere is developed. The nonhydrostatic model with the shallow-atmosphere approximation is discretized by the three-point MMFV scheme in space and horizontally-explicit and vertically-implicitly(HEVI) Runge-Kutta implicit-explicit scheme in time. The benchmark tests such as 3D Rossby Haurwitz waves, mountain-induced Rossby waves, gravity waves and baroclinic instability tests indicate that the present model is competitive to the existing advanced global atmospheric models.

4.2.3 Operationally available Numerical Weather Prediction (NWP) Products

In 2016, The GRAPES_GFS model is put into operational run. In 2018, many variables which are outputs from the model integration are added to operationally available NWP products. A list of GRAPES_GFS model products is given in table 4.2.3.1 and table 4.2.3.2.

Table 4.2.3.1 The List of GRAPES_GFS model isobaric surface Products (GRIB2 format)

Variables	Unit	Layer	Level (hPa)	Area
Geopotential height	Gpm	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	**The globe：** 0.25°×0.25° 1440×720 0°N－359.75°N， 89.875°E－-89.875°E
Temperature	K	30		
U-wind	m/s	30		
V-wind	m/s	30		
Vertical velocity	m/s	30		
vorticity	s-1	30		
divergence	s-1	30		

Specific humidity	Kg/kg	30	
Relative humidity	%	30	
Cloud water mixing ratio	Kg/kg	30	
Rain water mixing ratio	Kg/kg	30	
Ice water mixing ratio	Kg/kg	30	
Snow water mixing ratio	Kg/kg	30	
graupel	Kg/kg	30	
Cloud cover	%	30	
10m U-wind	m/s	1	10 m above ground
10m V-wind	m/s	1	10 m above ground
2m Temperature	K	1	2 m above ground
Surface temperature	K	1	surface
Sea surface pressure	Pa	1	mean sea level
Surface Pressure	Pa	1	surface
2m Specific humidity	kg/kg	1	2 m above ground
2m Relative humidity	%	1	2 m above ground
Convective precipitation	mm	1	Surface
Large scale precipitation	mm	1	Surface
Total precipitation	mm	1	Surface
Low-level cloud cover	%	1	cloud base
Middle-level cloud cover	%	1	cloud base
High-level cloud cover	%	1	cloud base
Total cloud cover	%	1	cloud base
Total column integrated vapour content	kg/m**2	1	Total Column
Total column integrated water content	kg/m**2	1	Total Column
Total column integrated ice content	kg/m**2	1	Total Column
Surface sensible heat flux	W m**-2 s	1	surface
Surface latent heat flux			
Surface solar radiation	W m**-2 s	1	surface
upward long- wave radiation flux(surface)	W m**-2 s	1	surface
Terrain height	Gpm	1	surface
Dew point temperature	K	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000
Temperature Advection	K/s	30	
Vorticity Advection	1/s2	30	
Dew point temperature difference	°C	30	
Water vapour flux	g/cm·hPa·s	30	
Divergence of vapour flux	g/cm2·hPa·s	30	
Pseudo-equivalent potential temperature	K	30	
radar reflectivity	dBz	30	
Strong weather threat index	-	1	Surface
Convective available potential energy	J/kg	1	Surface
Convective inhibition energy	J/kg	1	Surface

Lifting index	K	1	Surface	
Condensation layer pressure	hPa	1		
K index	°C	1	mean sea level	
Radar composite reflectivity	dBz			
Simulated satellite brightness temperature of vapor channel	K	1	Surface	
Simulated satellite brightness temperature of infrared channel	K	1	Surface	
Albedo	%	1	surface	
2m Dew point temperature	K	1	2m	
Snow depth	m	1	surface	
Amount of snow	m	1	surface	
Soil moisture	Kg/kg	1	0-0.1m below ground	
Soil moisture	Kg/kg	1	0.1-0.3m below ground	
Soil moisture	Kg/kg	1	0.3-0.6m below ground	
Soil moisture	Kg/kg	1	0.6-1.0m below ground	
Soil temperature	K	1	0-0.1m below ground	
Soil temperature	K	1	0.1-0.3m below ground	
Soil temperature	K	1	0.3-0.6m below ground	
Soil temperature	K	1	0.6-1.0m below ground	
North-south stress	n/m^2s	1	surface	
East-west stress	n/m^2s	1	surface	
Shawlt index	K	1	surface	
Boundary height	m	1	surface	
Atmospheric top Net shor-twave radiation	w.m^-2.s	1	Top of atmosphere	
Surface clear sky net short-wave radiation	w.m^-2.s	1	Surface	
atmospheric clear sky net short-wave radiation	w.m^-2.s	1	Top of atmosphere	
Ground-up long-wave radiation	w.m^-2.s	1	surface	
Atmospheric top upward long-wave radiation	w.m^-2.s	1	Top of atmosphere	
Surface upward short-wave radiation	w.m^-2.s	1	Surface	
Atmospheric top upward short-wave radiation	w.m^-2.s	1	Top of atmosphere	
Surface clear sky upward short-wave radiation	w.m^-2.s	1	Surface	
Atmospheric top clear sky upward short-wave radiation	w.m^-2.s	1	Top of atmosphere	
Surface clear sky upward long-wave radiation	w.m^-2.s	1	Surface	
Atmospheric top clear sky upward long-wave radiation	w.m^-2.s	1	Top of atmosphere	
Surface clear sky downward long-wave radiation	w.m^-2.s	1	Surface	
roughness		1	Surface	
2m Maximum temperature	K	1	2m	
2m Minimum temperature	K	1	2m	
2m Maximum relative humidity	%	1	2m	
2m Minimum relative humidity	%	1	2m	

Table 4.2.3.2 The List of GRAPES_GFS model Products

Variables	unit	layer	Area
Exner pressure	-	62	**The global：** 0.25°×0.25° 1440×720 0°N－359.75°N， 89.875°E－-89.875°E
Potential temperature	K	61	
u-wind	m/s	60	
v-wind	m/s	60	
Vertical velocity	m/s	61	
Specific humidity	kg/kg	61	
Cloud fraction	0-1	61	
Cloud water mixing ratio	kg/kg	61	
Rain water mixing ratio	kg/kg	61	
Ice water mixing ratio	kg/kg	61	
Snow water mixing ratio	kg/kg	61	
graupel	kg/kg	61	
Perturbed potential temperature	K	61	
Perturbed Exner pressure	-	62	
temperature	K	61	
Geopotential height	Gpm	61	
pressure	hPa	61	

4.2.4 Operational techniques for application of NWP products *(MOS, PPM, KF, Expert Systems, etc..)*

4.2.4.1 In operation

Global grid meteorological elements forecast system was put in quasi-operation. Its products information is given in following table.

No	Variable	unit	Forecast hours	Resolution/Area/Frequency
1	Maxmum temperature	C	024，048，072，096，120，144，168，192，216，240，264，288，312，336，360	horizontal resolution：0.1*0.1 -90°N ~90°N 0°E ~360°E 00UTZ，12UTZ
2	Minmum temperature	C		
3	Maxmum relative humidity	%		
4	Minmum relative humidity	%		
5	Temperature	C	000，003，006，009，012，015，018，021，024，027，030，033，036，039，042，045，048，051，054，057，060，063，066，069，072，075，078，081，084，087，090，093，096，099，102，105，108，111，114，117，120，126，132，138，144，150，156，162，168，180，192，204，216，228，240	
6	Relative humidity	%		
7	Cloud	%		
8	Wind	m/s		

4.2.4.2 Research performed in this field

Based on model output and regional observation station data, more MOS forecast products are developed and put into interpolation-process of grid meteorological elements forecast system over China area.

4.2.5 Ensemble Prediction System (EPS) (Number of members, initial state, perturbation method, model(s) and number of models used, number of levels, main physics used, perturbation of physics, post-processing: calculation of indices, clustering)

4.2.5.1 In operation

The new global operational ensemble prediction system (GEPS) based on GRAPES global model (GRAPES-GEPS) has been operationally running since Dec. 26 2018, which replaces the previous T639-GEPS. The analysis of the control forecast of GRAPES-GEPS is generated by GRAPES 4D-Var data assimilation system. The configuration of GRAPES-GEPS is as follows:

- Number of members: 31 members; 30 perturbed members (adding/subtracting 15 initial perturbations which are generated from singular vectors) plus one control run;
- Initial state perturbation method: Singular Vector Method;
- Number of models used: one model, GRAPES_GFS with the horizontal resolution of 0.5^{o};
- The vertical levels of integrations of GRAPES-GEPS: 60 levels with model top at 3hPa;
- Perturbation of physical process: Stochastic Physical Processes Tendency (SPPT) method; The Stochastic Kinetic Energy Backscatter (SKEB) scheme
- Running cycle: twice a day with initial time at 00 and 12UTC;
- Integration time: 15 days.

4.2.5.2 Research performed in this field

The research and development work on the global ensemble based on GRAPES_GFS model (GRAPES-GEPS) were continuously going at CMA, and major achievements of research works have been used in the new operational GRAPES-GEPS by the end of 2018. The tropical cyclone (TC) targeted SVs are improved, and have been included in the initial perturbations. The inclusion of the SKEB in the GRAPES-GEPS have been further tested, and the typical season experiments of using the combination of SPPT and SKEB for representation of model uncertainties have been conducted. The comparison between T639-GEPS and GRAPES-GEPS were carried out through objective verifications and subject verifications from the viewpoint of forecasters.

4.2.5.3 Operationally available EPS Products

The GRAPES-based global ensemble prediction model products generated in operational are 0-360h forecasts for 00UTC and 12UTC initial time. Ensemble size is 31 including 30 perturbed forecast and control run. The output interval is 6 hours. A list of NWP GEPS Products in graphical format is given in table 4.2.5.3.1. A selection is available via the CMA website at: http://www.nmc.cn/publish/grapes-new/Probability/24h-Accum-Precip/25mm.html.

Table 4.2.5.3.1 The list of global EPS products in graphical format

Variables	**Unit**	**Laye**	**Level**	**EPS products**	**Probability threshold**
Geopotential height	Gpm (geopotential meters)	1	500hPa	Spaghetti	
				Ensemble Mean & Spread	
Relative humidity	%	2	700, 850hPa	Ensemble Mean & Spread	
Temperature	K	1	850 hPa	Ensemble Mean & Spread	
24-hr Accum. Precip.	mm	1	Surface	Ensemble Mean	
				Mode & Maximum	
				Thumbnails	
				PRBT	1, 10, 25, 50 ,100mm
Sea Surf Pres	hPa	1	mean sea level	Ensemble Mean & Spread	
2m Temperature	K	1	2 m above ground	Ensemble Mean & Spread	
10m Wind speed	m/s	1	10m above ground	Ensemble Mean & Spread	
				PRBT	10.8, 17.2m/s
Extreme Forecast Index for 24-HR Accum. Precip		1	Surface	Extreme forecast index	
Extreme Forecast Index for 2m Temp		1	2 m above ground		
Extreme Forecast Index for 10m Wind			10m above ground		
EPS METEOGRAM (including Total cloud cover 6-H Accum Precip 10m Wind 2m Temp)				BOX & WHISKERS	

4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

The GRAPES regional 3DVAR system is global and regional unified assimilation system with 10km horizontal resolution and 50 vertical levels the same as the GRAPES_MESO model. The system domain covers the whole China (from 70°E to 145°E and from 15°N to 65°N) and the grid space is

751×501. The data assimilated include the conventional GTS data、GPS/PW and FY_2E. The analysed variables include zonal and meridional winds, no-dimensional pressure and specific humidity. The cloud analysis package uses radar reflectivity and other cloud observational information to update several hydrometeor variables and potential temperature in the 3DVAR analysis step. The first guess is from the operational 6-hour prediction of T639 global model with the digital filter for initialization. Based on GRAPES regional 3DVAR, Grapes Rapid Analysis and Forecast System is implemented with 12 hour assimilation time window, starting at 00/12 UTC and observations are assimilated every 3 hour. The cold start steps (00 and 12UTC) in RAFS provide 84-hour forecasting products and the warm start steps in RAFS provide 30-hour forecasting products every 3 hours.

The GRAPES regional 3DVAR system has been upgraded form version 4.2 to 4.3 on August 1st 2018. Main improvements include new tuning horizontal correlation scale for background error, and developing parallel input-output.

4.3.1.2 Research performed in this field

In 2018, data assimilation improvements of GRAPES-MESO model include: 1) evaluating FY4 satellite cloud data in cloud analysis system; 2) converting radar radial wind form polar coordinates to longitude and latitude, then thinning to be prepared for assimilation; 3) developing noise removal algorithm for radial wind quality control scheme; 4) evaluating radar radial wind quality for assimilation application; 5) optimizing pre-process scheme for radar wind profile quality control.

4.3.2 Model

4.3.2.1 In operation

The operational GRAPES_Meso is a non-hydrostatic grid point model with 10km horizontal resolution and 50 levels in the vertical. The domain of the model integration covers the whole East Asia, and the forecast range is up to 84hrs. The specification of GRAPES_Meso is:

- Equations: Fully compressible and non-hydrostatical equations with shallow atmosphere approximation
- Variables: Zonal wind u, meridional wind v, vertical velocity w, potential temperature θ, specific humidity q(n) and Exner pressure π.
- Numerical technique: 2-time level semi-implicit and semi-Lagrangian method for time-space discretization; 3D vectored trajectory scheme used in computation of the Lagrangian trajectory; Piece-wise Rational Method (PRM) for scalar advection.
- Horizontal staggered grid: Arawaka C-grid.
- Time step: 60s.
- Vertical grid: Height-based terrain-following vertical coordinate with Charney-Phillipps variable arrangement in vertical.

- Physics: RRTM L W/ Fouquart & Bonnel SW, KF cumulus, WSM-6 microphysics, MRF vertical diffusion, NOAH land surface.

- The GRAPES-MESO system has been upgraded form version 4.2 to 4.3 on August 1st 2018. The improvements include the upgrade of reference temperature profiler from isothermal atmosphere to initial averaged thermal atmosphere, optimization of surface process and parallel output and new grid2 decode.

4.3.2.2 Research performed in this field

In 2018, many research was performed in this field. Model improvements include: introducing double-moment microphysics scheme developed by NMPC into GRAPES_MESO system to improve precipitation and water phase forecast; implementing process for initial fields and boundary condition of GRAPES_MESO provided by GRAPES_GFS forecast pressure result; introducing RRTMG radiation scheme into GRAPES_MESO system; implementing diagnostic scheme for cloud cover and cloud liquid water path; evaluating the forecast performance of GRAPES_MESO with 3km horizontal resolution and domain covered the whole China mainland.

4.3.3 Operationally available NWP products

In 2018, many variables which are outputs from the model integration are added to operationally available regional NWP products. A list of GRAPES_MESO products is given in table 4.3.3.1 and 4.3.3.2.

Table 4.3.3.1 The List of GRAPES_MESO model isobaric surface Products (GRIB2 format)

<table>
<tr><th>No.</th><th>Variable</th><th>unit</th><th>Layer</th><th>Level(hPa)</th><th>Area</th></tr>
<tr><td>1</td><td>Geopotential height</td><td>Gpm (geopotential meters)</td><td>30</td><td rowspan="15">10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000</td><td rowspan="19">horizontal resolution：0.1*0.1

Grid points：751*501

15°N ~65°N
70°E ~145°E</td></tr>
<tr><td>2</td><td>Temperature</td><td>K</td><td>30</td></tr>
<tr><td>3</td><td>U-wind</td><td>m/s</td><td>30</td></tr>
<tr><td>4</td><td>V-wind</td><td>m/s</td><td>30</td></tr>
<tr><td>5</td><td>Vertical velocity</td><td>m/s</td><td>30</td></tr>
<tr><td>6</td><td>vorticity</td><td>s-1</td><td>30</td></tr>
<tr><td>7</td><td>divergence</td><td>s-1</td><td>30</td></tr>
<tr><td>8</td><td>Specific humidity</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>9</td><td>Relative humidity</td><td>%</td><td>30</td></tr>
<tr><td>10</td><td>Cloud water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>11</td><td>Rain water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>12</td><td>Ice water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>13</td><td>Snow water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>14</td><td>Graupel</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>15</td><td>Cloud cover</td><td>%</td><td>30</td></tr>
<tr><td>16</td><td>10m U-wind</td><td>m/s</td><td>1</td><td>10 m above ground</td></tr>
<tr><td>17</td><td>10m V-wind</td><td>m/s</td><td>1</td><td>10 m above ground</td></tr>
<tr><td>18</td><td>2m Temperature</td><td>K</td><td>1</td><td>2 m above ground</td></tr>
<tr><td>19</td><td>Surface temperature</td><td>K</td><td>1</td><td>surface</td></tr>
</table>

20	Sea surface pressure	Pa	1	mean sea level	
21	Surface pressure	Pa	1	surface	
22	2m Specific humidity	kg/kg	1	2 m above ground	
23	2m Relative humidity	%	1	2 m above ground	
24	Convective precipitation	mm	1	surface	
25	Large scale precipitation	mm	1	surface	
26	Total precipitation	mm	1	surface	
27	Surface sensible heat flux	W/m**2	1	surface	
28	Surface water vapor flux	kg/(m2·s)	1	surface	
29	Surface solar radiation	W/m**2	1	surface	
30	upward long- wave radiation flux(surface)	W/m**2	1	surface	
31	Terrain height	Gpm	1	surface	
32	Dew point temperature	K	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	
33	Temperature Advection	K/s	30		
34	Vorticity Advection	1/s2	30		
35	Dew point temperature difference	K	30		
36	Water vapour flux	g/cm·hPa·s	30		
37	Divergence of vapour flux	g/cm2·hPa·s	30		
38	Pseudo-equivalent potential temperature	K	30		
39	Radar reflectivity	dBz	30		
40	Strong weather threat index	-	1	--	
41	Convective available potential energy	J/kg	1	--	
42	Convective inhibition energy	J/kg	1	--	
43	Lifting index	K	1	--	
44	Condensation layer pressure	hPa	1	--	
45	K index	K	1	--	
46	Snow	m	1	surface	
47	0-1000m storm-relative helicity	M2/s2	1	0_1000m	
48	0-3000m storm-relative helicity	M2/s2	1	0-3000m	
49	Planetary boundary layer height	M	1	--	
50	Height of radar echo top	M	1	--	
51	Richardson number of surface layer	-	1	Surface	
52	Richardson number of PBL	-	1	Boundary layer	
53	Maximum of u10m in output interval	m/s	1	10m	
54	Maximum of v10m in output interval	m/s	1	10m	
55	0-1000m Vertical speed shear	1/s	1	0-1000m	
56	0-3000m Vertical speed shear	1/s	1	0-3000m	
57	0-6000m Vertical speed shear	1/s	1	0-6000m	
58	Radar composite reflectivity	dBz	1	--	
59	Simulated satellite brightness temperature of vapor channel	K	1	--	
60	Simulated satellite brightness temperature of infrared channel	K	1	--	
61	Maximum vertical speed in output interval	m/s	1	--	

62	The best lifting index	K	1	--	
63	Maximum radar composite reflectivity in output interval	dbz	1	--	
64	Hail index	--	1	--	
65	Shawalter index	K	1	--	
66	Wind index	m/s	1	--	
67	Height of 0 degree isothermal level	m	1	--	
68	Height of -20 degree isothermal level	m	1	--	
69	Down convective available potential energy	j/kg	1	--	
70	Storm strength index	J/kg	1	--	
71	Soil moisture	Kg/kg	1	0-0.1m below ground	
72	Soil moisture	Kg/kg	1	0.1-0.3m below ground	
73	Soil moisture	Kg/kg	1	0.3-0.6m below ground	
74	Soil moisture	Kg/kg	1	0.6-1.0m below ground	
75	Soil temperature	K	1	0-0.1m below ground	
76	Soil temperature	K	1	0.1-0.3m below ground	
77	Soil temperature	K	1	0.3-0.6m below ground	
78	Soil temperature	K	1	0.6-1.0m below ground	
79	Total index	K	1	--	
80	2m dew point temperature	K	1	2m	
81	Maximum ascending helicity	M^2/s^2	1	2000-5000m	
82	The whole layer precipitable water	Kg/m^2	1	--	
83	Total cloud cover	%	1	cloud base	
84	Low-level cloud cover	%	1	cloud base	
85	Middle-level cloud cover	%	1	cloud base	
86	High-level cloud cover	%	1	cloud base	
87	Atmospheric total column vapour	kg/m^2	1	entire atmosphere Total Column	
88	Atmospheric total column cloud water	kg/m^2	1	entire atmosphere Total Column	
89	Atmospheric total column cloud ice	kg/m^2	1	entire atmosphere Total Column	

Table 4.3.3.2 The List of GRAPES_GFS model Products

Variables	unit	layer	Area
Exner pressure	-	51	horizontal resolution：0.1°×0.1° Grid points: 751×501 70°N－145°N，15°E－65°E
Potential temperature	K	50	
u-wind	m/s	49	
v-wind	m/s	49	
Vertical velocity	m/s	50	
Specific humidity	kg/kg	50	
Cloud fraction	0-1	50	
Cloud water mixing ratio	kg/kg	50	
Rain water mixing ratio	kg/kg	50	
Ice water mixing ratio	kg/kg	50	
Snow water mixing ratio	kg/kg	50	
graupel	kg/kg	50	

Perturbed potential temperature	K	50	
Perturbed Exner pressure	-	51	
temperature	K	50	
Dew-point temperature	K	50	
Dew point temperature difference	K	50	
Pseudo-equivalent potential temperature	K	50	
Richardson number	-	49	
Geopotential height	Gpm	50	
Radar reflectivity	dBz	50	
Maximum radar reflectivity at output interval	dBz	50	

4.3.4 Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc..)

4.3.4.1 In operation

Specific content refer to 4.2.4.1.

4.3.4.2 Research performed in this field

Specific content refer to 4.2.4.2.

4.3.5 Ensemble Prediction System (Number of members, initial state, perturbation method, model(s) and number of models used, perturbation of physics, post-processing: calculation of indices, clustering)

4.3.5.1 In operation

The GRAPES-MEPS ensemble calculates the initial condition perturbations using the ensemble transform Kalman filter (ETKF) in 2016. A Multiple Scale Blending (MSB) perturbations method has been operationally implemented since March 2017. Aside from the change of ICs perturbations, the multiple parameterization schemes and Stochastically Perturbed Parameterization Tendencies (SPPT) scheme were employed in GRAPES-MEPS to describe the model uncertainty. In GRAPES SPPT scheme, the random field which is described with first order Markov chain has a time-related characteristics and Gaussian distribution, and also has a continuous and smooth horizontal structure. The system configurations are as follows:

- Number of models used: one model (GRAPES-MESO V4.2.0 with 15km horizontal resolution and 51 vertical levels);
- Domain: 70-140^{o} E, 15-60^{o} N;

- Number of members: 15 members; 14 perturbed members (perturbations produced by Ensemble Transform Kalman Filter method and Multiple Scale Blending perturbations) plus one control run;

- Initial condition perturbation method: A Multiple Scale Blending (MSB) perturbations of initial conditions and Ensemble Transform Kalman Filter (ETKF);

- Perturbation of physical process: Different combinations of two PBL schemes and four cumulus schemes and Stochastically Perturbed and Parameterization Tendencies (SPPT) scheme；

- Running cycle: 00UTC and 12UTC;

Integration time: 96h for both 00UTC and 12UTC.

4.3.5.2 Research performed in this field

Unlike the retail-like statistical post-processing methods, an innovative wholesale-like dynamical approach is proposed to correct forecast bias during model integration. By subtracting a bias tendency from model total tendency, it is intended to automatically debias all variables at once at the end of model integration. Three experiments were tested to examine the effectiveness of ways to subtract bias tendency. The verification of 500-hPa temperature indicates that all three experiments significantly improved the raw ensemble forecasts: reduced bias error, more accurate ensemble mean, better spread-skill relation, and more reliable and sharper probabilities. When the verification was expanded to include more variables, a summary scoreboard shows that the three experiments also had a general positive impact on both upper air and surface variables especially the height and temperature fields. Precipitation forecasts remained little changed. Given its advantages, this approach represents a future of correcting biases in a numerical weather prediction model.

We experimented a unified scheme of stochastic physics and bias correction within a regional ensemble model GRAPES-REPS. It is intended to maximize ensemble prediction skill by reducing both random and systematic errors at the same time. The result showed that: (1) the stochastic physics can effectively increase the ensemble spread, while the bias correction cannot. Therefore, the ensemble averaging of the stochastic physics run can reduce more random error than the bias correction run. (2) The bias correction can significantly reduce systematic error, while the stochastic physics cannot. As a result, the bias correction greatly improved the quality of ensemble mean forecast but the stochastic physics didn’t. (3) The unified scheme can greatly reduce both random and systematic errors at the same time. These results were further confirmed by the verification of ensemble mean, spread and probabilistic forecasts of many atmospheric fields both at upper air and surface including precipitation. Based on this study, we recommend operational numerical weather prediction to adopt this unified scheme approach in ensemble models to achieve the best forecasts.

To represent model uncertainties more comprehensively, a stochastically perturbed parameterization (SPP) scheme consisting of temporally and spatially varying perturbations of 18 parameters in the microphysics, convection, boundary layer and surface layer parameterization schemes is developed in the Global and Regional Assimilation and Prediction Enhanced System-Regional Ensemble Prediction System (GRAPES-REPS). The stochastically perturbed parameterization tendencies (SPPT) scheme and the stochastic kinetic energy backscatter (SKEB) scheme are also applied with the SPP to evaluate various combinations of multiple stochastic physics schemes. The results show that: (1) all combinations of stochastic parameterization schemes perform better than the single SPP scheme, indicating that combinations of multiple stochastic parameterization schemes can better represent model uncertainties; (2) the combination of all three stochastic physics schemes (SPP, SPPT and SKEB) outperforms any other combination of two schemes in precipitation forecasting and surface and upper air verification to best capture the model errors and improve the forecast skill; (3) by assessing the performance of the SPP_SPPT and SPP_SKEB experiments against that of using only SPP, we found that SPPT had a larger impact on the simulation of precipitation, while SKEB had a larger impact on improving the ensemble spread and reducing the outlier for wind speed; and (4) the introduction of SPP has a positive added value and does not change the energy evolution characteristics of the model at any wavelength or level. This study indicates the potential of combining multiple stochastic physics schemes and lays a foundation for the future development and design of regional and global ensembles.

4.3.5.3 Operationally available EPS Products

GRAPES-based mesoscale ensemble prediction system model products generated in operational are 0-72h forecasts for 00UTC and 12UTC initial time. The ensemble size is 15 including 14 perturbed forecast and control run. The output interval is 3 hours. A list of NWP GEPS Products in graphical format is given in table 4.3.2. A selection is available via the CMA website at:

http://www.nmc.cn/publish/nwpc/grapes-regional/probability/24hrain/index-3.html

Table 4.3.2 The list of Mesoscale EPS products in graphical format

Variables	Unit	Layer	Level	EPS products	Probability threshold
24-HR Accum. Precip.	mm	1	Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 10, 25, 50 ,100
12-HR Accum. Precip.	mm	1	Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 5, 15, 30 ,70
6-HR Accum.	mm			Thumbnails	

Precip.				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 4, 13, 25 ,60
3-HR Accum. Precip.	mm		Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 3, 10, 20 ,50
Sea Surf Pres	hPa		mean sea level	Ensemble Mean & Spread	
2m Temp	K		2 m above ground	Ensemble Mean & Spread	
10m Wind	m/s		10 m above ground	Ensemble Mean & Spread	
				PRBT	5.5,8, 10.8, 17.2, 24.5, 32.7
Convective Available Potential Energy	J/kg			Ensemble Mean & Spread	
				PRBT	200, 500, 1000, 1500, 2000, 2500
Convective Inhibition	J/kg			Ensemble Mean & Spread	
				PRBT	50, 100, 150, 200
Combined Radio Reflection Ratio	dbz			Thumbnails	
				Ensemble Mean & Spread	
				PRBT	5, 10, 20, 30, 40
K index				Ensemble Mean & Spread	
				PRBT	30, 35, 40, 45
Best Lifting Index				Ensemble Mean & Spread	
				PRBT	0, -2, -4, -6
0-1km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	8, 12, 16, 18
0-3km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	12, 16, 20, 24
0-6km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	20, 26, 32, 38
Down CAPE	J/kg			Ensemble Mean & Spread	
				PRBT	500, 1000, 1500, 2000
Hail Index				Ensemble Mean & Spread	
				PRBT	0.2, 0.5, 0.8, 1, 1.5
EPS METEOGRAM (Including 3-H Accum. Precip. 10m Wind 2m Temp 2m RH)				BOX & WHISKERS	

4.4 Nowcasting and Very Short-range Forecasting Systems (0-12 hrs)

In May 2018, the CMA issued the Action Plan for Seamless Intelligent Grid Forecasting, which clearly sets out the research and development tasks of scientific laws, forecasting techniques, system platforms and evaluation methods in nowcasting and very short-range forecasting. It is planned that the next generation Severe Weather Analysis and Nowcasting system the SWAN3, which integrates the above research results, will be put into trial use in national and local meteorological forecast units in 2020. China is gradually establishing the seamless operations from real-time monitoring to very short-time prediction. And the seamless grid digital products has been transferred to aviation weather service products such as temperature, wind speed, wind direction, visibility, thunderstorm, heavy rainfall of terminal airport and dangerous weather of route (thunderstorm, turbulence, ice, etc.)

4.4.1 Nowcasting system

4.4.1.1 In operation

The SWAN is greatly improved. Through the parallel modification and optimization of the algorithm, the real-time puzzle of nearly 200 radars in China is completed in 2 minutes, and the operation of TITAN, TREC, QPF and other algorithms is completed in 4 minutes. In addition, some new algorithms, such as thunderstorm gale identification and prediction algorithm based on radar data and PredRNN radar echo prediction model based on deep learning, are integrated into the SWAN system, which makes the automatic early warning ability of SWAN for severe convective weather significantly improved. The SWAN system has evolved from a warning system that can only support local forecasting units to an operational system that can also effectively support severe convective weather monitoring and watching at the national level.

The 5km classification severe convective weather prediction system is running by the Severe Weather Prediction Center. It provides 8 times a day updated hourly thunderstorm, short-term heavy rainfall with 1-h accumulated precipitation over 20mm and 50mm, hail and thunderstorm gale probability forecast products based on the outputs of the 3-hours update mesoscale model, the GRPAES-RAFS from CMA, using the ingredients method.

4.4.1.2 Research performed in this field

In 2018, CMA launched the design and prototype construction of the next generation Severe Weather Analysis and Nowcasting system, the SWAN3, which aims to develop the SWAN system from a 0-2h nowcasting system based on radar data to a 0-12h disastrous weather intelligent monitoring and early warning system based on multi-source data such as radar, satellite and numerical model outputs.

The application of AI in nowcasting and very short-range forecasting has been deepened step by step. The PredRNN deep learning model developed by Tsinghua University and NMC has been successfully applied to 0-2h every 6-minutes echo prediction. The QPF model based on the PredRNN deep learning model is being tested. The preliminary results show that the accuracy of QPE and QPF products based on the model is higher than that based on the Z-R relationship. In addition, data such as radar radial velocity are introduced into the model to try to develop a deep learning model of cross-border migration in order to improve the prediction accuracy in 1-2h period. The deep learning model based on UNET and LINKNET is applied to lightning prediction by using the 3km GRAPES model outputs. In order to obtain a more suitable deep learning model for weather prediction, the loss function is replaced by weather prediction evaluation indexes such as CSI and POD.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

Specific content refer to 4.3.1.

4.4.1.2 Research performed in this field

Specific content refer to 4.3.1.

4.5 Specialized numerical predictions (on sea waves, storm surge, sea ice, marine pollution transport and weathering, tropical cyclones, air pollution forecasting, smoke, sand and dust, etc.)

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation

- **CUACE/Dust**

The operational sand/dust storm prediction system in CMA is called CUACE/Dust. It is a sectional dust aerosol model with detailed microphysics of dust aerosol under a comprehension wind erosion database. It has been fully coupled with MM5. A data assimilation system has also been developed to improve the initial condition of dust aerosol. The prediction starts from 00:00 and 12:00 UTC on a routine basis, which provides 72-hour sand/dust storm predictions for both China and Asia as a whole. The overall forecasting performance of the model is good. The model provides dust load, dust concentration, dust optical depth and dry/wet deposition.

It has been selected as one of the operation models for sand and dust storm for SDS-WAS Asian Regional Centre. And all the products have been issued in the web portal for the regional centre: http://eng.weather.gov.cn/dust/.

- **CUACE/haze-fog**

CUACE/haze-fog is a regional haze-fog forecast model in China. It is based on the CUACE which can simulate 7 types of aerosols, i.e. sea-salt, dust, OC, BC, nitrate, ammonia and sulfate. Visibility is produced based on the 7 types of aerosol concentrations and humidity condition. CUACE/Haze-fog has been upgraded to 2.0 version (CUACE/Haze-fog V2.0) in 2015. In 2017, to improve the forecast level for CUACE, the time limit of CUACE/Haze-fog V2,0 forecasting is extended to120 hours, and the time length forecast products is extended to 120 hours. At the same time, the operational system of fog and haze forecast for 6-9 days is realized by constructing a two-stage operational forecast system.

The regional grid configuration of the 6-9 day forecast system is consistent with the original CUACE/Haze-fog V2,0. The grid number is 360*320 and the grid distance is 15km. Vertical direction from the ground to 100 hPa altitude by unequal distance is divided into 23 layers, of which there are about 8 layers in the boundary layer.

The V2.0 forecast modeling system run twice a day operationally in CMA. It issues 120-hrs products of visibility, $PM_{2.5}$ and some gas species. It can predict the timing and distribution of the regional haze-fog over China.

In 2018, the new generation of high-performance computer system of China Meteorological Administration "PI" started its business application. The CUACE/haze-fog regional haze-fog forecast model has been transplanted to PI server. The model system runs stable. The production and distribution of products are normal.

4.5.1.2 Research performed in this field

The CUACE/Haze-fog V2.0 forecast system is doing better than the old version. According to the evaluation result, the visibility (under 10km) TS scoring is improved 0.01-0.05; the MB of daily average PM2.5 concentration decrease 50% and NMB decrease 93%. The V2.0 forecast system has high stability and consistency in the forecast of fog and haze process, well represent the occurrence, development and dissipation phase of the haze or fog process.

4.5.2 Specific Models (as appropriate related to 4.5)

4.5.2.1 In operation

- Environmental emergency response system (EERS):

For the global environmental emergency response system, GRAPES_GFS is used for driving the atmospheric transport model HYSPLIT. The horizontal resolution of GRAPES_GFS is 0.25^{o}, and there are 60 levels in vertical. However, the ensemble T639L61 meteorological fields are still used to force HYPSLIT, the new global ensemble ATDM system can provide the global probability forecast atmospheric dispersion products with 15 members.

- Regional fine-gridded environmental emergency response system:
- For regional EERS, the status is still maintained. The GRAPES_MESO with 10km resolution in horizontal, 51 vertical levels and 1houly output is used to drive the HYSPLIT model.

Additionally, the ensemble GRAPES_MESO meteorological fields are used to force HYSPLIT, the new ensemble ATDM system can provide the regional probability forecast atmospheric dispersion products with 15 members.

- Regional Typhoon prediction system GRAPES-TYM

GRAPES-TYM was changed in physics package: the Cumulus convection scheme was changed to Kfeta from MESO_SAS and the boundary scheme changed to MRF from YSU.

- Global typhoon track prediction system.

The TC track ensemble prediction system was put into operational in 2018 and provide TC ensemble tracks and strike probility Ocean wave models.

- Ocean wave models

NMC is operating a wave model suite consists of global and regional nested grids. The domains of the system are global seas, the Western North Pacific (WNP) and China Offshore (CO). The wave models, built on the third-generation WAVEWATCH III model, are driven by meteorological inputs resulting from the operational numerical weather prediction system. For the WNP and CO wave models, the above wind fields are input with GRAPES_TYM typhoon winds when possible. These wind fields are available at 3h intervals. Sea Surface Temperatures as needed in the stability correction for wave growth are obtained taken from the same model. Boundary data for the regional WNP model is obtained from the global model and the boundary data for the regional CN model is obtained from the WNP model and these data are updated 3h. No wave data assimilation is performed. All models are run on the 00z and 12z model cycles, and start with a 12h hindcast to assure continuity of swell. Additional model information is provided in the table and bullets below. The four time steps are the global step, propagation step for longest wave, refraction step and minimum source term step. Additional model information is provided in the table below.

	Global	Western North Pacific (WNP)	China Offshore(CO)
Domain	0º—360ºE，78ºS—78ºN	90º—170ºE，0ºN—51ºN	105º—130ºE，7ºN—42ºN
Resolution	0.5°×0.5°	1/6°×1/6°	1/15°×1/15°
Grid size	720×311	481×307	376×526
Forecast hour	240h	120h	72h
Atmospheric input	T639	GRAPES_TYM	GRAPES_TYM
Minimum water depth	2.5m	2.5m	2.5m
Time steps	3600s,480s,1800s, 30s	1800s，450s，900s，15s	300s，185s，150s，15s

Model physics	Wave propagation：ULTIMATE QUICKEST propagation scheme； Source term：Tolman and Chalikov source term package； Nonlinear interactions：Discrete interaction approximation； Bottom friction： JONSWAP bottom friction formulation.

4.5.2.2 Research performed in this field

- Regional Typhoon prediction system GRAPES-TYM

Coupled GRAPES-TYM with HYCOM still under development; experiment on higher vertical resolution was designed and tested;

- Global typhoon track prediction system

Model surface layer process was tested and modified in order to improve GRAPES-GFS TC track and intensity prediction.

- Micro-scale environmental emergency response system (EERS):

The new meteorological down-scaling technique is developed, which is used to interpolating 1km GRAPES_MESO numerical data to 250m. The meteorological down-scaling is composed of the terrain adjustment and the land surface/cover process adjustment.

4.5.3 Specific products operationally available

- Environmental emergency response system and Regional fine-gridded environmental emergency response system (EERS):

The products of EERS include 1) trajectories at different heights, forecast valid is 72 hours; 2) exposure from 0 to 500m for 0~24hours, 24~48hours and 48~72hours; 3) the surface accumulated deposition for 0~24hours, 0~48hours and 0~72hours; 4) the Time Of Arrival (TOA) products at 6 hours interval for 0~24hours, 24~48hours and 48~72hours.

- Regional Typhoon prediction system GRAPES-TYM:

TC numerical prediction products of the regional Typhoon prediction system include 1) track and intensity of TCs, 2) precipitation and wind during TCs landfall, 3) the environmental shear and the steering flow of TCs, and 4) geopotential height, temperature, moisture, vorticity, divergence in model domain and so on.

- Global typhoon track prediction system

Ensemble TC track and probability up to 120h.

- Ocean wave forecasting system.

Ocean wave numerical prediction products from the system include: 1) effective wave height HS; 2) the average wave period Tm; 3) the average wave direction; 4) wind speed and wind direction over sea surface.

4.5.4 Operational techniques for application of specialized numerical prediction products *(MOS, PPM, KF, Expert Systems, etc..)* (as appropriate related to 4.5)

4.5.4.1 In operation

- CUACE/Dust

CUACE/Dust - CMA sand/dust storm numerical prediction system - was upgraded to CUACE / Dust V2.0. The system updated its software for product generation and dissemination, its predictions include dust concentration and wind field at all levels, sand flux, dry deposition rate, wet deposition rate, boundary layer elements and the city predictions. Improvements were made in the sand/dust storm data assimilation system for assimilating visibility and weather data from conventional weather stations, PM10 concentrations from sand/dust storm stations, infrared difference dust index (IDDI) derived from FY-4A satellite data. The software SDSDVAS allows forecasters to display and analyze sand/dust storm products.

To enhance the forecast accuracy of Asia dust surface concentrations, we developed a multi-model ensemble dust forecast system. Five operational dust forecast models were used in the system, which were from China Meteorological Administration (CMA), Korea Meteorological Administration (KMA), European Centre for Medium-Range Weather Forecasts (ECMWF), National Centers for Environmental Prediction (NCEP), and Finnish Meteorological Institute (FMI). Mean ensemble, weighted ensemble, multiple linear regression ensemble, and BP-artificial neural network ensemble were applied for each grid. And finally, a best ensemble was obtained based on evaluations of forecast results in previous 7 days of each ensemble method. Evaluation results showed that multi-model ensemble system decreased the uncertainties of forecast accuracy and spatial distribution of Asia dust surface concentrations compared with single dust forecast model.

- CUACE/haze-fog

In 2018, we initially realized the online bidirectional coupling between CUACE and GRAPES_MESO, which is the latest version of weather forecast model in China. We have developed a parameterization scheme of initial emission size spectrum that considers both aerosol mass spectrum and number spectrum distribution, and improved the key microphysical processes such as nucleation and condensation. We have solved the key technical problem of overestimating visibility forecast for severe fog-haze weather, and improved the visibility prediction accuracy of severe fog-haze weather significantly. We optimized the CUACE model to provide numerical prediction products for ozone forecasting operations, including hourly concentration and distribution of O 3, NO x, etc.

Based on the deviation analysis of GRAPES-CUACE model, we adopted "adaptive partial least squares regression method" ， a non-linear dynamic statistical correction technique. Aiming at the concentration of six conventional pollutants predicted by the model, the optimal combination scheme of independent variables in different regions and seasons was selected after a variety of sensitivity tests. We established a correction model for prediction bias of CUACE model in different regions of China.

To enhance the forecast accuracy of air pollutants' concentrations in China, we developed a multi-model ensemble air quality forecast system. Four operational regional models were used in the system, which were China Meteorological Administration Unified Atmospheric Chemistry Environment for aerosols (CUACE), Beijing Regional Environmental Meteorology Prediction System (BREMPS), Regional Atmospheric Environmental Model System for eastern China (RAEMS), and Pearl River Delta Air Quality Forecast System (PRDAQFS). Mean ensemble, weighted ensemble, multiple linear regression ensemble, and BP-artificial neural network ensemble were applied for each site and each forecast time. And finally, a best ensemble was obtained based on evaluations of forecast results in previous 50 days of each ensemble method. Evaluation results showed that multi-model ensemble system largely increased the forecast accuracy compared with single air quality forecast model.

- Environment emergency response products:

The Atmospheric Environment emergency response system provides the following products: 1) 3D dispersion trajectories at 500m, 1500m and 3000m of the pollutants 0-72 hours after their detection; 2) 24-hour average pollution concentration in 0-72 hours; 3) 0-24 hour, 0-48 hours and 0-72 hours accumulated deposition (wet & dry) distribution; 4) improved the time of arrival products， 0-24 hours, 24-48 hours, and 48-72 hours.

- Regional fine-gridded environmental emergency response system (EERS)

The Regional Refined Atmospheric Environment Emergency Response System provides the products superimposed with detailed geographic information, as follows: 1) 3D dispersion trajectories of the pollutants (0-12 hours after detection); 2) hourly average pollution concentration in 0-12 hours; 3) Total deposition (wet & dry) distribution accumulated in 0-12 hours. In a special emergency response procedure, the system can provide the above products in more details.

4.5.4.2 Research performed in this field

We have studied on the formation mechanism of particulate matter pollution and photochemical pollution and developed a composite environmental meteorological index（EMI） products based on the emission source, the concentration of various pollutants and meteorological conditions. In 2018, the EMI products was put into operational application and established an operational application platform, which provided technical support for quantitative assessment of the proportion of emissions and meteorological factors in pollution reduction.

In order to forecast the ozone concentration near the ground, we analysed the temporal and spatial distribution characteristics of ozone based on long time series ozone concentration monitoring data, and studied the meteorological factors and chemical mechanisms affecting ozone concentration. The correlation statistics of ozone concentration with solar radiation intensity, temperature, humidity, wind direction, wind speed, boundary layer height, NO2, PM2.5 and visibility were carried out. We refined the ozone concentration prediction factors, constructed an objective ozone concentration prediction model in China, and applied it to the prediction of ozone pollution process in summer 2018.

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

The environment emergency response, haze and heavy pollution weather probability forecast products have been developed in 2018.

- Environment emergency response products:

The global ensemble atmospheric dispersion forecast system is maintained in 2018, which based on 15 members of T639L61 ensemble numerical prediction system. And the global ensemble forecast products include the ensemble trajectories, the ensemble average and probability products of concentration and accumulated deposition in 0-72 hours.

- Regional fine-gridded environmental emergency response system (EERS):

The regional ensemble atmospheric dispersion forecast system is maintained in 2018, which based on 15 members of GRAPES_MESO ensemble numerical prediction system. And the regional ensemble forecast products of atmospheric dispersion include the ensemble trajectories, the ensemble average and probability products of concentration and accumulated deposition in 0-12 hours.

4.5.5.2 Research performed in this field

Based on the analysis of atmospheric circulation background and boundary layer physical quantities of fog/haze generation and disappearance, and on the basis of fine particle pollution characteristics and source intensity distribution in different regions of China, the medium and long term fog/haze prediction factors and indicators were constructed in different regions. Using ECMWF extended period ensemble forecasting products, multi-linear stepwise regression method and artificial neural network machine learning technology, the mid-long term probabilistic forecasting test products of fog/haze for 1 to 15 days were developed. Good results have been achieved in the forecast of fog and haze processes since 2017.

4.5.5.3 Operationally available probabilistic prediction products

- **Sea wave numerical prediction products:** Ocean wave numerical prediction products from the system include: 1) effective wave height HS; 2) the average wave period Tm; 3) the average wave direction; 4) wind speed and wind direction over sea surface.

- **Environment emergency response products:** Atmospheric Environment emergency response system provides the following products: (1) 3D dispersion trajectories of the pollutants 0-72 hours after their detection; (2) 24-hour average pollution concentration in 0-72 hours; (3) The accumulated deposition (wet & dry) distribution accumulated in 0-24, 0-48 and 0-72 hours. Regional Refined Atmospheric Environment Emergency Response System provides the products superimposed with detailed geographic information, as follows: (1) 3D dispersion trajectories of the pollutants (0-12 hours after detection); (2) hourly average pollution concentration in 0-12 hours; (3) Total deposition (wet & dry) distribution accumulated in 0-12 hours. In a special emergency response procedure, the system can provide the above products in more details.

- **Fog and haze probability forecast products:** （**1**） Medium-term (1-15 days) probabilistic prediction products of $PM_{2.5}$ concentration； （2） Medium-term (1-15 days) probabilistic prediction products of visibility； （3） Medium-term (1-10 days) probabilistic prediction products of Fog and haze.
- **TC track numerical prediction products:** The global TC track prediction system provides the following products (1) TC tracks to 120h; (2) maximum wind at surface;(3) vertical shear;(4)steering flow; (5)vorticity; and(6)divergence.
- **TC ensemble prediction system**: This system mainly provides the TC ensemble tracks and the strike probability.

4.6 Extended range forecasts (ERF) *(10 days to 30 days)* (Models, Ensemble, Methodology)

4.6.1 In operation

The second generation Dynamical Extended Range Forecast System (DERF2.0) in Beijing Climate Centre (BCC) has become operational since Dec 2014. DERF2.0 was developed based on BCC atmospheric general circulation model (BCC_AGCM2.2) in 2011. The ensemble prediction generated by lagged-average-forecast (LAF) method includes 20 members of the latest five days.

4.6.2 Research performed in this field

The Tibetan Plateau snow cover, an important land surface factor, whose time scales of change is longer than the atmosphere and shorter than the ocean. This study analyses the effect of the Tibetan Plateau snow depth anomaly on the extended-range prediction technique at extratropical region. The reforecast data from DERF2.0 model, provided by National Climate Centre of China, the daily snow depth data inversion calculated by scanning multichannel microwave radiometer （SMMR）and special sensor microwave imager （SSM/I）in 1983 to 2014 are used. The results show that the skills in extended prediction of DERF2.0 is significantly higher in abnormal years than the normal years, especially over the region closely affected by the snow cover of the Tibetan Plateau like the Tibetan Plateau region, the Lake of Baikal region and the North Pacific region. With the extension of forecast time, the skills in extended prediction attenuated slowest in more snow years, and attenuated the fastest in normal snow years. The above shows that the predictable time is longer in the Tibetan Plateau snow abnormal years. The skills in extended prediction improved, which can be seen from the first pentad in the Tibetan Plateau snow abnormal years, especially in more snow years. The influence time of the snow cover is obviously earlier than that of the ocean. The Tibetan Plateau snow cover has an important contribution to the skills in extended prediction, suggesting that the Tibetan Plateau snow anomaly is a potential source of prediction for the East Asian extended-range period.

4.6.3 Process and sort of the products in extended range forecast

Products are provided in a routine operation way, which includes surface temperature, precipitation, sea level pressure, 200hPa, 500hPa, 700hPa geopotential height, 200hPa, 700hPa wind field, as well as re-explanation of numerical forecasts such as temperature and precipitation expressed in terms of three categories including below normal, near normal and above normal. The periods of prediction are the coming 1st ten days, 2nd ten days, 3rd ten days, 4th ten days, 1-30 days and 11-40 days.

4.6.4 Performance Evaluation

The evaluation is carried on every 10 days. The main comparison is the forecasting capability of different numerical models for the circulation and the main weather process. At present, the work is still at an early stage.

4.6.5 Operationally available NWP model and EPS ERF products

Products are provided in a routine operation way, which includes surface temperature, precipitation, sea level pressure, 200hPa, 500hPa, 700hPa geopotential height, 200hPa, 700hPa wind field, as well as re-explanation of numerical forecasts such as temperature and precipitation expressed in terms of three categories including below normal, near normal and above normal. The periods of prediction are the coming 1st ten days, 2nd ten days, 3rd ten days, 4th ten days, 1-30 days and 11-40 days.

4.7 Long range forecasts *(30 days up to two years)* (Models, Ensemble, Methodology)

4.7.1 In operation

In recent years, a new generation coupled climate system model (BCC_CSM) has been developed in BCC. With a better assimilation of temperature and salinity than the first-generation system, the second-generation ocean data assimilation system is now at the quasi-operation level. The land data assimilation system is still under development, but the multisource precipitation merging subsystem is now quasi-operational and can produce reanalysis of precipitation as a forcing to land system. The atmospheric general circulation model BCC_AGCM2.2 and the climate system model BCC_CSM1.1(m) are the main tools for the second-generation monthly-scale DERF and the second-generation seasonal prediction system, respectively. The former has entered quasi-operational use since middle August of 2012 and conducted four-member real-time forecast jobs and 80 hindcast jobs every day, and the latter has also entered its quasi-operational stage in the end of 2013. A preliminary evaluation indicates that the second-generation system shows a certain capability in predicting the pentad, ten-day, monthly, seasonal and inter-annual climate variability. BCC-CSM1.1m has been operational in application from 2016 to 2018.

4.7.2 Research performed in this field

BCC/CMA is committed to carry out a series of dynamical-statistical seasonal precipitation prediction research and operational application, and establish the forecast system on dynamical and analogy skills (FODAS) in recent years, and carried out the improved the new forecast system based on dynamical and analogy capabilities (FODAS2.0) in 2018. The system is based on the second generation seasonal model including BCC (BCC-CSM1.1), NCEP_CFSv2 and ECMWF_SYSTEM4, and use the 74 circulation factors of BCC, 40 circulation factors of NOAA and optimal multiple factor regression method to correct model errors. This operational system had a rather higher prediction skill for summer precipitation anomaly percentages over China. The Prediction Skill (PS) score of FODAS2.0 on the summer precipitation is 71 in 2018. And the FODAS2.0 will be further developed and more applied in the future. Based on the hindcast data of BCC Climate System Model BCC-CSM1.2, the anomalous circulation characteristics of intraseasonal variation of East Asian in Meiyu Period was evaluated by employing deterministic methods. The results show that the performance of the BCC-CSM1.2 is significantly good in the subtropical high over the Western Pacific (WPSH). In addition, we are planning to develop the multi-model ensemble prediction system.

4.7.3 Operationally available products

a) 30-day period prediction

- The spatial resolution of the global 10-day and monthly prediction products is 2.5°×2.5°. These products are issued in the first day of each pentad (5-day period) each month. The variables include geopotential heights at 200 hPa, 500 hPa and 700 hPa levels, precipitation, 2-m temperature, wind fields at 200 hPa and 700 hPa levels and SLP.

b) seasonal and interannual prediction

- The spatial resolution of the global seasonal and interannual prediction products is 2.5°×2.5° covering such variables as 850 hPa temperature, geopotential heights at 500 hPa and 200 hPa levels, wind fields at 200 hPa and 850 hPa levels, and a Gaussian-grid with horizontal resolution of 192×96 for precipitation, 2-m temperature and sea level pressure. The lead time of the seasonal predictions varies from 0 to 8 months. These products are issued in the first pentad every month. Currently, all these products are issued in the NetCDF format, which can be used directly with GrADS software. And it is planned to change them to GRIB-2 format, to facilitate transmission and download through FTP, GTS and Internet.

5. Verification of prognostic products

5.1 Annual verification summry

5.1.1 The verification against analysis of operational model (T639)

The verification against analysis of operational numerical forecast model (GRAPES_GFS) in 2018 is shown in the following table 5.1.1.

Table 5.1.1 RMSE of GRAPES_GFS model (500 hPa height Z and 250 hPa and 850 hPa wind speed W) against analysis field in 2018

Month	Valid time	Z(500)		W(250)			W(850)
		NH	SH	NH	SH	Tropics	Tropics
1	24	12.5	12.5	4.6	4.6	4.4	2.7
	72	33.3	32.8	10.1	10.7	7.9	5.9
	120	59.5	56.5	15.1	15.1	9.4	7.8
2	24	12.5	13.1	4.7	4.7	4.1	2.7
	72	34.9	36.8	10.2	11	7	5.9
	120	65.3	65.3	15.8	16.9	8.8	8.3
3	24	11.5	13.8	4.5	4.7	4.1	2.9
	72	31.8	37.9	9.5	10.7	7	6.1
	120	57	66.5	14.3	16.4	8.7	8.7
4	24	10.8	14.6	4.2	5	4.1	3
	72	30.5	40.5	9.3	11.4	7.2	6.5
	120	54	76.1	14.5	18.1	8.8	9.6
5	24	10.5	15.4	4.4	5	3.9	3.3
	72	29.1	45.3	9.9	11.9	6.9	7.2
	120	54.4	77.2	15.4	18.2	8.6	10.1
6	24	10	16.2	4.4	5.2	4	3.4
	72	27.2	46.1	9.7	11.9	7	7.2
	120	47.8	78.4	14.3	18	8.8	10.1
7	24	9.3	14.6	4.2	4.8	4.1	3.3
	72	25	42.6	9.2	11.4	7.2	7.1
	120	43.9	73.4	13.4	17.3	9.1	9.8
8	24	9.2	14.4	4.3	4.9	4.2	3.2
	72	24.8	42.9	9.6	11.4	7.1	7.1
	120	42.8	75.2	13.9	17.2	8.7	10
9	24	9.4	14	4.2	4.8	3.9	3.1
	72	25.6	39.2	9.5	10.7	7.1	6.6
	120	47.8	70.5	14.4	17	9.3	9.5
10	24	10.2	13.2	4.4	4.8	3.9	3
	72	28.4	37.1	9.8	10.6	6.8	6.3
	120	52.4	65	15	16.1	8.5	8.8
11	24	10.4	12.4	4.5	4.7	4.2	2.8
	72	29.6	33.3	9.9	10.1	7.2	5.7
	120	56.6	57.6	15.6	15.1	9	8.1
12	24	11.7	11.7	4.4	4.5	4.3	2.8
	72	32.8	32.1	9.8	10	7.2	5.7
	120	57.8	57.6	14.8	14.9	8.9	7.9

5.1.2 The verification against observations of operational numerical forecast model (GRAPES_GFS)

The verification against observations of operational numerical forecast model (GRAPES_GFS) in 2018 is shown in the following table 5.1.2.

Table 5.1.2 RMSE of GRAPES_GFS model (500 hPa height Z and 250 hPa wind speed W) against observations in 2018

Month	Valid time	Z(500)				W(250)			
		N.A	Europe	Asia	Australia	N.A	Europe	Asia	Australia
1	24	17.2	18.2	21	13.4	6	6.2	4.9	7.2
	72	28.2	34.3	42.3	34.5	8.6	10.4	9.7	12.6
	120	48	58.3	73.9	63.1	11.7	14.9	14.5	18.3
2	24	16.7	17.3	21	13.5	6.1	6.2	4.8	6.8
	72	26.5	33	44.8	34.1	9	10.5	9.8	12.3
	120	43.6	62.3	85	57.9	11.9	15.6	15.5	17.9
3	24	15.9	17.2	20.4	13.6	6.9	6.5	4.2	6.9
	72	29.9	33.8	42.7	29	10.5	10.4	8	11.4
	120	52	56.1	74.5	52.9	14.3	14.7	12.8	16.9
4	24	15.8	17.6	20.2	16.8	6.5	6.2	4.4	7.1
	72	26.6	32	42.7	32.6	9.7	10.2	8.7	11.7
	120	46.6	52.3	70.6	53.6	14	14.8	12.8	17.4
5	24	15.7	16.8	18.2	10.4	7.2	6.6	5.2	6.7
	72	28.6	31.8	41.3	22.9	11	10.8	10.7	10.8
	120	48.6	54.5	75	43.8	15.5	15.8	16.2	16.3
6	24	16.1	16.7	19	11.5	7.3	6.6	5.8	6.9
	72	24.5	28.1	41	24	11.1	10.8	11	11.4
	120	35.9	45	71.7	39.2	13.9	14.7	16.4	15.9
7	24	16.2	16.5	16.7	11.4	6.8	6.2	5.9	6
	72	21.9	26	37.2	18.6	10.4	10.1	11.2	9.4
	120	35.4	41.9	66.3	31.9	13.8	13.7	16.9	12.8
8	24	15	15.1	16	11.9	6.3	6	6.2	6.2
	72	23.2	25.8	36.2	20.6	10.3	10.4	12.2	10.3
	120	35	41.5	61.9	35.3	13.2	14.3	17.3	14.1
9	24	14.5	15.9	16.6	11.9	6.1	5.8	5.4	5.8
	72	23.9	27	35.4	23.5	9.8	10.1	10.7	10
	120	37.1	45.5	63.8	38.3	13.5	15	16.8	14.8
10	24	15.2	17	17.8	13.3	5.9	5.9	5.3	6.2
	72	24.6	31.2	40.3	28.8	9.3	10.6	11.1	10.7
	120	45.1	53.5	72.2	48.4	13.3	15.4	16.5	16.2
11	24	14.7	16	18.2	12.5	6.1	6	4.9	6.2
	72	27.1	32	40.9	31.7	9.6	10.5	9.8	12.1
	120	46.7	56.1	68.9	55.4	13.5	15.9	14.8	18.4
12	24	16	17.5	19.1	13.9	5.4	5.9	5	7.1
	72	25.3	34.1	43.9	35.3	8.4	10.6	10	12.9
	120	43.2	57.3	75.4	60.6	11.4	15.2	15	18.7

5.1.3 Verification of CMA EPS

The verification against an analysis of operational Ensemble system is shown in the following table 5.1.3.

Table 5.1.3 Brier Score Skill (BSS) for CMA EPS (500 hPa height, 850 hPa Temperature) relative to an analysis in 2018

Month	Threshold / Valid time	Z(500)		T(850)	
		>climatology +1sd	<climatology -1sd	>climatology +1sd	<climatology -1sd
1	48	0.83	0.78	0.63	0.66
	72	0.74	0.67	0.55	0.56
	120	0.54	0.49	0.42	0.44
	168	0.37	0.32	0.29	0.32
2	48	0.85	0.82	0.71	0.68
	72	0.77	0.73	0.63	0.58
	120	0.59	0.56	0.49	0.43
	168	0.45	0.38	0.38	0.30
3	48	0.85	0.82	0.73	0.68
	72	0.76	0.73	0.66	0.60
	120	0.59	0.52	0.54	0.45
	168	0.44	0.33	0.43	0.29
4	48	0.74	0.75	0.66	0.56
	72	0.64	0.62	0.58	0.47
	120	0.47	0.41	0.45	0.37
	168	0.29	0.22	0.35	0.28
5	48	0.77	0.76	0.70	0.63
	72	0.65	0.64	0.64	0.52
	120	0.45	0.41	0.50	0.35
	168	0.28	0.22	0.38	0.24
6	48	0.74	0.70	0.70	0.64
	72	0.63	0.57	0.63	0.55
	120	0.44	0.40	0.51	0.41
	168	0.27	0.24	0.42	0.30
7	48	0.72	0.62	0.70	0.67
	72	0.60	0.44	0.63	0.59
	120	0.41	0.24	0.52	0.44
	168	0.27	0.11	0.43	0.33
8	48	0.71	0.65	0.69	0.64
	72	0.57	0.50	0.62	0.56
	120	0.37	0.32	0.51	0.43
	168	0.23	0.19	0.43	0.33
9	48	0.74	0.73	0.72	0.69
	72	0.63	0.61	0.66	0.62
	120	0.47	0.44	0.56	0.50
	168	0.29	0.26	0.46	0.41
10	48	0.81	0.77	0.70	0.69
	72	0.72	0.66	0.63	0.61
	120	0.54	0.48	0.50	0.49
	168	0.36	0.33	0.37	0.39
11	48	0.80	0.80	0.66	0.70
	72	0.71	0.71	0.57	0.62
	120	0.53	0.51	0.44	0.48
	168	0.31	0.27	0.32	0.34
12	48	0.81	0.79	0.65	0.66
	72	0.73	0.71	0.56	0.57
	120	0.55	0.49	0.43	0.41
	168	0.37	0.31	0.32	0.29

5.2 Research performed in this field

- Update radiosonde station list based on WMO standards, and bootstrapping methods using in significant test in operational verification.
- Application of global GTS in near-surface variable assessment for operational models.
- Development of Interactive webpage for operational verification based on highcharts techniques.
- Application of neighborhood spatial verification method on precipitation evaluation.
- Development of evaluation tools for fine-resolution regional models (HRET).
- Update new verification methods in GRAPES Evaluation Tools (GETv2.5)

6. Plans for the future *(next 4 years)*

6.1 Development of the GDPFS

6.1.1 Major changes in the Operational DPFS which are expected in the next year

The GRAPES-GEPS will be transplanted from IBM high performance computer with AIX system to new high performance computer with the linux system, and the operational GRAPES-GEPS system will be built with the new computer. The GRAPES Global Ensemble Prediction System (GRAPES-GEPS) will be put into operational run with 50km horizontal resolution and 60 levels in vertical by the end of 2018 or at the begin of 2019.

A new generation of Beijing Climate Center Climate Prediction System (BCC_CPS) will be tested and verified, based on a mid-resolution version with T266 horizontal resolution and 56 vertical levels. The new generation of BCC_CPS will be put into quasi-operation run in 2020, and it will provide sub-seasonal, seasonal, and interannual prediction products.

6.1.2 Major changes in the Operational DPFS which are envisaged in the next year

1) In the new version of coupled climate model, the horizontal resolution of atmosphere component will be increased from T106 to T266 and the vertical resolution is increased from 26 levels to 56 levels, and the ocean component will be replaced from MOM4 to MOM5. Some key physical parameterization schemes will be modified. The updated climate model will be used in the new generation of BCC_CPS. In addition, the analysis data from a coupled assimilation system in BCC will be used as initial fields of the prediction model.

2) Based on the new version of Beijing Climate Center climate system model, a seamless forecast system for the sub-seasonal to interannual prediction will be built in next 4 years.

6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

6.2.1 Planned Research Activities in NWP

1) To improve the performance and scalability of GRAPES global 4DVar.

2) To put into operation of the new generation scalable high-order nonhydrostatic multi-moment constrained finite volume model.

2) To set up a high resolution (1-3km grid length) GRAPES that will cover the mainland of China, including a variational data assimilation based on ensemble and hybrid approach.

3) To improve the physics scheme in GRAPES based on the observation and field experiments held in China, including the typhoon and the heavy rainfall field experiments, especially on the moist physics scheme.

4) To set up the GRAPES global ensemble NWP systems based on SVs.

6.2.2 Planned Research Activities in Nowcasting

In the next few years, as the new generation of dual-polarization radar and FY-4 satellite remote sensing detection data are applied in operations, the convection-allowing rapid update numerical analysis and prediction technology and artificial intelligence technology such as deep learning are applied, in severe convective weather forecasting, and the tornado monitoring and warning experiment is launched, China will gradually establish the seamless operations from real-time monitoring to very short-time prediction.

6.2.3 Planned Research Activities in Long-range Forecasting

The new generation of Beijing Climate Center Climate Prediction System (BCC_CPS) is being developed, which will be applied in the sub-seasonal to interannual timescales climate predictions. To achieve this goal in the next few years, BCC is planning to:

1) Build a high-resolution climate system model, in which the atmospheric component has a T266 horizontal resolution and 56 vertical levels, and the ocean component has 1/4° horizontal grid resolution.

2) Physical schemes appropriate for the East Asia climate will be developed for the seamless climate prediction system. The study will focus on the development of cloud and microphysics scheme, cumulus parameterizations scheme, shallow convection scheme, atmospheric boundary scheme, and atmospheric chemistry scheme, and so on.

3) Develop ensemble assimilation techniques and establish an atmosphere-ocean-land-sea ice coupled assimilation system.

4) Investigate ensemble initialization techniques and the influences of different initial perturbations on climate forecast at various time scales.

5) Assessment of the predictability of sub-seasonal to interannual climate variability.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

Environmental Emergency Response System: continue to develop the meteorological field's down-scaling of GRAPES_MESO 3km, and apply the new technology to high-resolution EERs.

Chemical weather forecasting system: GRAPES/Chem, a planned activity to integrate both global and regional GRAPES with CUACE, the Chinese Unified Atmospheric Chemistry Environmental. With the GRAPES/Chem, the interactions between weather and air quality are fully coupled. The researches on aerosol-cloud-radiation interactions and gas chemistry updating will continue in the future. Data assimilation and an inverse model of CUACE will be implemented into GRAPES/Chem to facilitate the ability to estimate the emissions of various chemical species with ambient monitoring data in China.

Coupled version of GRAPES-TYM and HYCOM will be put into operational running in the near future.

7. References

Chen H, Chen J, Wang J, et al. Sensitivity tests of the influence of observation mean square error on GRAPES regional ensemble prediction[J]. Transactions of Atmospheric Sciences, 2017.

Chen Lianglü, CHEN Jing, XUE Jishan, et al. Development and Testing of the GRAPES Regional Ensemble-3DVAR Hybrid Data Assimilation System[J]. Journal of Meteorology, 2015, 29(6):981-996.

Chen D. H.，Xue J. S., Yang X. S. et al. New Generation of multi-scale NWP system (GRAPES): general scientific design. Chinese Science Bulletin，2008,53（22），3433-3445.

Dehui CHEN, Xuesheng YANG, Jianglin HU and Hongliang ZHANG. On strategic design of multi-scale unified dynamical cores. 《Journal of Applied Meteorology》 (in Chinese), Vol. 14, No. 4,2003, P452-461.

Li Z.J., Wang L.L, et al. Rainfall-Runoff Simulation and Flood Forecast of Huaihe River[J]. Water Science and Engineering. 2008, 1(3):24-35.

Liu K, Chen Q, Jian S. Modification of cumulus convection and planetary boundary layer schemes in the GRAPES global model[J]. Journal of Meteorology, 2015, 29(5):806-822.

Guo Yunyun, DENG Liantang, FAN Guangzhou, Comparative Analysis of Different Cumulus Parameterization Schemes in GRAPES_Meso Model, Meteorological Monthly, 2015, 41(8): 932-941.

M.H. Wang, a high order, positive and conservative scalar variable advection scheme in GRAPES model. Master thesis in May 2007; available in Chinese Academy of Meteorological Sciences (in Chinese).

Ma Xuling, Ji Yanxia, Zhou Boyang, A new scheme of blending initial perturbation of the GRAPES regional ensemble prediction system, Transactions of Atmospheric Sciences, 2018, 41(2): 248-257.

Shen Xueshun, Su Yong, Hu Jianglin, Development and Operation Transformation of GRAPES Global Middle-range Forecast System, Journal of Applied Meteorological Science, 2017, 28(1): 1-9.

Su Yong, Sheng Xueshun, Chen Zitong, A study on the three-dimensional reference atmosphere in GRAPES_GFS:Theoretical design and ideal test, Acta Meteorologica Sinica, 2018, 76(2): 241-254.

Wang L.L.,Chen D.H. Coupling Green-Ampt infiltration method and Two-dimensional kinematic wave theory for flood forecast in semi-arid basin[J]. Water Science and Engineering, 2011.review.

Wang L.L, Li Z.J., et al. Application of Developed Grid-GA distributed hydrologic Model in Semi-Humid and Semi-Arid Basin [J]. Trans.Tianjin Univ. 2010,16(3):209-215.

Wu Tongwen, Yu Rucong, Zhang Fang, Wang Zaizhi, Dong Min, Wang Lanning, Jin Xia, Deliang Chen, Laurent Li. The Beijing Climate Centre atmospheric general circulation model: description and its performance for the present-day climate. Clim. Dyn, 2010, 34 (1):123-147

Wu Yang, XU Zhifang, WANG Ruichun, Improvement of GRAPES3Dvar with a New Multi-Scale Filtering and Its Application in Heavy Rain Forecasting, Meteorological Monthly, 2018, 44(5): 621-633.

Wu Yu, Ma Suhong, Li Xun, Test and Analysis of GRAPES_TYM Model for TC Track and Environmental Steering Flow Forecast, Meteorological Science and Technology, 2016, 44(6): 937-948.

Xia Yu, Chen Jing, Liu Yan, A tentative experiment of GRAPES En-3DVAR hybrid data assimilation method over the Tibet Plateau, Transactions of Atmospheric Sciences, 2018, 41(2): 239-247.

Xiao F., Peng X.D.A convexity preserving scheme for conservative advection transport, J.Comput.Phys., 2004, 198, 389:402.

Y. Su, Application of the improved PRM scheme in GRAPES model. Master thesis in May 2009; available in Chinese Academy of Meteorological Sciences (in Chinese).

Zhang H, Chen J, Zhi X, et al. Study on the Application of GRAPES Regional Ensemble Prediction System[J]. Meteorological Monthly, 2014.

Zhang Hanbin, Chen Jing* (correspoding author), Zhi Xiefei, Wang Yi, Wang Yanan.Study on Multi-Scale Blending Initial Condition Perturbations for a Regional Ensemble Prediction System.Adv.Atmos.Sci.,2015,32(8),1143-1155.

Zheng Xiaohui, XU Guoqiang, JIA Lihong, Incorporation of a Cumulus Fraction Scheme in the GRAPES_Meso and Evaluation of Its Performance, Chinese Journal of Atmospheric Sciences, 2016, 40(5): 908-919.