National Meteorological Center,CMA
National Climate Center,CMA

==

JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2019

CHINA

NMC and NCC
China Meteorological Administration
August, 2020

JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2019
CHINA, August 2020

CONTENTS

1. Summary of highlights

- **The GRAPES_GFS model has been updated to GRAPES_GFS V2.4.**

The operation system GRAPES_GFS has been updated to GRAPES_GFS V2.4. The new version developed linear NASA convection parameterization and Tompkins large-scale condensation scheme with satellite bias correction and other four technical optimizations. Meanwhile, the assimilation of METOP-A/B IASI, FY-3D MWHS2 and GPS PW data was added. The products of the updated system and distribution time remain unchanged. The operational hindcast and parallel test results show that the analysis and forecast of the updated GRAPES_GFS V2.4 is better than the old version. The operational products of GRAPES_GFS V2.4 were put into operation on 15 July 2019.

- **The GRAPES_MESO has been put into quasi operation.**

The regional high resolution NWP - GRAPES_MESO 3km has been put into quasi operation since 6 June 2019. The new system outperforms the old version and the forecast area has been extended to the whole country.

- **The GRAPES_REPS has been updated to GRAPES_REPS V3.0.**

The regional ensemble prediction system – GRAPES_REPS has been updated to GRAPES_REPS V3.0. The improvement are as follows: 1) the resolution increased from 0.15^{o} to 0.1^{o}; 2) the initial uncertainty technique of ETKF based multi scale hybrid perturbation was replaced by ETKF initial perturbation method; 3) the model uncertainty technique of multiple parameterization schemes and Stochastically Perturbed Parameterization Tendencies (SPPT) scheme was replaced by physical process and SPPT; 4) the boundary uncertainty of T639 global EPS was replaced by GRAPES_GEPS; 5) the typhoon relocation scheme was applied in GRAPES_REPS; 6) cloud analysis scheme was applied in GRAPES_REPS; 7) the one-hour precipitation, radar echo and other products were added. The operational products of GRAPES_REPS V3.0 were put into operation on 29 September 2019.

- **The GRAPES_TYM has been updated to GRAPES_TYM V3.0.**

The typhoon NWP – GRAPES_TYM has been updated to GRAPES_TYM V3.0. The vertical resolution was increased and physical process was optimized that the track and intensity of the Tropical Cyclone (TC) forecasting capacity was improved significantly. The prediction area was extended to cover northwest Pacific, South China Sea and north Indian Ocean. The operational prediction process has been built for TC in the north Indian Ocean. The integrated operation of typhoon NWP and sea fog NWP was realized through the optimization of physical process. The operational products of GRAPES_TYM V3.0 were put into operation on 13 August 2019.

- **The World Meteorological Centre (Beijing) official web portal was improved.**

The WMC (Beijing) under the WMO GDPFS framework provides all WMO Members and other users with a variety of NWP products based on CMA's global models. These include deterministic and ensemble medium-range forecasts based on GRAPES and seasonal forecasts based on BCC_CSM. Graphic products

are available via the WMC (Beijing) web portal as follows:
http://www.wmc-bj.net/.

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, in which the peak performance was more than 1PFlops, were installed in Beijing in 2013. More details are shown 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 shown 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 National Meteorological Information Centre (NMIC) of CMA in use are shown in Table 3.1, according to one day data used by GRAPES_GFS in June 2019.

Table3.1 Observation data for assimilation system

Data type	**Mean**	**Data type**	**Mean**	**Data type**	**Mean**
SYNOP	125500	AIREP/AMDAR	383342	NOAA15_AMSUA	73948
SHIP/BUOY	8276	SATOB (WIND)	202588	NOAA18_AMSUA	54394
TEMP	1619	AIRS	81352	METOP2_AMSUA	108808

GNSS(including COSMIC)	92994	NOAA19-AMSUA	61890	METOP1_AMSUA	75673
ASCAT	12011	FY3C-AMSUB	6321	NPP-ATMS	166153
FY4A-hps	74206				

4. Forecasting system

4.1 System run schedule and forecast ranges

In the new IBM Flex Power P460 and PI-Sugon, the operational schedule is shown 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_GFS2.4)	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)	13:10～13:50	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)	01:10～01:50	PI-Sugon
Regional Forecasting System (GRAPES_MESO4.3)	03:20 (00Z_ ASSIM +84HR_.FCST)	03:20～04:30	PI-Sugon
	05:00 (03Z_ ASSIM +30HR_.FCST)	05:00～05:40	PI-Sugon
	08:00 (06Z_ ASSIM +30HR_.FCST)	08:00～08:40	PI-Sugon
	11:00 (09Z_ ASSIM +30HR_.FCST)	11:00～11:40	PI-Sugon
	15:20 (12Z_ ASSIM +84HR_.FCST)	15:20～16:30	PI-Sugon
	17:00 (15Z_ ASSIM +30HR_.FCST)	17:00～17:40	PI-Sugon
	20:00 (18Z_ ASSIM +30HR_.FCST)	20:00～20:40	PI-Sugon
	23:00 (21Z_ ASSIM +30HR_.FCST)	23:00～23:40	PI-Sugon
Ensemble Forecasts With 31 members (GRAPES_GEPS)	04:30 (00Z_ASSIM+360HR_FCST)	04:30～06:30	PI-Sugon
	16:30 (12Z_ASSIM+360HR_FCST)	16:30～18:30	PI-Sugon
Regional Typhoon Forecasting System （GRAPES_TYM 2.2）	04:20 (00Z_120HR_FCST)	04:20～06:30	PI-Sugon
	11:00 (06Z_120HR_FCST)	11:00～13:10	PI-Sugon
	17:00 (12Z_120HR_FCST)	17:00～19:10	PI-Sugon
	23:00 (18Z_120HR_FCST)	23:00～01:10	PI-Sugon
Regional Ensemble Forecasting system with 15 members (GRAPES_REPS)	05:20(00Z_84HR_FCST)	05:20~07:20	PI-Sugon
	17:20(12Z_84HR_FCST)	17:20~19:20	PI-Sugon
Sand/dust Forecasting system	06:30 (00Z_120HR_FCST)	06:30～06:50	PI-Sugon
	18:30 (12Z_120HR_FCST)	18:30～18:50	PI-Sugon
Ocean Wave Forecasting	07:20 (00Z_120HR_FCST)	07:20～07:55	PI-Sugon

System (WW3)	19:20 (12Z_120HR_FCST)	19:20～19:55	PI-Sugon
HAZE Forecast System	00:10（00Z_216HR_FCST）	00:10~02:10	PI-Sugon
	12:10（12Z_216HR_FCST）	12:10~14:10	PI-Sugon
GRAPES_MESO(HR 3KM) Forecast System	04:30 (00Z+36HR_FCST)	04:30～06:10	PI-Sugon
	10:30 (06Z+36HR_FCST)	10:30～12:10	PI-Sugon
	16:30 (12Z+36HR_FCST)	16:30～18:10	PI-Sugon
	22:30 (18Z+36HR_FCST)	22:30～00:10	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 GRAPES global 4D-var system was built to run on Sugon HPCs for the first time on July 1st 2018 and upgraded to version 2.4 in 2019. By occupying more CPUs, the run time of 240hrs forecast is within 70 minutes.

4.2.1.2 Research performed in this field

The 87-level (87L) global tangent-linear and adjoint models are developed based on the new dynamical core. The global 4D-Var system has been updated and extended vertically from 60L to 87L with the altitude of the model lid increased from 36 km to 60 km. The background error covariances and balance regression coefficients are re-computed for the 87-level global 4D-Var system using the first training dataset which come from both the 87-level model forecasts using the ERA-Interim reanalysis as the initial conditions and EDA samples.

The matrix of energy weighting coefficients is used in the 4D-Var weak constrain term to replace the previous diagonal matrix composed of the inverse background error variance. The one-month 4D-Var cycled trails are also carried out using the prototype version of 87-level global 4D-Var system. The significant improvements in the stratosphere are found even without adding new observations.

The bias correction predictors were re-selected in view of the characteristics of the upper atmosphere. The bias correction coefficients of AMSUA, IASI and AIRS were recomputed. Some upper channels have been used in the 87-level global 4D-Var system. The preliminary results show that the new channels have a positive impact on the 4D-Var analysis in the stratosphere. The update of the radiative transfer model from RTTOV version 9.3 to version 12.2 is in progress. It will benefit the use of the upper and new satellite observations.

In the aspect of satellite data assimilation, the focus is also on the assimilation of FY-3D infrared hyperspectral data, FY-3D microwave thermometer data, FY3C/D imager data, FY2H imager data, FY4A imager data, and CrIS data. The performance of the FY satellite observations in the full observation experiment is generally neutral.

The assimilation of GNSSRO data has been improved through the optimization of the observation operator and the quality control algorithm. The bias correction for GNSSRO data used in the operational global 4D-Var system has been switched off.

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 the 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

A research version of GRAPES global model has been built, which uses Predictor-Corrector SISL scheme and 3D reference profile, vertical layers changing from 60 levels, 36km (about 4hPa), to 87 levels, 63km (about 0.1hPa) and a new spectral filter terrain. The sponge layers have been adjusted to control computational noise at the model top and in the polar region, which include an implicit vertical velocity damping similar to ENDGame to control noises in the polar regions and the upper layers, a Rayleigh Friction sponge based on a linear relaxation, working on u and v field to control the overly strong wind speed.

The nonorographic gravity waves in the stratosphere has been developed to parameterize the drags induced by breaking of gravity waves produced by the nonorographic sources, such as fronts, jet.

Based on the multi-moment finite volume (MMFV) framework, the scalable high-order nonhydrostatic multi-moment finite volume dynamical core on the cubed sphere has been developed, and the experiment with simple microphysics achieved a comparable result to other advanced models. Moreover, a high-accuracy advection scheme and a preprocessing system have been developed.

4.2.3 Operationally available Numerical Weather Prediction (NWP) Products

In 2016, The GRAPES_GFS model was put into operation. In 2019, many variables from the model integration are added to operationally available NWP products. List of GRAPES_GFS model products are given in Table 4.2.3.1 and Table 4.2.3.2.

Table 4.2.3.1 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,	global:
Temperature	K	30	150, 175, 200, 225, 250,	0.25°×0.25°
U-wind	m/s	30	275, 300, 350, 400, 450,	1440×720

V-wind	m/s	30	500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	0 °N - 359.75 °N , 89.875 °E - -89.875 °E
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,	
Temperature Advection	K/s	30		
Vorticity Advection	1/s2	30		
Dew point temperature	℃	30		

difference			750, 800, 850, 900, 925, 950, 975, 1000	
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	℃	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	2 m	
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 short-wave 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	2 m	
2m Minimum temperature	K	1	2 m	
2m Maximum relative humidity	%	1	2 m	
2m Minimum relative humidity	%	1	2 m	
Precipitable Water	Kg/m2	1	entire atmosphere total column	
Probability of thunder and lightning	%	1		
Height of 0 ℃ isothermal level	M	1	--	
Wind index	m/s	1	--	
0-1000m Vertical speed shear	1/s	1	1000-0 m	
0-3000m Vertical speed shear	1/s	1	3000-0 m	
0-6000m Vertical speed shear	1/s	1	6000-0 m	
Down convective available potential energy	J/kg	1	--	
Best Lifting index	K	1	--	
Hail index	--	1	--	
Visibility	m	1	surface	
Gust	m/s	1	10m	

Table 4.2.3.2 List of GRAPES_GFS model layer products

Variables	unit	layer	Area
Exner pressure	-	62	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 objective weather forecast system developed by China Meteorological Administration (CMA-GOWFS) was put into operation, providing meteorological elements forecast both at grids and at 11621 observation locations. The products information is given in the following tables.

Table 4.2.4.1.1 List of global gridded guidance forecast of CMA-GOWFS

No	Variable	unit	Forecast hours	Resolution/Area/ Frequency
1	24 h maximum temperature	°C	Every 24 h out to 240 h	horizontal resolution： 0.1° * 0.1° -90°N ~90°N 0°E ~360°E
2	24 h Minimum temperature	°C		
3	24 h Maximum relative humidity	%		
4	24 h Minimum relative humidity	%		
5	24 h accumulated precipitation	mm		
6	Temperature	°C	Every 3 h out to 240 h	
7	3 h Maximum temperature	°C		
8	3 h Minimum temperature	°C		
9	3 h accumulated precipitation	mm		

10	Relative humidity	%		00:00UTC 12:00UTC
11	Total cloud cover	%		
12	Low cloud cover	%		
13	Wind speed (u and v)	m/s		
14	Visibility	Km		
15	Surface pressure	hPa		

Table 4.2.4.1.2 List of global guidance forecast at observation locations of CMA-GOWFS

No	Variable	unit	Forecast hours	Resolution/Area/ Frequency
1	Temperature	°C	Every 3 h out to 240 h	11621 locations 00:00UTC 12:00UTC
2	Relative humidity	%		
3	Total cloud cover	%		
4	Low cloud cover	%		
5	Wind speed	m/s		
6	Wind direction	°		
7	Visibility	Km		
8	Surface pressure	hPa		
9	3 h accumulated precipitation	mm		
10	3 h Weather phenomenon	/		
11	12 h maximum temperature	°C		
12	12 h Minimum temperature	°C		
13	12 h Maximum relative humidity	%		
14	12 h Minimum relative humidity	%		
15	12 h average total cloud cover	%		
16	12 h average low cloud cover	%		
17	12 h weather phenomenon	/		
18	12 h maximum wind speed	m/s		
19	The wind direction corresponding to the first appearance of 12 h maximum wind speed	°		
20	12 h accumulated precipitation	mm		
21	24 h accumulated precipitation	mm		

4.2.4.2 Research performed in this field

Referring to the latest development of international objective prediction technology, based on the GRAPES and ECMWF global numerical model output, and the observation data of global international exchange stations, CMA-GOWFS uses the multi statistical post-processing methods to correct the forecast errors both at grid points and observation locations. To maximally improve the prediction performance, besides the conventional methods such as DMO, MOS, Kalman filtering and frequency matching, the self-developed method of OMOS that adopts prior spatial observational predictors is applied too.

According to the latest performance of all the forecasts by different models and methods, dynamic optimal

integration is performed to obtain the best forecast for individual stations and different lead-times.
Lastly, with the gridded corrected forecast as the background field, the station correction increments are objectively analyzed to the grid points to get the optimized gridded prediction by fusing the good performance of observation location forecast.

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 global operational ensemble prediction system (GEPS) based on GRAPES global model (GRAPES_GEPS) has been operationally running since 26 December 2018. 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 3 hPa;
- 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) are focused on two aspects. One is to improve the existed SPPT by increasing range of random values in SPPT. Another is to include the linearized moist physics in the calculation of the tropical cyclone (TC) targeted SVs, and to carry out ensemble experiments to assess its impact on the TC forecasts.

4.2.5.3 Operationally available EPS Products

The GRAPES based global ensemble prediction model products in operational are 0-360h forecasts for 00UTC and 12UTC initial time. Ensemble size is 31 including 30 perturbed forecast and 1 control run. The output interval is 6 hours. A list of GRAPES_GEPS products in graphical format is given in Table 4.2.5.3.1. The graphical products are available via the CMA website as follows:
http://www.nmc.cn/publish/grapes-new/Probability/24h-Accum-Precip/25mm.html.

Table 4.2.5.3.1 List of global EPS products in graphical format

Variables	Unit	Layer	Level	EPS products	Probability threshold
Geopotential height	Gpm	1	500 hPa	Spaghetti	
				EM & Spread	
Relative humidity	%	2	700 hPa, 850 hPa	EM & Spread	
Temperature	K	1	850 hPa	EM & Spread	
24-hr Accum. Precip.	mm	1	Surface	Ens Mean	
				Mode & Max	
				PRBT	1, 10, 25, 50 ,100 mm
Mean SLP	hPa	1	MSL	EM & Spread	
2m Temp	K	1	2 m	EM & Spread	
10m Wind	m/s	1	10 m	EM & Spread	
				PRBT	10.8, 17.2 m/s
EFI for 24-HR Accum. Precip	/	1	Surface	Extreme forecast index	
EFI for 2m Temp	/	1	2 m	Extreme forecast index	
EFI for 10m Wind	/	1	10 m	Extreme forecast index	
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 a 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 cloud analysis system with 3 km horizontal resolution which domain covers the whole China is quasi-operational run on 6 June 2019.

The operational Radar Application Pre-process System (RAPS) was upgraded and made progresses including: 1) updated radar site information in operational system by using the latest radar site information table; 2) added ability to process SC/CD/CC/CA type radar data; 3) optimized quality control algorithms, improved EMI and test pattern identification technology, developed ring echo quality control technology; 4) optimized the system flow, improving the operational efficiency.

4.3.1.2 Research performed in this field

In 2019, the improvements of analysis in GRAPES_MESO model included:

1) researching on analysis variables which is applicable to meso and small-scale analysis;

2) merging large scale information of global model with meso-scale information of regional analysis in the GRAPES_RAFS system using Discrete Cosine Transform (DCT) filter;

3) adding the large scale information as a weak constraint to the cost function;

4) researching on superposition of Gaussian components to increase the meso and small scale information of analysis increments and mitigate the inappropriate negative correlation information opposite to the wind field observation;

5) optimizing the diabatic digital filtering initialization with high resolution;

6) estimating the impact of GRAPES_RAFS short-term forecasting and diagnosing the problems of GRAPES_RAFS to improve the ability of analysis and prediction;

7) improving the cloud analysis system to mitigate the problem of more humidity forecast ;

8) in order to retain more accurate observations, a dealiase operator is added to the radar radial wind assimilation operator;

9) updating the surface humidity observation operator.

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.

GRAPES_MESO 3km system covered Chinese territory put in quasi-operational running since June 6th 2019. The main technique progresses for 4D-Var include: the upgrade of reference profile; optimization of the 4th-order horizontal diffusion scheme; implementation of the time step auto-adjusting scheme; optimization of boundary layer scheme; introducing ECMWF cloudiness diagnostic scheme; adjusting scheme of couple physical parameterization with dynamic core.

4.3.2.2 Research performed in this field

In 2019, many researches were performed in this field. Model improvements include: implementing process for initial fields and boundary condition of GRAPES_MESO provided by GRAPES_GFS forecast model layer result; developing three dimensional reference profile into GRAPES_MESO system; evaluating the effect of boundary layer parameterization for the over-prediction of precipitation problem; optimization of cloudiness diagnosis scheme to reduce deviation of high-level cloud; introducing new version of Tiedtke shallow convection parameterization into GRAPES_MESO 3km system.

4.3.3 Operationally available NWP products

In 2019, many variables from the model integration were added to operationally available regional NWP products. Lists of GRAPES_MESO products are given in Table 4.3.3.1 and Table 4.3.3.2.

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

No.	Variable	unit	Layer	Level (hPa)	Area
1	Geopotential height	Gpm (geopotential meters)	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	horizontal resolution：0.1*0.1 Grid points：751*501 15°N ~65°N 70°E ~145°E
2	Temperature	K	30		
3	U-wind	m/s	30		
4	V-wind	m/s	30		
5	Vertical velocity	m/s	30		
6	Vorticity	s-1	30		
7	Divergence	s-1	30		
8	Specific humidity	Kg/kg	30		
9	Relative humidity	%	30		
10	Cloud water mixing ratio	Kg/kg	30		

11	Rain water mixing ratio	Kg/kg	30	
12	Ice water mixing ratio	Kg/kg	30	
13	Snow water mixing ratio	Kg/kg	30	
14	Graupel	Kg/kg	30	
15	Cloud cover	%	30	
16	10m U-wind	m/s	1	10 m above ground
17	10m V-wind	m/s	1	10 m above ground
18	2m Temperature	K	1	2 m above ground
19	Surface temperature	K	1	surface
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 ħPa s	30	
37	Divergence of vapour flux	g/cm2 ħPa 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	10 m	
54	Maximum of v10m in output interval	m/s	1	10 m	
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	2 m	
81	Maximum ascending helicity	M^2/s^2	1	2000-5000 m	
82	The whole layer perceptible 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	
89	Height of maximum radar reflectivity	m	1	--	
90	Speed of maximum vertical speed shear	m/s	1	600-0 m	
91	Angle of maximum vertical speed shear	degree	1	600-0 m	
92	Visbility	m	1	surface	
93	Gust	m/s	1	10 m	
94	Precipitation type	-	1	surface	

Table 4.3.3.2 List of GRAPES_GFS model layer 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

Same as the medium range forecasting system and products. Refer to section 4.2.4.1 for details.

4.3.4.2 Research performed in this field

Same as the medium range forecasting system and techniques. Refer to section 4.2.4.2 for details.

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_REPS 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_REPS to describe the model uncertainty. In GRAPES SPPT scheme, the random field which is described with the first order Markov chain has a time-related characteristics and Gaussian distribution, and also has a continuous and smooth horizontal structure.

In 2019, the core model GRAPES_MESO has been updated to V.4.3. The horizontal resolution has been updated to 10 km, and the MSB scheme was abandoned by considering the physical consistency. Cloud analysis scheme and typhoon relocation scheme were applied in GRAPES_REPS. The system configurations are as follows:

- Number of models used: one model (GRAPES_MESO V4.3.0 with 10 km horizontal resolution and 51 vertical levels);
- Domain: 70-140 °E, 15-60 °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: 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: 84 h for both 00UTC and 12UTC.

4.3.5.2 Research performed in this field

Anagnosto and Krajewsk (1997) mentioned that their simulated radar reflectivity ignored the variability of the subgrid-scale rain-fall, which was an important problem in radar-rainfall estimation. Haase and Crewell (2000) also mentioned that their simulation lacked some subgrid-scale rainfall due to the coarse model resolution, and the impact could be quite significant for convective situations.

We note that previous simulated methods are mostly based on cloud microphysics theory and the resolvable grid-scale precipitation to simulate radar reflectivity, it does not consider the subgrid-scale precipitation and cannot reflect the information of the subgrid-scale precipitation. This is a common problem in most of models using cumulus parameterization schemes.

To solve this problem and improve the simulated radar reflectivity, we designed a new simulated radar reflectivity calculation method based on the 10 km GRAPES_MESO regional model and obtained a new diagnostic field of radar reflectivity corresponding to the grid-scale and subgrid-scale precipitation. Based on this new method, the two 15-day forecast experiments were carried out for two different time periods (April 11–25, 2019 and August 1–15, 2019) and the radar reflectivity products obtained by the new method and previous method were compared.

The results show that the radar reflectivity obtained by the new simulated radar reflectivity calculation method gives a clear indication of the subgrid-scale precipitation in the model. And the verification results show that the threat scores of the improved experiments are generally better than those of the control experiments and the reliability of the simulated radar reflectivity on the indication of the precipitation is improved. It concludes that the new simulated radar reflectivity calculation method is effective and the reflectivity products are significantly improved.

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 indicated 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 showed 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 tried 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 results 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 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 that the operational numerical weather prediction adopts this unified scheme approach in ensemble models to achieve the best forecasts.

4.3.5.3 Operationally available EPS Products

GRAPES based mesoscale ensemble prediction system model products 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 GRAPES_REPS products in graphical format is given in Table 4.3.5.3.1. The graphical products are available via the CMA website as follows:

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

Table 4.3.5.3.1 List of GRAPES_REPS products in graphical format

Variables	Unit	Layer	Level	EPS products	Probability threshold
24-hr Accum. Precip.	mm	1	Surf	Ens Mean	
				Mode & Max	
				Thumbnails	
				PRBT	1, 10, 25, 50 ,100
12-hr Accum. Precip.	mm	1	Surf	Ens Mean	
				Mode & Max	
				Thumbnails	
				PRBT	1, 5, 15, 30 ,70
6-hr Accum. Precip.	mm	1	Surf	Ens Mean	
				Mode & Max	
				Thumbnails	
				PRBT	1, 4, 13, 25 ,60
3-hr Accum. Precip.	mm	1	Surf	Ens Mean	
				Mode & Max	
				Thumbnails	

				PRBT	1, 3, 10, 20 ,50
Sea Surf Pres	hPa	1	MSL	EM & Spread	
2m Temperature	K	1	2m	EM & Spread	
10m Wind speed	m/s	1	10m	EM & Spread	
				PRBT	5.5,8, 10.8, 17.2, 24.5, 32.7
Convective Available Potential Energy	J/kg	/	/	EM & Spread	
				PRBT	200, 500, 1000, 1500, 2000, 250
Convective Inhibition	J/kg	/	/	EM & Spread	
				PRBT	50, 100, 150, 200
Combined Radio Reflection Ratio	dbz	/	/	Thumbnails	
				EM & Spread	
				PRBT	5, 10, 20, 30, 40
K index	/	/	/	EM & Spread	
				PRBT	30, 35, 40, 45
Best Lifting Index	/	/	/	EM & Spread	
				PRBT	0, -2, -4, -6
0-1km Vertical Wind shear	/	1	0-1km	EM & Spread	
				PRBT	8, 12, 16, 18
0-3km Vertical Wind shear	/	1	0-3km	EM & Spread	
				PRBT	12, 16, 20, 24
0-6km Vertical Wind shear	/	1	0-6km	EM & Spread	
				PRBT	20, 26, 32, 38
Down CAPE	J/kg	/	/	EM & Spread	
				PRBT	500, 1000, 1500, 2000
Hail Index	/	/	/	EM & 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 & WHISKER	

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 building 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 the monitoring of severe convective weather at the national level.

The 5 km classification severe convective weather prediction system is run by the Severe Weather Prediction Center of NMC. It provides 8 times a day the 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 2019, CMA launched the 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 showed 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 were 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 was applied to lightning prediction by using the 3 km GRAPES model outputs. In order to obtain a more suitable deep learning model for weather prediction, the loss function was replaced by weather prediction evaluation indexes such as CSI and POD.

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://www.asdf-bj.net/.

- **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 was 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 was extended to120 hours, and the time length forecast products was extended to 120 hours. At the same time, the operational system of fog and haze forecast for 6-9 days was 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 15 km. 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 stably. 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 10 km) TS scoring was improved by 0.01-0.05; the MB of daily average PM2.5 concentration decreased by 50% and NMB decreased by 93%. The V2.0 forecast system has high stability and consistency in the forecast of fog and haze process and 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°, and there are 60 levels in vertical. However, the NEW ensemble GRAPES_GEPS meteorological fields are used to force HYPSLIT, the new global ensemble ATDM system can provide the global probability forecast atmospheric dispersion products with 31 members.

- Regional fine-gridded environmental emergency response system:

For regional EERS, the GRAPES_MESO with 10 km resolution with 72h forecast in horizontal, 51 vertical levels and 1 hourly output is used to drive the HYSPLIT model. Meanwhile, the new GRAPES_MESO 3km meteorological fields are used to force HYSPLIT providing the 36 h forecast. Additionally, the ensemble GRAPES_REPS meteorological fields are still 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

The GRAPES_TYM V3.0 was put into operation in 2019. Compared with last version GRAPES_TYM V2.2，GRAPES_TYM V3.0 was upgraded in the following aspects:

1) the model horizontal resolution was increased from 0.12°to 0.09°and vertical resolution was increased from 50 to 68 levels;

2) the integration domain was extended from 90°E-171°E 、0°N- 50.25°N to 40°E-180.04°E; 15°S-60.06°N and the north Indian Ocean was included;

3) the cumulus convection scheme was changed back to MESO-SAS and the boundary scheme was changed back to YSU.

- Global typhoon track prediction system.

The TC track prediction from global model GRAPES_GFS and GEPS system was upgraded in 2019 (details as described in 4.2) as a part of GRAPES_GFS and GEPS system.

- Ocean wave models

NMC operates a wave model suite consisting 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 global wave model, the wind fields are input with GRAPES GFS replaced T639 in 2019; For the WNP and CO wave models, the above wind fields are input with GRAPES_TYM typhoon winds. Sea Surface Temperatures as needed in the stability correction for wave growth are obtained 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 3 h. 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 4.5.2.1. The four time steps are the global step, propagation step for longest wave, refraction step and minimum source term step.

Table 4.5.2.1 List of ocean wave model information

	Global	Western North Pacific (WNP)	China Offshore(CO)
Domain	0 °- 360 °E , 78 °S - 78 °N	90 °- 170 °E , 0 °N - 51 °N	105 °- 130 °E , 7 °N - 42 °N
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	GRAPES_GFS	GRAPES_TYM	GRAPES_TYM
Minimum water depth	2.5m	2.5m	2.5m
Time steps	2400s,480s,900s, 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

Experiment on surface roughness was carried out in order to decrease the intensity forecast error of sever typhoon and super typhoon. Scale-aware cumulus convection scheme was modified to improve precipitation forecast.

Coupled GRAPES_TYM with HYCOM is still under development; experiment on higher vertical resolution was designed and tested.

- Global typhoon track prediction system

A new TC vortex initialization scheme was developed based on 4Dvar data assimilation system through assimilation the central sea level pressure of TC.

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

The new meteorological down-scaling technique is still under development, which is used to interpolate 1 km GRAPES_MESO 3km numerical data to 200 m. 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 for 0~72 hours;

2) exposure from 0 to 500 m for 0~24 h, 24~48 h and 48~72 h;

3) the surface accumulated deposition for 0~24 h, 0~48 h and 0~72 h;

4) the Time Of Arrival (TOA) products at 6 h interval for 0~24 h, 24~48 h and 48~72 h.

- Regional Typhoon prediction system GRAPES_TYM:

The specific products of GRAPES_TYM include the following as shown in Table 4.5.3.1

Table 4.5.3.1 List of GRAPES_TYM model isobaric surface Products (Pictures)

Area	Variable	Times
NWP	3h accumulated precipitation	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
	6h accumulated precipitation	006,012,018,024,030,036,042,048,054,060,066,072,078,084,090,096,102,108,114,120
	12h accumulated precipitation	012,024,036,048,060,072,084,096,108,120

	24h accumulated precipitation	024,048,072,096,120
	48h accumulated precipitation	048,096
	72h accumulated precipitation	072
	96h accumulated precipitation	096
	120h accumulated precipitation	120
	6h accumulated maximum wind speed at 10m	006,012,018,024,030,036,042,048,054,060,066,072,078,084,090,096,102,108,114,120
	12h accumulated maximum wind speed at 10m	012,024,036,048,060,072,084,096,108,120
	24h accumulated maximum wind speed at 10m	024,048,072,096,120
	72h accumulated maximum wind speed at 10m	072
	Wind speed at 10m for 120h with 3h interval	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
	TC track	0-120
	TC intensity	0-120

- Global typhoon track prediction system

Ensemble TC track and probability products available up to 120h.

- Ocean wave forecasting system.

In 2019, the winds wave and swell variables from the global wave model were added to operationally available ocean wave products. A list of ocean wave products is given in Table 4.5.3.2.

Table 4.5.3.2 List of ocean wave model products

Variables	unit	Area
U-component of wind at 10 meters height	m/s	Global sea 0°- 360°E, 78°S - 78°N
V-component of wind at 10 meters height	m/s	
Significant Height of Combined Wind Waves and Swell	m	Western North Pacific 90°- 170°E, 0°N - 51°N
Mean length of Combined Wind Waves and Swell	m	
Mean Period of Combined Wind Waves and Swell	s	
Mean direction of Combined Wind Waves and Swell	rad	China Offshore 105°- 130°E, 7°N - 42°N
Peak frequency	s	
Peak direction	rad	
Significant Height of Wind Waves	m	Global sea 0°- 360°E, 78°S - 78°N
Primary swell wave height	m	
Secondary swell wave height	m	
Mean Period of Wind Waves	s	
Primary Wave Mean Period	s	
Secondary Wave Mean Period	s	
Mean wave length of wind waves	m	
Primary swell wave length	m	
Secondary swell wave length	m	
Mean Direction of Wind Wave	rad	
Primary Wave Direction	rad	
Secondary Wave Direction	rad	

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), and 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 ensembles, 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.

The numerical dust forecast model from Japan Meteorological Agency (JMA) has joined our multi-model ensemble dust forecast system in 2019. And some new artificial neural network ensemble methods have been tried to improve its forecast accuracy. For example, radial basis function, elman, wavelet, Takagi-Sugeno fuzzy artificial neural networks.

- 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.

- 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 h after their detection;

2) 24-h average pollution concentration in 0-72 h;

3) 0-24 h, 0-48 h and 0-72 h accumulated deposition (wet & dry) distribution;

4) improved the time of arrival products for 0-24 h, 24-48 h and 48-72 h.

- 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 h after detection);

2) hourly average pollution concentration in 0-12 h;

3) Total deposition (wet & dry) distribution accumulated in 0-12 h.

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

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.

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 of 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.

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.

Using GRAPES_MESO high-resolution numerical model and back propagation neural network model, the visibility fine grid forecast product were developed, which provide hourly visibility forecast with 3 km resolution in China. Based on the technology of weather classification and recognition, according to the standard of distinguishing fog and haze, the fine grid forecast products of fog and haze were developed.

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 was developed, which based on 31 members of GRAPES_GEPS ensemble numerical prediction system with 0.5^{o} in horizontal and 61 level in vertical. 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 was maintained in 2018, which based on 15 members of GRAPES_REPS ensemble numerical prediction system. The regional ensemble forecast products of atmospheric dispersion include the ensemble trajectories, the ensemble average and probability products of concentration and accumulated deposition in 0-24 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. The mid-long-term forecast of fog and haze has been extended to 30 days in 2019, which can provide more time advance for formulating air pollution reduction measures.

The ensemble ocean waves prediction system is under development in NMC. The system has been established with running the existing operational wave model WAVEWATCH III using winds from the 31 members' ensemble weather forecast system based on the GRAPES GFS model. The ensemble model calculates 31 members wave field, including one control forecast and 30 perturbation members forecast. The model computes the waves over all the oceans up to 10 days from 12 UTC at 0.5^{o} resolution. Based on hot initialization, the model uses the 12-h wave hindcast as its initial field.

4.5.5.3 Operationally available probabilistic prediction products

- **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 h average pollution concentration in 0-72 h; (3) the accumulated deposition (wet & dry) distribution accumulated in 0-24, 0-48 and 0-72 h.

- 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 h after detection); (2) hourly average pollution concentration in 0-12 h; (3) Total deposition (wet & dry) distribution accumulated in 0-12 h. In a special emergency response procedure, the system can provide the above products in more details.
- **Fog and haze probability forecast products:** (1) medium-long-term (1-30 days) probabilistic prediction products of $PM_{2.5}$ concentration ; (2) medium-long-term (1-15days) probabilistic prediction products of visibility ; (3) medium-long-term (1-15 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 up to 120 h; (2) maximum wind at surface; (3) vertical shear; (4) steering flow; (5) vorticity; (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 Western North Pacific Subtropical High (WNPSH) dominates the summer climate over East Asia by influencing the spatiotemporal distribution of precipitation, temperature anomalies and tropical cyclones through its intensity, position and shape. We investigated the performance of the Global Seasonal Forecast System Version 5 (GloSea5) in the simulation and prediction of the WNPSH using a hindcast dataset. Analysis of the hindcast dataset showed a systematic bias in the mean circulation over the west Pacific, with negative geopotential height anomalies over the western north Pacific (WNP) and cyclonic anomalies in the 850 hPa winds and water vapor transport, indicating a weakening and eastward shift of the WNPSH. In addition to the model's bias in the climatology, the interannual variability of both the monthly and seasonal-mean intensity of the WNPSH and the position of the ridge line in the boreal summer were captured well from 1993 to 2015. The seasonal hindcasts indicated that there is significant prediction skill at up to three months lead time for both the intensity and position of the ridge line.

The relationship between the WNPSH and different phases of the El Niño-Southern Oscillation (ENSO) in both the observational dataset and the GloSea5 hindcasts was investigated. The model captured the summer

WNPSH anomalies well during most of the phases of ENSO, except in the La Niña decaying and neutral summers. The intensity of the anticyclone in the WNP was weak in the decaying phase of El Niño in the GloSea5 hindcasts compared with the reanalysis datasets. GloSea5 was capable of representing the lagged teleconnection between El Niño events in the previous winter and the intensity of the WNPSH in the following summer. Regression analysis showed weakened negative sea surface temperature anomalies for the WNP in GloSea5, which decreased the gradient between the tropical western Pacific and the tropical Indian Ocean, resulting in a weaker easterly anomaly and stronger westerly anomaly, contributing to the weak anomalous anticyclone over the WNP and the weakened WNPSH relative to the reanalysis dataset.

4.6.3 Process and sort of the products in extended range forecast

Products are provided in a routine operation way, which include surface temperature, precipitation, sea level pressure, 200 hPa, 500 hPa, 700 hPa geopotential height, 200 hPa, 700 hPa 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, 200 hPa, 500 hPa, 700 hPa geopotential height, 200 hPa, 700 hPa 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 1^{st} ten days, 2^{nd} ten days, 3^{rd} ten days, 4^{th} 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 2019.

4.7.2 Research performed in this field

(1) 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 new forecast system based on dynamical and analogy capabilities (FODAS2.0) in 2019. 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 70 in 2019. 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 showed that the performance of the BCC-CSM1.2 is significantly good for the subtropical high over the Western Pacific (WPSH). In addition, we are planning to develop the multi-model ensemble prediction system.

(2) It is well known that the stratospheric quasi-biennial oscillation (QBO) is forced by equatorial waves with different horizontal/vertical scales, including Kelvin waves, mixed Rossby–gravity (MRG) waves, inertial gravity waves (GWs), and mesoscale GWs, but the relative contribution of each wave is currently not very clear. Proper representation of these waves is critical to the simulation of the QBO in general circulation models (GCMs). In this study, the vertical resolution in the Beijing Climate Center Atmospheric General Circulation Model (BCC-AGCM) is increased to better represent large-scale waves, and a mesoscale GW parameterization scheme, which is coupled to the convective sources, is implemented to provide unresolved wave forcing of the QBO.

Results show that BCC-AGCM can spontaneously generate the QBO with realistic periods, amplitudes, and asymmetric features between westerly and easterly phases. There are significant spatiotemporal variations of parameterized convective GWs, largely contributing to a great degree of variability in the simulated QBO. In the eastward wind shear of the QBO at 20 hPa, forcing provided by resolved waves is 0.1–0.2 m s^{-1} day^{-1} and forcing provided by parameterized GWs is ~0.15 m s^{-1} day^{-1}. On the other hand, westward forcings by resolved waves and parameterized GWs are ~0.1 and 0.4–0.5 m s^{-1} day^{-1}, respectively. It is inferred that the eastward forcing of the QBO is provided by both Kelvin waves and mesoscale convective GWs, whereas the westward forcing is largely provided by mesoscale GWs. MRG waves barely contribute to the formation of the QBO in the model.

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 summary

5.1.1 The verification against analysis of operational model (GRAPES_GFS)

The verification against analysis of operational numerical forecast model (GRAPES_GFS) in 2019 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 2019

Month	Valid time	Z(500)		W(250)			W(850)
		NH	SH	NH	SH	Tropics	Tropics
1	24	12.2	11.4	4.5	4.3	4.5	2.6
	72	35	32.9	9.8	10.4	7.6	5.4
	120	63	57.5	15.3	15.8	9.6	7.7
2	24	11.8	11.6	4.6	4.5	4.3	2.8
	72	34.7	34.5	10	10.4	7.1	5.7
	120	60.7	62.5	14.8	15.9	8.8	8.2
3	24	11.1	11.7	4.5	4.7	4	2.8
	72	33.3	34.8	10.1	10.7	6.6	5.9
	120	61.5	62.1	15.4	16.2	8.3	8.2
4	24	9.9	13	4.4	4.7	3.9	2.9
	72	29.6	37.4	9.4	10.9	6.6	6.2
	120	55.1	66.6	14.7	16.8	8.2	9
	24	9.5	12.7	4.4	4.8	4	3.2

5	72	26.2	38.6	9.3	10.5	6.5	6.6
	120	48.1	67.5	14.2	16.1	7.9	9.2
6	24	9	13.7	4.4	5.2	4.2	3.3
	72	23.8	41.7	9.2	11.6	7.1	7
	120	43.2	78.9	13.6	18.2	9	10.1
7	24	8.4	14.2	4.2	4.8	4.3	3.4
	72	21.6	41.8	8.9	10.8	6.9	7
	120	39.7	75.3	13.1	16.6	8.6	9.6
8	24	8.4	14.4	4.2	4.7	4.3	3.4
	72	21.9	43	9	10.7	6.8	6.9
	120	39.2	76.1	13.3	16.6	8.4	9.8
9	24	9.1	13.8	4.3	4.7	4.2	3.2
	72	25.3	40.6	9.5	10.5	6.7	6.6
	120	46.9	74	14.7	16.5	8.4	9.5
10	24	9.2	13.2	4.3	4.7	3.9	3.1
	72	27.5	37.1	9.5	10.1	6.2	6.1
	120	50.6	65	14.7	15.2	7.8	8.5
11	24	10	11.7	4.3	4.5	4	2.9
	72	28.1	33.7	9.3	9.7	6.5	5.7
	120	54.8	59.6	15.1	15.1	8	8.1
12	24	11.1	11	4.3	4.6	4.2	2.8
	72	31.7	29.6	9.6	9.7	6.7	5.3
	120	59.6	54.2	15	14.6	8.3	7.5

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 2019 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 2019

Month	**Valid time**	**Z(500)**				**W(250)**			
		N.A	**Europe**	**Asia**	**Australia**	**N.A**	**Europe**	**Asia**	**Australia**
1	24	15.7	18.1	21	14.1	5.6	5.9	4.7	7.5
	72	27.4	36.7	46.2	38.7	9	10.8	8.7	14.2
	120	46	63	82.7	71.8	12.4	16.2	15	21.9
2	24	17.3	18.2	20.2	15.8	6.6	6.3	5.1	6.8
	72	26	35.1	45.8	34.6	9.7	10.9	10.2	11.6
	120	46.6	58.4	78.2	60.1	13.8	15.2	14.6	16.1
3	24	15.7	17.1	19.6	12.5	6.4	6	4.6	6.4
	72	27	34.5	44.1	34.5	10.1	10.7	9.9	12
	120	50	62.1	83.3	57.7	14.6	16	16.2	16.7
4	24	14.3	16.4	17.6	12.5	6.9	6.3	4.4	6.9
	72	24.4	30.6	40.7	30.7	10.3	10.3	9.5	11.9
	120	41.7	53.3	71.7	56.1	14.1	15.2	15.1	17.6
5	24	14.5	15.2	16.9	11.6	6.5	6.1	4.4	6.8
	72	26.6	28.2	35.2	25.7	10.4	10.2	8.7	11.5

	120	40.6	47.5	62.3	42.8	14.5	14.8	13.6	16.3
6	24	14.3	15	17.4	10.8	7.3	6.4	5.3	6.8
	72	23.8	25.4	35	21.9	11.5	10.1	10	10.4
	120	35.3	41.8	65.4	35.1	14	13.6	15.3	14.4
7	24	14.3	13.9	15.6	10.6	6.5	5.9	5.3	5.8
	72	21.7	23.3	32.9	18.7	10.6	9.8	10.2	9.4
	120	31.7	38.3	59.8	31.4	13.5	13.5	16	12.6
8	24	14	13.7	16.2	9.8	6	5.7	5.3	6
	72	21.1	23.6	31.8	20	9.9	9.7	11.1	10
	120	30.4	38.4	54.6	36.2	13.2	13.7	16.2	14.1
9	24	13.9	14.3	17	11.5	5.8	5.7	5.4	6.1
	72	22.7	25.9	35.9	21.8	9.5	10	11.1	10.4
	120	35.4	46.1	61.1	41	12.9	15.1	17	14.9
10	24	15.6	15.6	20.3	13.2	5.6	5.5	4.9	6.2
	72	26.1	29.8	40.2	32	9.6	10.1	9.9	11.4
	120	43	52.5	68.9	53.3	13.7	15.3	15.2	16.6
11	24	16.8	16.2	21.5	13.1	5.3	5.5	4.7	6.2
	72	26.2	30	38.8	29.6	8.5	9.7	8.9	10.9
	120	45.2	54.9	70.2	54.8	12.7	15.2	14.6	17.2
12	24	15.9	16.9	21.4	13.2	5	5.6	4.6	6.2
	72	26.9	32.8	42.9	30.6	8.3	10.4	9.4	11.1
	120	43.6	59.1	75.1	60.7	11.9	15.4	14.1	17.4

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 CRPS for CMA EPS (500 hPa height, 850 hPa Temperature)
relative to an analysis in the second half of 2019

Month	Variable / Valid time	Z(500) (Geopotential meter)	T(850) (K)
7	48	10.97	0.8813
	72	15.814	1.1465
	120	26.297	1.5258
	168	34.613	1.9378
8	48	10.585	0.8462
	72	15.614	1.0494
	120	26.096	1.4182
	168	34.608	1.6903
9	48	12.108	0.8729
	72	17.538	1.0664
	120	28.481	1.4707
	168	37.75	1.8104
10	48	11.43	0.8548
	72	16.651	1.0384

	120	27.927	1.4052
	168	37.264	1.7334
11	48	12.796	0.9281
	72	18.235	1.1346
	120	31.865	1.6193
	168	44.755	2.0908
12	48	14.578	1.0072
	72	21.282	1.2363
	120	36.141	1.7343
	168	46.838	2.1425

5.2 Research performed in this field

- Development of spatial verification methods for ensemble precipitation forecasts.
- Update new verification methods in GRAPES Evaluation Tools (GETv2.6)
- Making plan for Developing of evaluation tools for models based on Python

6. Plans for the future

6.1 Development of the GDPFS

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

To improve the global operation 4D-Var system, with the horizontal resolution increased from 25km to 12.5km. To establish a global ensemble variational assimilation system with a horizontal resolution of 12.5km and to improve the assimilation of unconventional data such as satellites and radars. Develop the assimilation capability of new-type satellite remote sensing detection data, and continue to increase the proportion of satellite data. Develop land and ocean data assimilation systems. On the basis of the three-dimensional reference profile and the dynamic framework of the prediction-correction algorithm, the parallel computing and communication scheme will be optimized, and the horizontal resolution of the global model is increased from 25km to 12.5km. The hybrid vertical coordinate will be improved to increase the model stability. Other refers to optimize the stratospheric physics process, to optimize the interaction of the wet physics and to reduce the simulation bias in tropical regions.

A new generation of Beijing Climate Center Climate Prediction System (BCC_CPS) will begin a quasi-operational run and provide sub-seasonal, seasonal, and interannual prediction products, based on a high-resolution climate system model with T266 horizontal resolution and 56 vertical levels in atmospheric component and 1/4 ^{o}horizontal grid resolution in oceanic component.

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

6.2.1 Planned Research Activities in NWP

By 2025, the horizontal resolution of the global NWP system will reach 10 km. The hybrid 4D-Var for global and hybrid 3D-Var for regional data assimilation will be established. The application of unconventional data such as satellites and radars will be increased. The high-quality development of assimilation of Fengyun satellites will be promoted. The prototype of the coupling assimilation of the ocean-atmosphere and land-atmosphere will be built.

The horizontal resolution of the regional NWP system will reach 1 km. For operation needs such as short-term forecast and early warning, a nationwide 1km-resolution and 1h cycle assimilation and forecast system will be established, which can effectively assimilate weather radar, wind profile radar, stationary satellite, lightning, and ground dense precipitation observations data. The ability of short-term forecasting will be significantly improved.

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. Interactive short-time prediction operations will be practiced between nation and provinces, 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

In the next few years, a new generation of Beijing Climate Center Climate Prediction System (BCC_CPS) will be designed. BCC is planning to increase the atmospheric model resolution to T382 horizontal resolution and 70 vertical levels, and further improve the cumulus convection scheme, atmospheric boundary scheme, gravity wave parameterization, and atmospheric chemistry scheme, and so on. Meanwhile, based on the new version of climate system model, a coupled atmosphere-ocean-land-sea ice assimilation scheme and a stochastically perturbed parametrization tendency ensemble scheme will be developed and used in subseasonal and seasonal prediction.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

In 2019, a system to assess the meteorological impacts on air pollution was established based on an Environmental Meteorology Index (MEI) and observational data, and has been put into operation at CMA.

Recently, an on-line bio-mass burning emission module has been implemented into the CUACE system, enabling the forecast of bio-mass burning impact on air quality in China based upon the fire-spot observations of FY satellite series (3 and 4). The planned activity for the bio-mass burning module is to phase the system into CMA specialized numerical operational platform.

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

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. 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. 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. 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. 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. 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. 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. Meteorological Monthly, 2014.
Zhang Hanbin, Chen Jing, 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.

List of abbreviations

CMA	China Meteorological Administration
NMC	National Meteorological Centre
NCC	National Climate Centre
BCC	Beijing Climate Centre
NMIC	National Meteorological Information Centre
WMC (Beijing)	World Meteorological Centre (Beijing)
GRAPES	Global Regional Assimilation and PrEdiction System
GRAPES_GFS	GRAPES_Global Forecast System
GRAPES_GEPS	GRAPES_Global Ensemble Prediction System
GRAPES_REPS	GRAPES_Regional Ensemble Prediction System
GRAPES_TYM	GRAPES_TYphoon Model
GRAPES_MESO	GRAPES_MESO scale
GRAPES_RAFS	GRAPES_Rapid Analysis and Forecasting System
BCC_CSM	BCC_coupled Climate System Model (BCC_CSM)
SWAN	Severe Weather Analysis and Nowcasting system
CUACE	China Meteorological Administration Unified Atmospheric Chemistry Environment for aerosols
DERF	Dynamical Extended Range Forecast System

List of authors

CHEN	Qiying	Numerical Weather Prediction Centre, CMA
CUI	Yingjie	Numerical Weather Prediction Centre, CMA
GAO	Li	Numerical Weather Prediction Centre, CMA
GONG	Shanling	Chinese Academy of Meteorological Sciences
HU	Jiangkai	Numerical Weather Prediction Centre, CMA
HUANG	Liping	Numerical Weather Prediction Centre, CMA
Li	Hongqi	Numerical Weather Prediction Centre, CMA
LI	Li	Numerical Weather Prediction Centre, CMA
LI	Xiaoli	Numerical Weather Prediction Centre, CMA
LI	Yinglin	Numerical Weather Prediction Centre, CMA
LIU	Xiangwen	National Climate Centre, CMA
LIU	Shuang	World Meteorological Centre (Beijing) Operations Office, CMA
MA	Xin	Numerical Weather Prediction Centre, CMA
MA	Suhong	Numerical Weather Prediction Centre, CMA
RAO	Xiaoqin	National Meteorological Centre, CMA
SHENG	Li	Numerical Weather Prediction Centre, CMA
SUN	Jing	National Meteorological Information Centre, CMA
SUN	Minghua	Numerical Weather Prediction Centre, CMA
SUN	Jian	Numerical Weather Prediction Centre, CMA
TIAN	Weihong	Numerical Weather Prediction Centre, CMA
TONG	Hua	Numerical Weather Prediction Centre, CMA
WANG	Jingzhuo	Numerical Weather Prediction Centre, CMA
WANG	Yu	Numerical Weather Prediction Centre, CMA
WANG	Yi	World Meteorological Centre (Beijing) Operations Office, CMA
YANG	Bo	National Meteorological Centre, CMA
ZHANG	Lin	Numerical Weather Prediction Centre, CMA
ZHANG	Tianhang	National Meteorological Centre, CMA
ZHAO	Ruixia	National Meteorological Centre, CMA
ZHAO	Junhu	National Climate Centre, CMA
ZHAO	Bin	Numerical Weather Prediction Centre, CMA
ZHENG	Zhihai	National Climate Centre, CMA
ZHOU	Qingliang	World Meteorological Centre (Beijing) Operations Office, CMA
ZHUANG	Zhaorong	Numerical Weather Prediction Centre, CMA