National Meteorological Center,CMA
National Climate Center,CMA

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

CHINA

NMC and NCC

China Meteorological Administration

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1. Summary of highlights

- **The GRAPES_GFS model has been updated to GRAPES_GFS V3.0.**

The operation system GRAPES_GFS has been updated twice. On 6th May, the GRAPES_GFS was updated to GRAPES_GFS V2.5. The 4D-var system incorporated FY-3D infrared hyperspectral data HIRAS, microwave thermometer data MWTS-2, FY-3C/D Microwave imager data MWRI, FY-2H imager data VISSR, FY-4A imager AGRI, FY-3D/KOMPSAT/PAZ occultation data.

On 25th July, the GRAPES_GFS was updated to GRAPES_GFS V3.0 with following improvements: using three-dimensional reference atmosphere and prediction-correction algorithm dynamic framework; the model top layer was raised to 0.1hPa; the non-terrain gravity wave parameterization was added to improve the stratospheric physical process depiction; background field error covariance was updated; the fast radiation transmission mode was upgraded to RTTOV12; upper-level satellite data was added; application of occultation data was optimized. The verification shows that GRAPES_GFS V3.0 has significant improvements in assimilation and forecasting skills than GRAPES V2.5 and its operations are stable and reliable.

- **The GRAPES_MESO has been upgraded to V5.0 with higher update frequency.**

On 25th June, the regional high resolution NWP - GRAPES_MESO has been upgraded to V5.0 and the operational update frequency was increased from 6 hours to 3 hours per day. The main improvements are as follows: the high-resolution assimilation system for meso-scale weather systems was developed; the land surface data assimilation system was developed; the cloud analysis system was optimized; rapid update cycle (RUC) technology was developed to establish a national 3km 3-hour RUC assimilation forecast system; the assimilation of radar radial wind, wind profiler radar, FY4-A imager radiance, satellite cloud motion wind, satellite GNSSRO, ground precipitation observation and near-surface data was applied to improve the assimilation capability of unconventional local dense data. The verification shows that test scores of GRAPES_MESO V5.0 surpasses the quasi-operational GRAPES_MESO 3km system with better forecasting skills in severe weather especially the warm-zone convection under weak large-scale forcing.

- **The updated GRAPES_GEPS and GRAPES_REPS have been put into operation.**

On 6th May, the updated global EPS – GRAPES_GEPS has been put into operation: the model version was updated to GRAPES_GFS V2.4; the ensemble stochastic perturbation schemes SPPT and SKEB were updated; the 4 surface weather element extremes processing procedures were added into the post-processing module of GRAPES_GESP. The 11-day continuous tests for 2019 winter demonstrate that the forecasting skill of GRAPES_GEPS V1.1 outperforms GRAPES_GEPS V1.0.

The regional EPS – GRAPES_REPS has been updated with the new scheme for calculating the ensemble member's radar echo reflectivity of sub-grid precipitation that the radar echo forecasting skill was improved. The 30-day verification test shows that the new scheme can better simulate the sub-grid precipitation radar echo reflectivity than GRAEPS_REPS V3.0.

- **The new World Meteorological Centre (Beijing) products have been developed.**

The new World Meteorological Centre (Beijing) (WMC-Beijing) products including GRAPES Extreme Weather Index (EFI), CMA 40-yr Global Reanalysis (CRA-40) and climate monitoring indices have been developed and are made available on the WMC-Beijing website (http://www.wmc-bj.net). WMC-Beijing is the operational centre under the WMO GDPFS framework that provides all WMO members and other users with a variety of products including global NWP guidance as well as special reports for global severe weather monitoring and forecasting.

2. Equipment in use at the Centre

There are two major high-performance computer systems in CMA.

The total peak performance of Sugon HPC system is 8189.5 TFlops and the total storage capacity is about 35PB. Two sets of subsystems of this HPC were installed in Beijing in 2018. More details are showed in Table 2.1.

Table 2.1 Details of sub-systems of CMA Sugon HPC Systems

Subsystem	**SS1**	**SS2**
Site	Beijing	
Peak Performance (TFlops)	4094.77	4094.77
Storage (TB)	35688	
CPU Cores	49216	49216
Memory (GB)	345216	345216

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 showed in Table 2.2.

Table 2.2 Details of sub-systems of CMA IBM Flex System and/or P460 HPC System

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

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 Des 2020.

Table3.1 Observation data for assimilation system

Data type	Mean	Data type	Mean	Data type	Mean
SYNOP	131572	AIREP/AMDAR	156609	NOAA15_AMSUA	87084
SHIP/BUOY	11016	SATOB (WIND)	313256	NOAA18_AMSUA	94596
TEMP	2000	AIRS	76800	METOP2_AMSUA	163625
GNSS(including COSMIC)	382240	NOAA19-AMSUA	131808	METOP1_AMSUA	75673
ASCAT	12180	NOAA19-MHS	23460	NPP-ATMS	171056
FY4A-hps	74206	METOP-B IASI	408660	FY3C-AMSUB	1800
FY3-D MWTS2	31668	METOP-B MHS	24476	FY3-D MWHS2	8844
FY3-D HIRAS	116364	FY3-D MWRI	11828		

4. Forecasting system

4.1 System run schedule and forecast ranges

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_GFS3.0)	03:40 (00Z_ASSIM+240HR_FCST)	03:40 ~ 05:40	PI-Sugon
	07:10 (00Z_ASSIM. +6HR_.FCST)	07:10 ~ 08:15	PI-Sugon
	13:10(06Z_ ASSIM +6HR_.FCST)	13:10 ~ 14:15	PI-Sugon
	15:40(12Z_ASSIM.+240HR_FCST)	15:40 ~ 17:40	PI-Sugon
	19:10(12Z_ASSIM.+ 6HR_.FCST)	19:10 ~ 20:15	PI-Sugon
	01:10(18Z_ASSIM.+ 6HR_.FCST)	01:10 ~ 02:15	PI-Sugon
Regional Forecasting System (GRAPES_MESO4.3)	03:20 (00Z_ ASSIM +84HR_.FCST)	03:20～04:30	PI-Sugon
	15:20 (12Z_ ASSIM +84HR_.FCST)	15:20～16:30	PI-Sugon
Ensemble Forecasts With 31 members (GRAPES_GEPS)	04:30 (00Z_ASSIM+360HR_FCST)	04:30～07:00	PI-Sugon
	16:30 (12Z_ASSIM+360HR_FCST)	16:30～19:00	PI-Sugon
Regional Typhoon Forecasting System （GRAPES_TYM 3.0）	04:20 (00Z_120HR_FCST)	04:20～05:50	PI-Sugon
	11:00 (06Z_120HR_FCST)	11:00～12:30	PI-Sugon
	17:00 (12Z_120HR_FCST)	17:00～18:30	PI-Sugon
	23:00 (18Z_120HR_FCST)	23:00～00:30	PI-Sugon
Regional Ensemble	05:20(00Z_84HR_FCST)	05:20~07:30	PI-Sugon

Forecasting system with 15 members (GRAPES_REPS)	17:20(12Z_84HR_FCST)	17:20~19:30	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 System (WW3)	07:20 (00Z_120HR_FCST)	07:20～07:55	PI-Sugon
	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	03:50 (00Z+36HR_FCST)	03:50～05:50	PI-Sugon
	05:30 (03Z+36HR_FCST)	05:30～07:30	PI-Sugon
	08:30 (06Z+36HR_FCST)	08:30～10:30	PI-Sugon
	11:30 (09Z+36HR_FCST)	11:30～13:30	PI-Sugon
	15:50 (12Z+36HR_FCST)	15:50～17:50	PI-Sugon
	17:30 (15Z+36HR_FCST)	17:30～19:30	PI-Sugon
	20:30 (18Z+36HR_FCST)	20:30～22:30	PI-Sugon
	23:30 (21Z+36HR_FCST)	23:30～01:30	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 upgraded to version 3.0 in 2020. This new version of model has been updated and extended vertically from 60L to 87L with the altitude of the model lid increased from 36 km to 60 km.

4.2.1.2 Research performed in this field

The radiative transfer model RTTOV has been upgraded from version 9.3 to 12.2 based on the 87-level global 4D-Var system. The FY-3C microwave hygrometer, microwave imager, FY-3D infrared hyperspectral, microwave thermometer, microwave hygrometer, microwave imager, FY-4A infrared hyperspectral and imager are introduced into the 87-level global 4D-Var system using the corresponding transmittance coefficient. The assimilation of NOAA18 MHS, NOAA19 MHS, METOP-A MHS, METOP-B MHS hygrometer observations are also included. The static bias correction coefficients for all satellite observations are revised from the forecasts using the ERA-Interim reanalysis as the initial fields.

Four sets of 4-month retrospective trials have been performed using the 87-level global 4D-Var system. The 4D-Var analysis and forecasts at the upper levels has been significantly improved.

A new linearized planetary boundary layer scheme is developed based on the nonlinear NMRF scheme using the Charney-Phillips (C-P) grid. The linearized NMRF scheme using the C-P grid can improve the perturbed fields at the lower levels in the tangent-linear model and result in the better global forecast.

The prototype global 4D-Var system with the horizontal resolution of 0.125 degree has been set up. The model trajectories are provided by the standalone model integration for the calculation of the observation increment in the 4D-Var outer loop to save the computational cost in real-time environment. The input of the model trajectory and the output of the 4D-Var analysis are also accelerated. The cost for the global 4D-Var analysis with 0.125 degree horizontal resolution has been shortened from about 2 hours to 35 minutes.

The key parameters of the global En4DVar assimilation system have been optimized, including ensemble weighting coefficients, horizontal and vertical localization scales, ensemble error variance inflation coefficients, etc. The global En4DVar trials were carried out for 52 days each in winter and summer. The test results show that En4DVar has an overall improvement over 4D-Var.

As the preliminary study of global land surface data assimilation, Optimal Interpolation (OI) soil analysis scheme is planned to be used in GRAPES_GFS. Some preparatory work has been done. The variables and coefficients used to calculate OI coefficients were carefully tested, and the weather conditions were strictly selected to exclude the column grids where the soil forecast error has low relationship with atmosphere.

A skin sea surface temperature model has been developed within the GRAPES-GFS. Within this model, the diurnal variability of sea surface temperature can be described.

4.2.2 Model

4.2.2.1 In operation

4.2.2.2 Research performed in this field

4.2.3 Operationally available Numerical Weather Prediction (NWP) Products

In 2016, The GRAPES_GFS model was put into operation. In 2020, GRAPES_GFS was upgraded to version 3.0, main change is its vertical layers changing from 60 levels, 36km (about 4hPa), to 87 levels, 63km (about 0.1hPa). So many upper layers of some 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	40	0.1,0.2,0.5,1,1.5,2,3,4,5,7,10, 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	global: 0.25°×0.25° 1440×720 0°N - 359.75°N， 89.875°E - -89.875°E
Temperature	K	40		
U-wind	m/s	40		
V-wind	m/s	40		
Vertical velocity	m/s	30	10, 20, 30, 50, 70, 100, 125,	

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

Divergence of vapour flux	g/cm2·hPa·s	30		
Pseudo-equivalent potential Temperature	K	30		
Radar reflectivity	dBz	30		
Potential vorticity	K.m^2/s.kg	30		
Strong weather threat index	-	1	surface	
Convective available potential energy	J/kg	1	surface	
Convective inhibition energy	J/kg	1	surface	
Lifting index	K	1	surface	
Condensation layer pressure	hPa	1		
K index	°C	1	mean sea level	
Radar composite reflectivity	dBz			
Simulated satellite brightness temperature of vapor channel	K	1	surface	
Simulated satellite brightness temperature of infrared channel	K	1	surface	
Albedo	%	1	surface	
2m Dew point temperature	K	1	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	w.m^-2.s	1	top of atmosphere	

long-wave radiation				
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°C 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	-	89	global: 0.25°×0.25° 1440×720 0°N - 359.75°N， 89.875°E - -89.875°E
Potential temperature	K	88	
U-wind	m/s	87	
V-wind	m/s	87	
Vertical velocity	m/s	88	
Specific humidity	kg/kg	88	
Cloud fraction	0-1	88	
Cloud water mixing ratio	kg/kg	88	
Rain water mixing ratio	kg/kg	88	
Ice water mixing ratio	kg/kg	88	
Snow water mixing ratio	kg/kg	88	
Graupel	kg/kg	88	
Perturbed potential temperature	K	88	
Perturbed Exner pressure	-	89	
temperature	K	88	
Geopotential height	Gpm	88	
pressure	hPa	88	

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) has been operating stably since it was officially put into operation nationwide on June 15, 2020. It provides meteorological elements guidance forecast to all meteorological departments across China both at grids and at 11621 observation locations. It also carries out some international assistance such as in Laos grid forecast. 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

The multi statistical post-processing methods were used to correct the numerical model forecast errors both at grid points and observation locations in CMA-GOWFS. The station forecast revision based on the observation data of global international exchange stations greatly improves the prediction performance of the stations and their surrounding grid points; The gridded prediction correction based on gridded analysis observation data fused by multi-source observation can further make up for the prediction performance over sparse-observation-station areas in land and ocean.

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.

Dynamical optimal integration of multi forecasts from different models and methods according to their latest performance is performed to obtain the best forecast for individual stations and different lead-times. Besides the GRAPES and ECMWF global numerical model output, the NCEP model output was taken as the input data to improve the integrated members and forecast performance in 2020.

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.

Furthermore, the hourly forecast experiment within 24 hours was also carried out in 2020. The biggest challenge and difficulty is the scarcity and unstable quality of 1h observation data. However, by lots of quality control efforts and making full use of the temporal and spatial consistency technology, relatively reliable prediction performance of hourly forecast within 24 hours was finally achieved.

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

4.2.5.2 Research performed in this field

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	
24-hr Accum. Precip.	mm	1	Surface	EM	
				STAMP	
				Max	
				PRBT	1, 10, 25, 50 ,100 mm
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

4.3.1.2 Research performed in this field

4.3.2 Model

4.3.2.1 In operation

4.3.2.2 Research performed in this field

4.3.3 Operationally available NWP products

In 2020, no change of NWP products from 2019. 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,	horizontal resolution：0.1*0.1 Grid points：
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	700, 750, 800, 850, 900, 925, 950, 975, 1000	751*501 15°N ~65°N 70°E ~145°E
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·hPa·s	30		
37	Divergence of vapour flux	g/cm2·hPa·s	30		
38	Pseudo-equivalent potential temperature	K	30		
39	Radar reflectivity	dBz	30		
40	Strong weather threat index	-	1	--	
41	Convective available potential energy	J/kg	1	--	
42	Convective inhibition energy	J/kg	1	--	
43	Lifting index	K	1	--	
44	Condensation layer pressure	hPa	1	--	
45	K index	K	1	--	

46	Snow	m	1	surface	
47	0-1000m storm-relative helicity	M2/s2	1	0-1000m	
48	0-3000m storm-relative helicity	M2/s2	1	0-3000m	
49	Planetary boundary layer height	M	1	--	
50	Height of radar echo top	M	1	--	
51	Richardson number of surface layer	-	1	Surface	
52	Richardson number of PBL	-	1	Boundary layer	
53	Maximum of u10m in output interval	m/s	1	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

4.3.5.2 Research performed in this field

Ensemble forecast is a method to faithfully describe initial and model uncertainties in a weather forecasting system. Initial uncertainties are much more important than model uncertainties in the short-range numerical prediction. Currently, initial uncertainties are described by Ensemble Transform Kalman Filter (ETKF) initial perturbation method in Global and Regional Assimilation and Prediction Enhanced System-Regional Ensemble Prediction System (GRAPES-REPS). However, an initial perturbation distribution similar to the analysis error cannot be yielded in the ETKF method of the GRAPES-REPS. To improve the method, we introduce a regional rescaling factor into the ETKF method (we call it ETKF_R). We also compare the results between the ETKF and ETKF_R methods and further demonstrate how rescaling can affect the initial perturbation characteristics as well as the ensemble forecast skills. The characteristics of the initial ensemble perturbation improve after applying the ETKF_R method. For example, the initial perturbation structures become more reasonable, the perturbations are better able to explain the forecast errors at short lead times, and the lower kinetic energy spectrum as well as perturbation energy at the initial forecast times can lead to a higher growth rate of themselves. Additionally, the ensemble forecast verification results suggest that the ETKF_R method has a better spread-skill relationship, a faster ensemble spread growth rate and a more reasonable rank histogram distribution than ETKF. Furthermore, the rescaling has only a minor impact on the assessment of the sharpness of probabilistic forecasts. The above results all suggest that ETKF_R can be effectively applied to the operational GRAPES-REPS.

To more comprehensively and accurately address model uncertainties in the East Asia monsoon region, a single-physics suite where each ensemble member uses the same set of physics parameterizations as the control member in combination with multiple stochastic schemes is developed to investigate if the multistochastic schemes that combine different stochastic schemes together can be an alternative to a multiphysics suite, where each ensemble member uses a different set of physics parameterizations (e.g., cumulus convection, boundary layer, surface layer, microphysics, and shortwave and longwave radiation). For this purpose, two experiments are performed for a summer monsoon month over China: one with a multiphysics suite and the other with a single-physics suite combined with multistochastic schemes. Three stochastic schemes are applied: the Stochastically Perturbed Parameterizations (SPP) scheme, consisting of temporally and spatially varying perturbations of 18 parameters in the microphysics, convection, boundary layer, and surface layer parameterization schemes; the Stochastically Perturbed Parameterization Tendencies (SPPT) scheme; and the Stochastic Kinetic Energy Backscatter (SKEB) scheme. The combination of the three stochastic schemes is compared with the multiphysics suite in the Global and Regional Assimilation and Prediction Enhanced System-Regional Ensemble Prediction System with a horizontal grid-spacing of 15-km. Verification results show that, overall, a single-physics suite that combines SPP, SPPT, and SKEB outperforms the multiphysics suite in precipitation verification and verification for upper-air weather variables, 10-m zonal wind, and 2-m temperature in the East Asian monsoon region. The indication is that a single-physics suite combining SPP, SPPT, and SKEB may be an appropriate alternative to a multiphysics suite. This finding lays a foundation for the development and design of future regional and global ensembles.

To represent model uncertainties more comprehensively, a stochastically perturbed parameterization (SPP) scheme consisting of temporally and spatially varying perturbations of 18 parameters in the microphysics, convection, boundary layer, and surface layer parameterization schemes, as well as the stochastically perturbed parameterization tendencies (SPPT) scheme, and the stochastic kinetic energy backscatter (SKEB) scheme is applied in the Global and Regional Assimilation and Prediction Enhanced System-Regional Ensemble Prediction System (GRAPES-REPS) to evaluate and compare the general performance of various combinations of multiple stochastic physics schemes. Six experiments are performed for a summer month (1-30 June 2015) over China and multiple verification metrics are used. The results show that: (1) All stochastic experiments outperform the CTL experiment, and all combinations of stochastic parameterization schemes perform better than the single SPP scheme, indicating that stochastic methods can effectively improve the forecast skill, and combinations of multiple stochastic parameterization schemes can better represent model uncertainties; (2) the combination of all three stochastic physics schemes (SPP, SPPT, and SKEB) outperforms any other combination of two schemes in precipitation forecasting and surface and upper air verification to better represent the model uncertainties and improve the forecast skill; (3) Combining the SKEB with the SPP and/or SPPT results in a notable increase in spread and reduction in outlier for the upper-air wind speed. SKEB directly perturbs the wind field and therefore its addition will greatly impact the upper-air wind speed fields, and it contributes most to the improvement in spread and outlier for wind; (4) the introduction of SPP has a positive added value, and does not lead to large changes in the evolution of the kinetic energy (KE) spectrum at any wavelength; and (5) the introduction of SPPT and SKEB would cause a 5%-10% and 30%-80% change in the kinetic energy of mesoscale systems, and all three stochastic schemes (SPP, SPPT, and SKEB) mainly affect the kinetic energy of mesoscale systems. This study indicates the potential of combining multiple stochastic physics schemes and lays a foundation for the future development and design of regional and global ensembles.

This study experimented a unified scheme of stochastic physics and bias correction within a regional ensemble model GRAPES-REPS. It is intended to maximize ensemble prediction skill by reducing both random and systematic errors at the same time. Three experiments were performed on the top of GRAPES-REPS. The 1st experiment is adding the stochastic physics alone. The 2nd experiment is adding the bias correction scheme alone. The 3rd experiment is adding both the stochastic physics and bias correction. The experimental period is 10 days from 1 to 10 July 2015 over the China domain.

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

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
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	/	/	EM & Spread	
				PRBT	5, 10, 20, 30, 40
K index	/	/	/	EM & Spread	
				PRBT	30, 35, 40, 45
0-3km Vertical Wind shear	/	1	0-3km	EM & Spread	
				PRBT	12, 16, 20, 24
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)

4.4.1 Nowcasting system

4.4.1.1 In operation

4.4.1.2 Research performed in this field

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

4.5.1.2 Research performed in this field

4.5.2.1 Operation and research on Typhoon

- Environmental Emergency Response System (EERS):

For the global environmental emergency response system, GRAPES_GFS is used for driving the atmospheric transport model HYSPLIT. The horizontal resolution of GRAPES_GFS is 0.25^o, and there are 60 levels in vertical. However, the 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

No change to operational GRAPES_TYM.

Research were carried out in order to improve the precipitation forecast of GRAPES_TYM, including:

(1) A Scale-ware SAS was developed in order to reduce the over-prediction of light rain

(2) The static data was upgraded using MODIS observation

(3) The roughness parameterization scheme was changed to Moon et al 2007

(4) Cloud analyses was introduced in the continent and near land area of China

- Global typhoon track prediction system.

A new vortex initialization scheme was used in GRAPES-GFS in 2020.

- 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; 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 CO 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	0º - 360ºE， 78ºS - 78ºN	90º - 170ºE， 0ºN - 51ºN	105º - 130ºE， 7ºN - 42ºN
Resolution	$0.5^{o}\times0.5^{o}$	$1/6^{o}\times1/6^{o}$	$1/15^{o}\times1/15^{o}$
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 Operation and research on Wave

- 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 high-resolution about 100m ATDM technology is still under development, which is used to provide the high-resolution environmental emergency response services with 200 m or 100 m resolution for 100km range.

4.5.2.3 Operation and research on Dispersion Model

- Environmental Emergency Response System (EERS):

For the global environmental emergency response system, GRAPES_GFS is used for driving the atmospheric transport model HYSPLIT. The horizontal resolution of GRAPES_GFS is 0.25^{o}, and there are 87 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.

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.

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 0º - 360ºE, 78ºS - 78ºN
V-component of wind at 10 meters height	m/s	
Significant Height of Combined Wind Waves and Swell	m	
Mean length of Combined Wind Waves and Swell	m	Western North Pacific 90º - 170ºE, 0ºN - 51ºN
Mean Period of Combined Wind Waves and Swell	s	
Mean direction of Combined Wind Waves and Swell	rad	China Offshore 105º - 130ºE, 7ºN - 42ºN
Peak frequency	s	
Peak direction	rad	
Significant Height of Wind Waves	m	Global sea 0º - 360ºE, 78ºS - 78ºN
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

4.5.4.2 Research performed in this field

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 wave 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 0.5o 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 (0-24 h after detection); (2) hourly average pollution concentration in 0-24 h; (3) Total deposition (wet & dry) distribution accumulated in 0-24 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

Daily maximum temperature data collected at 2374 stations in China, the NCEP/NCAR atmospheric circulation data and NOAA sea surface temperature (SST) data are used to analyze the main types of midsummer high temperature in the southern China. Large-scale circulations corresponding to these high temperature types and their relation with SST anomalies are explored. The results show that the annual high temperature days in the southern China has a significant increasing trend. Cluster analysis is used to classify the midsummer high temperature in the southern China into three types: Jianghuai type, South China type and Central China type. The Jianghuai type high temperature is centered in the Jianghuai area, with a wide range and high occurrence frequency. When the Jianghuai type high temperature occurs, anomalous anticyclone occurs in the troposphere from low to high levels. Meanwhile, the Western Pacific subtropical high (WPSH) is stronger than normal and shifts to the west with the ridgeline located slightly northward. Therefore, Jianghuai type high temperature is a high temperature type under the control of the WPSH. This type of high temperature is mainly related to the attenuation of the central type El Niño from the pre-winter to the subsequent summer and warmer SST in the equatorial Atlantic in spring. The central area of South China type high temperature occurs from the southern Yangtze River basin to South China. The typical circulation systems are the southward displacement of the East Asian subtropical jet, the stronger and westward shift of the WPSH with a southward shift of the ridgeline. Also, the South China type high temperature is directly under the control of the WPSH, accompanied by a weakened southwesterly monsoon circulation. It has an obvious characteristic of dry heat. This type of high temperature is closely related to the attenuation of the eastern type El Niño and its associated Indian Ocean capacitor effect. The Central China type high temperature is mainly located in Hubei province and Hunan province. The corresponding circulation is that the WPSH is slightly weaker and shifts eastward, which shows a similar pattern to the North Atlantic-Eurasia remote correlation pattern in the middle and high latitudes. It is the high temperature under the control of continental high pressure, which makes the water vapor condition better than the other two types of high temperature. The North Atlantic- Eurasian teleconnection is a possible signal source of Central China type high temperature.

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.

4.7 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 2020.

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 2020. The system is based on the second generation seasonal model including BCC (BCC-CSM1.1), NCEP_CFSv2, ECMWF_SYSTEM5, JMA_CPS2 and UKMO_GLOSEA5, 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 81.7 in 2020. 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) What Drives the Super Strong Precipitation over the Yangtze–Huaihe River Basin in the Meiyu Period of 2020? During the Meiyu Period (June–July, JJ) of 2020, the Yangtze–Huaihe River Basin (YHRB) in China experienced record-breaking rainfalls, resulting in severe floods and disasters. These rainfall anomalies were closely related to the extremely strong anomalous anticyclone developed over the western North Pacific (WNPAC), which favored convergence of water vapor over YHRB. The aim of this study is to determine the cause of the record-breaking rainfalls and WNPAC in the Meiyu period of 2020. It was found that a weak Central-Pacific El Niño rapidly decayed in spring and developed to a La Niña in late summer, whereas sea surface temperature (SST) in the tropical Indian Ocean (TIO) and tropical northern Atlantic (TNA) was considerably and persistently high from the previous winter to summer. The results showed that the weak decaying El Niño alone was insufficient to sustain the strong WNPAC in JJ of 2020, whereas the long-lasting warm SST anomalies in the TIO and TNA significantly contributed to the enhancement and westward

shift of the WNPAC. The TIO warming intensifies the WNPAC by propagating Kelvin waves eastward and/or modulating the Hadley circulation. The TNA warming can force a westward-extending overturning circulation over the Pacific–Atlantic Oceans, with a sinking branch over the central tropical Pacific, which suppresses the convection activity over there and gives rise to the WNPAC. The TIO and TNA warming significantly contributed to the extremely strong WNPAC in JJ of 2020.

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.
- The real-time forecast accuracies of summer precipitation in Northeast China (NEC) from 1978 to 2018 were significantly low. Moreover, in the recent four years, when the prediction of the overall distribution of summer precipitation anomaly for the whole country was relatively accurate, the prediction of summer precipitation anomaly in NEC was contrary to the actual situation. Therefore, analyzing the cause for the low forecasting accuracy is necessary. In this paper, the forecasting ability of dynamic models and cognitive defects on forecasting summer rainfall in NEC are discussed. Moreover, by systematically reviewing the climatic characteristics, influencing factors, prediction methods of summer drought and flood in NEC, and the real-time forecasting skills, the causes have been obtained as follows: (1) The precipitation in early summer in NEC is mainly affected by the cold eddy activity in NEC, and in midsummer, it is mainly affected by the subtropical high in the West Pacific, the southerly wind in the Northeast, and the circulation pattern in the middle and high latitudes. However, the main dynamic climate models commonly used at home and abroad cannot accurately reflect the key circulation systems associated with precipitation in early summer and midsummer in NEC. (2) The relationship between the summer rainfall in NEC and the global sea surface temperature (SST) is weak and unstable. Especially, the influence of El Niño–southern oscillation (ENSO) on summer precipitation in NEC is complicated; the relationship between them varies from decade to decade. (3) The summer

rainfall in NEC has remarkable multi-timescale variability (inter-seasonal, inter-annual, and inter-decadal timescales), influenced by different circulation systems, which makes accurately predicting summer precipitation in NEC more difficult. Finally, some scientific problems and possible solutions regarding summer rainfall forecasting in NEC are further discussed, which may be helpful for the future summer rainfall predictions in this area.

5. Verification of prognostic products

5.1 Annual verification summary

5.2 Research performed in this field

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

The third generation of Beijing Climate Center Climate Prediction System (BCC-CPSv3) begins a quasi-operational run in 2021. It is based on a high-resolution climate system model with T266 horizontal resolution and 56 vertical levels in atmospheric component and 1/4º horizontal grid resolution in oceanic component. In the next year, it will finish all reforecast and real-time forecast experiments and provide sub-seasonal, seasonal, and inter-annual climate prediction products.

6.1.2 Strategy in the next four years

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

6.2.1 Planned Research Activities in NWP

6.2.2 Planned Research Activities in Nowcasting

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-CPSv4) 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 sub-seasonal and seasonal prediction.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

Air Quality Forecasts by Machine Learning

An automated air quality forecasting system based on machine learning has been developed and applied for daily forecasts of six common pollutants (PM2.5, PM10, SO2, NO2, O3, and CO) and pollution levels, which can automatically find the best "Model + Hyperparameters" without human intervention. Five machine learning models and an ensemble model (Stacked Generalization) were integrated into the system, supported by a knowledge base containing the meteorological observed data, pollutant concentrations, pollutant emissions, and model reanalysis data. Based on the analysis of seven evaluation criteria and pollution level forecasts, combined with the forecasting results for the next 3-days, it is found that the automated system can achieve satisfactory forecasting performance, better than most of numerical model results. This implied that the developed system unveils a good application prospect in the field of environmental meteorology.

Ocean wave forecasting system

The ocean wave forecasting system plans to increase the resolution of global and regional wave model, and develops wave assimilation technology.

Environmental Emergency Response System:

To develop an operational system for the mico-scale ATDM model with the horizontal resolution about 100m, and apply the GIS to new high-resolution system.

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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

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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
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