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 2017

CHINA

NMC and NCC
China Meteorological Administration
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CHINA, AUGUST 2018

1. Summary of highlights

1.1 Developments of operational NWP

The global model forecast system GRAPES-GFS (0.25L60) version 2.1 has been put into operation run in June 2017 using Typhoon vortex initialization. The regional model GRAPES-MESO had been updated from version 4.1 to 4.2 with an integration of GRAPES-MESO and GRAPES-RAFS. GRAPES Mesoscale Ensemble Prediction System (GRAPES-MEPS) was updated from version1.0 to 2.0. A Multiple Scale Blending (MSB) initial perturbations method and Stochastically and Perturbed Parameterization Tendencies (SPPT) scheme have been operationally implemented since March 2017 for GRAPES-MEPS.

1.2 Developments of GRAPES

1-year batch experiments and 1-month parallel test in operational environment with GRAPES global 4DVar was completed, and the verifications showed that GRAPES global 4DVar was systematically better than 3DVar, the previous operational system, so it has been put into operation on 1 July 2018. Meso-scale GRAPES model and Meso-scale GRAPES typhoon track model have been unified, but with some different physics options. A high resolution meso-scale GRAPES (3km grid length) which cover the whole China was tested, with better ETS scores than the version only covering East China.

2. Equipment in use at the Centre

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

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

Subsystem	SS1	SS2	SS3	SS4	SS5	SS6	SS7
Site	Beijing		Guangzhou	Shenyang	Shanghai	Wuhan	Chengdu
Peak Performance (TFlops)	527.10	527.10	391.69	77.24	51.80	77.24	26.35
Storage (TB)	2109.38	2109.38	949.22	210.94	140.63	210.94	70.31
CPU Cores	18560	18560	13792	2720	1824	2720	928

(Include I/O nodes)							
Memory (GB)	81792	81792	57856	10752	7168	10752	3584

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

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

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

3. Data and Products from GTS in use

Data from the database of NMIC in use are showed in table 3.1 according to one day data used by GRAPES-GFS in December 2017.

Table3.1 Observation data for assimilation system

Data type	Mean	Data type	Mean	Data type	Mean
SYNOP	21254	AIREP/AMDAR	178280	NOAA15_AMSUA	65851
SHIP/BUOY	28488	SATOB (WIND)	86249	NOAA18_AMSUA	55783
TEMP	1546	AIRS	0	METOP2_AMSUA	73138
GNSS(including COSMIC)	94770	NOAA19-AMSUA	73522	METOP1_AMSUA	95438
ASCAT	9357	FY3C-AMSUB		NPP-ATMS	152779

4. Forecasting system

4.1 System run schedule and forecast ranges

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

Table 4.1 Operational Schedule of NWP system in CMA

Systems	Cut-off time (UTC)	Run time (UTC)	Computer used
Global Forecasting System (GRAPES_GFS2.1)	03:30 (00Z_ASSIM+240HR_FCST)	03:30～06:30	IBM Flex P460
	07:00 (00Z_ASSIM. +6HR_.FCST)	07:00～07:40	IBM Flex P460
	13:00(06Z_ ASSIM +6HR_.FCST)	13:00～13:40	IBM Flex P460
	15:30(12Z_ASSIM.+240HR_FCST)	15:30～18:30	IBM Flex P460
	19:00(12Z_ASSIM.+ 6HR_.FCST)	19:00～19:40	IBM Flex P460
	01:00(18Z_ASSIM.+ 6HR_.FCST)	01:00～01:40	IBM Flex P460
Global Forecasting System (operational) (T639L60_GSI)	01:40 (18Z_ASSIM+9HR_FCST)	01:40～02:38	IBM Flex P460
	03:29 (00Z_ASSIM+240HR_FCST)	03:29～05:40	IBM Flex P460
	10:00 (00Z_ASSIM+9HR_FCST)	10:00～11:00	IBM Flex P460
	11:15(06Z_ASSIM+84HR_FCST)	11:15～12:40	IBM Flex P460

	13:40 (06Z_ASSIM+9HR_FCST)	13:40～14:40	IBM Flex P460
	15:29 (12Z_ASSIM+240HR_FCST)	15:29～17:35	IBM Flex P460
	22:00 (12Z_ASSIM+9HR_FCST)	22:00～23:00	IBM Flex P460
	23:45 (18Z_ASSIM+84HR_FCST)	23:45～01:05	IBM Flex P460
Regional Forecasting System (GRAPES_MESO4.2)	03:20 (00Z_ ASSIM +84HR_.FCST)	03:20～05:40	IBM Flex P460
	05:00 (03Z_ ASSIM +30HR_.FCST)	05:00～06:00	IBM Flex P460
	08:00 (06Z_ ASSIM +30HR_.FCST)	08:00～09:00	IBM Flex P460
	11:00 (09Z_ ASSIM +30HR_.FCST)	11:00～12:00	IBM Flex P460
	15:20 (12Z_ ASSIM +84HR_.FCST)	15:20～17:40	IBM Flex P460
	17:00 (15Z_ ASSIM +30HR_.FCST)	17:00～18:00	IBM Flex P460
	20:00 (18Z_ ASSIM +30HR_.FCST)	20:00～21:00	IBM Flex P460
	23:00 (21Z_ ASSIM +30HR_.FCST)	23:00～24:00	IBM Flex P460
Ensemble Forecasts With 15 members (T639-GEPS)	07:00 (00Z_ASSIM+240HR_FCST)	07:00～09:00	IBM Flex P460
	12:30 (06Z_ASSIM+6HR_FCST)	12:30～12:35	IBM Flex P460
	18:30 (12Z_ASSIM+240HR_FCST)	18:30～20:30	IBM Flex P460
	00:30 (18Z_ASSIM+6HR_FCST)	00:30～00:35	IBM Flex P460
Regional Typhoon Forecasting System（GRAPES-TYM 2.1）	05:00 (00Z_ASSIM+6HR_FCST)	05:00～06:50	IBM Flex P460
	11:00 (06Z_ASSIM+6HR_FCST)	11:00～12:20	IBM Flex P460
	17:00 (12Z_ASSIM+6HR_FCST)	17:00～18:20	IBM Flex P460
	01:00 (18Z_ASSIM+6HR_FCST))	01:00～02:20	IBM Flex P460
Regional Ensemble Forecasting system with 15 members (GRAPES-REPS)	05:20(00Z_96HR_FCST)	05:20~08:30	IBM Flex P460
	17:20(12X_96HR_FCST)	17:20~20:30	IBM Flex P460
Sand/dust Forecasting system (T639)	05:30 (00Z_72HR_FCST)	05:30～06:50	IBM Flex P460
	18:30 (12Z_72HR_FCST)	18:30～19:50	IBM Flex P460
Sea Wave Forecasting System (WW3)	07:00 (00Z_120HR_FCST)	07:00～07:10	IBM Flex P460
	19:00 (12Z_120HR_FCST)	19:00～19:15	IBM Flex P460
HAZE Forecast System (T639)	00:10（00Z_120HR_FCST）	00:10~05:40	IBM Flex P460
	12:00（12Z_120HR_FCST）	12:00~17:40	IBM Flex P460
GRAPES_MESO(HR 3KM) Forecast System	04:10 (00Z_ASSIM+36HR_FCST)	04:10～07:00	IBM Flex P460
	16:10 (00Z_ASSIM+36HR_FCST)	16:10～19:00	IBM Flex P460

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 3D-var system has been updated form version 2.0 to 2.1 on June 21 2017.The new version got the improvement in data assimilation schemes, dynamics and physical packages. The changes made the better in forecast performance and running stability. Others, It increased the forecast variables. GRAPES-MESO which in operation updated to Version 4.2 on Sep 1, 2017. Many changes in MESO package has been integrated and bugs fixed .The previous MESO flow and RAFS flow have been united to new the GRAPES-MESO operation system. The system forecast hours extend to 84hrs in 00 and 12UTC, and 30hrs in 03,06,09,15,18,21UTC. GRAPES based typhoon forecast system GRAPES-TYM updated to version 2.1 in December 2017. The HAZE forecast system were extend to 120 hours prediction.

4.2.1.2 Research performed in this field

The adaptive bias correction scheme of satellite data has been improved and validated through the retrospective trials. The new scheme runs stable and gives a positive contribution on the global analysis. The bias correction of radiosonde humidity observation and the assimilation of FY3C MWHS-2 118 GHz observation are also validated for the operational run.

The Lanczos-CG algorithm has been validated for the global 4D-Var minimization. There is a variable transformation interface between the hydrostatic analysis scheme and the non-hydrostatic model. If this interface is not properly handled, the Lanczos-CG algorithm may be interrupted. With respect to the previous L-BFGS algorithm, the Lanczos-CG algorithm has a quicker and smoother convergence. So we replace the L-BFGS algorithm with the Lanczos-CG algorithm in the default configuration of global 4D-Var system. The preconditioning of Lanczos-CG algorithm is also developed which uses the estimated eigenpairs from the previous minimization to construct the preconditioner as the scheme used in ECMWF IFS.

The linearized vertical diffusion and sub-grid scale orographic parameterization schemes have been validated to have a positive impact on the global 4D-Var analysis and forecast. The new linear deep convection and large-scale condensation schemes are under develop based on NSAS (Han and Pan, 2006) and Tompkins schemes (Tompkins and Janiskova, 2004). The preliminary results are encouraging.

4.2.2 Model

4.2.2.1 In operation

Medium-range system GRAPES GFS model has been upgraded on 21 June 2017, with improvements including solar zenith correction in short wave radiation and direct effect of aerosol on solar radiation, unifying physical constants in every part of global model, optimization of topography in Antarctic, improvement of water vapour advection scheme in polar areas.

4.2.2.2 Research performed in this field

In GRAPES global model, Predictor-Corrector SISL scheme and 3D reference profile have combined and completed 3-month tests, the results show that, the new dynamical core can improve the accuracies and stabilities of the model, and so reduce the off-center coefficient from 0.72 to 0.55, and increase time step from 300s to 450s. The new generation scalable high-order nonhydrostatic multi-moment constrained finite volume dynamical core has completed nonhydrostatic model on the cubed sphere. Multi-loop and small time step in calculating sedimentation term in microphysics, optimized convection tendencies of first model layer, iterative algorithm for condensation of large-scale macro cloud scheme, improved consistency between cloud cover and condensate, and optimization of latent heat fluxes on land and ocean respectively have been tested in batch experiments, with some positive results, but wet biases remaining. The 2-month (July and December) experiments with the improvement of microphysics and PBL scheme being rewritten using Charney-Phillips grid in the vertical have shown the positive effects on forecasts.

4.2.3 Operationally available Numerical Weather Prediction (NWP) Products

There is no change for T639 model available Numerical weather prediction products. The T639 model products generated from operational runs are 0-240h forecasts for 00UTC and 12UTC initial time and 0-72h forecasts for 06UTC and 18UTC initial one. A list of T639 model Products is given in table 4.2.3.1.

In 2016, The GRAPES_GFS model is put into operational run. In 2017, many variables which are outputs from the model integration are added to operationally available NWP products. A list of GRAPES_GFS model products is given in table 4.2.3.2 and table 4.2.3.3.

Table 4.2.3.1 The List of T639 model Products

Variables	Unit	Layer	Level (hPa)	Forecast hours	Area
Geopotential height	Gpm (geopotential meters)	26	10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	000，003，006，009，012，015，018，021，024，027，030，033，036，039，042，045，048，051，054，057，060，063，066，069，072，075，078，081，084，087，090，093，096，099，102，105，108，111，114，117，120，126，132，138，144，150，156，162，168，180，192，204，216，228，240	North-east hemisphere (0.28125*0.28125) 0°N－180°N，90°E－0°
Temperature	K	26			
U-wind	m/s	26			
V-wind	m/s	26			
Vertical velocity	Pa/s	26			
vorticity	s^{-1}	26			
divergence	s^{-1}	26			
Specific humidity	Kg/kg	26			
Relative humidity	%	26			
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 RH	%	1	2 m above ground		
The first layer of soil temperature	K	1	0-0.07 m below ground		
Second layer soil temperature	K	1	0.07-0.28 m below ground		
Third layer soil temperature	K	1	0.28-1 m below ground		

Fourth layer soil temperature	K	1	1-2.55 m below ground
The first layer of soil moisture	m^3/ m^3	1	0-0.07 m below ground
Second layer soil moisture	m^3/ m^3	1	0.07-0.28 m below ground
Third layer soil moisture	m^3/ m^3	1	0.28-1 m below ground
Fourth layer soil moisture	m^3/ m^3	1	1-2.55 m below ground
Convective precipitation	mm	1	
Large scale precipitation	mm	1	
Total precipitation	mm	1	
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
Maximum 2m Temperature	K	1	2 m above ground
Minimum 2m Temperature	K	1	2 m above ground
Surface sensible heat flux	W m**-2 s	1	surface
Surface latent heat flux	W m**-2 s	1	surface
Surface solar radiation	W m**-2 s	1	
Surface heat radiation	W m**-2 s	1	
Snow	M (water equivalent)	1	snow
Water content of Surface	m (water-e)	1	
Evaporation	m (water-e)	1	
Run-off	M	1	
Snow depth	m (water-e)	1	
Geopotential height	Gpm	1	surface
Sea-land marks	N/A	1	surface
Dew point temperature	K	19	200,250,300,350,400,450,500,550,600,650,700,750,800,850,900,925,950,975,1000
Wet potential vorticity vertical component	10-6 m-2 s-1 k kg-1	19	
Wet potential vorticity horizontal component	$10^{-6} m^{-2} s^{-1}$ k kg^{-1}	19	
Temperature Advection	10^{-6} K/s	6	200,500,700,850,925,1000
Vorticity Advection	$10^{-11} /s^2$	6	
Dew point temperature difference	10^{-1} C	4	500,700,850,925
Water vapour flux	10^{-1} g/cm·hPa·s	4	

Divergence of vapour flux	10^{-7} g/cm^{2}·hPa·s	4			
Pseudo-equivalent potential temperature	K	4			
K index	°C	1	mean sea level		

Table 4.2.3.2 The List of GRAPES_GFS model isobaric surface Products (GRIB2 format)

Variables	Unit	Layer	Level (hPa)	Area
Geopotential height	Gpm	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	**The globe:** 0.25°×0.25° 1440×720 0°N—359.75°N, 89.875°E—-89.875°E
Temperature	K	30		
U-wind	m/s	30		
V-wind	m/s	30		
Vertical velocity	m/s	30		
vorticity	s-1	30		
divergence	s-1	30		
Specific humidity	Kg/kg	30		
Relative humidity	%	30		
Cloud water mixing ratio	Kg/kg	30		
Rain water mixing ratio	Kg/kg	30		
Ice water mixing ratio	Kg/kg	30		
Snow water mixing ratio	Kg/kg	30		
graupel	Kg/kg	30		
Cloud cover	%	30		
10m U-wind	m/s	1	10 m above ground	
10m V-wind	m/s	1	10 m above ground	
2m Temperature	K	1	2 m above ground	
Surface temperature	K	1	surface	
Sea surface pressure	Pa	1	mean sea level	
Surface Pressure	Pa	1	surface	
2m Specific humidity	kg/kg	1	2 m above ground	
2m Relative humidity	%	1	2 m above ground	
Convective precipitation	mm	1	Surface	
Large scale precipitation	mm	1	Surface	
Total precipitation	mm	1	Surface	
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	W m**-2 s	1	surface	

radiation flux(surface)				
Terrain height	Gpm	1	surface	
Dew point temperature	K	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	
Temperature Advection	K/s	30		
Vorticity Advection	1/s2	30		
Dew point temperature difference	°C	30		
Water vapour flux	g/cm·hPa·s	30		
Divergence of vapour flux	g/cm2·hPa·s	30		
Pseudo-equivalent potential temperature	K	30		
radar reflectivity	dBz	30		
Strong weather threat index	-	1	Surface	
Convective available potential energy	J/kg	1	Surface	
Convective inhibition energy	J/kg	1	Surface	
Lifting index	K	1	Surface	
Condensation layer pressure	hPa	1		
K index	°C	1	mean sea level	
Radar composite reflectivity	dBz			
Simulated satellite brightness temperature of vapor channel	K	1	Surface	
Simulated satellite brightness temperature of infrared channel	K	1	Surface	
Albedo	%	1	surface	
2m Dew point temperature	K	1	2m	
Snow depth	m	1	surface	
Amount of snow	m	1	surface	
Soil moisture	Kg/kg	1	0-0.1m below ground	
Soil moisture	Kg/kg	1	0.1-0.3m below ground	
Soil moisture	Kg/kg	1	0.3-0.6m below ground	
Soil moisture	Kg/kg	1	0.6-1.0m below ground	
Soil 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	
North-south stress	n/m^2s	1	surface	
Shawlt index	K	1	surface	
Boundary height	m	1	surface	

Table 4.2.3.3 The List of GRAPES_GFS model Products

Variables	unit	layer	Area
Exner pressure	-	62	**The global：** 0.25°×0.25° 1440×720 0°N－359.75°N，89.875°E－-89.875°E
Potential temperature	K	61	
u-wind	m/s	60	
v-wind	m/s	60	
Vertical velocity	m/s	61	

Specific humidity	kg/kg	61	
Cloud fraction	0-1	61	
Cloud water mixing ratio	kg/kg	61	
Rain water mixing ratio	kg/kg	61	
Ice water mixing ratio	kg/kg	61	
Snow water mixing ratio	kg/kg	61	
graupel	kg/kg	61	
Perturbed potential temperature	K	61	
Perturbed Exner pressure	-	62	
temperature	K	61	
Geopotential height	Gpm	61	

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

4.2.4.1 In operation

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

<table>
<tr><th>No</th><th>Variable</th><th>unit</th><th>Forecast hours</th><th>Resolution/Area/Frequency</th></tr>
<tr><td>1</td><td>Maxmum temperature</td><td>C</td><td rowspan="4">024，048，072，096，120，144，168，192，216，240，264，288，312，336，360</td><td rowspan="8">horizontal resolution：0.1*0.1

-90°N ~90°N
0°E ~360°E

00UTZ，12UTZ</td></tr>
<tr><td>2</td><td>Minmum temperature</td><td>C</td></tr>
<tr><td>3</td><td>Maxmum relative humidity</td><td>%</td></tr>
<tr><td>4</td><td>Minmum relative humidity</td><td>%</td></tr>
<tr><td>5</td><td>Temperature</td><td>C</td><td rowspan="4">000，003，006，009，012，015，018，021，024，027，030，033，036，039，042，045，048，051，054，057，060，063，066，069，072，075，078，081，084，087，090，093，096，099，102，105，108，111，114，117，120，126，132，138，144，150，156，162，168，180，192，204，216，228，240</td></tr>
<tr><td>6</td><td>Relative humidity</td><td>%</td></tr>
<tr><td>7</td><td>Cloud</td><td>%</td></tr>
<tr><td>8</td><td>Wind</td><td>m/s</td></tr>
</table>

4.2.4.2 Research performed in this field

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

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

4.2.5.1 In operation

The global operational ensemble prediction system (GEPS) based on T639 model (T639-GEPS) has been operationally running since 2014. The analysis of the control forecast of T639-GEPS is generated by T639 GSI data assimilation system. The configuration of T639-GEPS is as follows:

- Number of members: 15 members; 14 perturbed members (adding/subtracting perturbations from seven independent breeding cycles) plus one control run;
- Initial state perturbation method: Breeding Growth Method(BGM);
- Number of models used: one model, T639L60 (about 30 km);
- Perturbation of physical process: Stochastic Physical Processes Tendency (SPPT) method;
- Running cycle: 00UTC and 12UTC, running twice per day;

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) is continuously going at CMA. **A dynamical upscaling approach to produce initial conditions of control forecast**: a dynamical upscaling approach was developed. The lower-resolution initial conditions for SVs calculations (horizontal resolution: $2.5^o * 2.5^o$) and the control forecast (horizontal resolution: $0.5^o * 0.5^o$) in the GRAPES-GEPS were produced by this method. The improvement of GRAPES singular vectors (SVs) calculation: the SVs were calculated in Northern Hemisphere extratropics(30^{o}N–80^{o}N) and the Southern Hemisphere extratropics(30^{o}S–80^{o}S) with the optimized GCR scheme for GRAPES adjoint model , the update of the nonlinear model and linearized tangent and adjoint models. The linearized PBL (planetary boundary layer) scheme and GWD (gravity wave drag) scheme was adopted to compute SVs. The calculation of the tropical cyclone (TC) targeted SVs was developed.The improvement of the initial perturbations calculation scheme: the initia conditionl perturbations are combinded the SVs with the evolved SVs so as to describe large-scale perturbation structures better. The original one-dimensional static error profile was replaced by operational GRAPES-GFS 3DVAR background error profile varying with month and area.

The Stochastic Kinetic Energy Backscatter (SKEB) scheme was developed based GRAPES-GFS model to account for the local kinetic energy dissipation caused by the numerical dissipation; SKEB was realized via the horizontal velocity perturbation.

4.2.5.3 Operationally available EPS Products

The T639-based global ensemble prediction model products generated in operational are 0-360h forecasts for 00UTC and 12UTC initial time and 0-6h forecasts for 06UTC and 18UTC initial time. Ensemble size is 15 including 14 perturbed forecast and control run. The output interval is 6 hours. A list of NWP GEPS Products in graphical format is given in table 4.2.5.3.1. A selection is available via the CMA website at: http://www.nmc.cn/publish/nwp/t639gep/index.html.

Table 4.2.5.3.1 The list of global EPS products in graphical format

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

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

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

The GRAPES regional 3DVAR system is global and regional unified assimilation system with 10km horizontal resolution and 50 vertical levels the same as the GRAPES_Meso model. The system domain covers the whole China (from 70°E to 145°E and from 15°N to 65°N) and the grid space is 751×501. The data assimilated include the conventional GTS data、GPS/PW and FY_2E. The analysed variables include zonal and meridional winds, no-dimensional pressure and specific humidity. The cloud analysis package uses radar reflectivity and other cloud observational information to update several hydrometeor variables and potential temperature in the 3DVAR analysis step. The first guess is from the operational 6-hour prediction of T639 global model with the digital filter for initialization. Based on GRAPES regional 3DVAR, Grapes Rapid Analysis and Forecast System is implemented with 12 hour assimilation time window, starting at 00/12 UTC and observations are assimilated every 3 hour. The cold start steps (00 and 12UTC) in RAFS provide 84-hour forecasting products and the warm start steps in RAFS provide 30-hour forecasting products every 3 hours.

4.3.1.2 Research performed in this field

Data assimilation improvements of GRAPES-MESO model included : 1) Using 6h prediction of GRAPES GFS global model instead of T639 as first guess of 3DVAR; 2) Estimating the horizontal correlation scale of background covariance with NMC method and instead of the simplex parameter with a profile in 3DVAR system; 3) Blending large scale information of T639 global analysis and small scale information of GRAPES regional analysis to improve the forecasting; 4) implementing radar radial wind and wind profile to assimilate in regional analysis system; 5) Implementing latent heat of precipitation nudging scheme; 6) Implementing multi-scale analysis scheme to obtain more small-scale information in high resolution analysis.

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.

4.3.2.2 Research performed in this field

Model improvements include: one dimensional profile of reference atmosphere was optimized by using domain area-averaged initial field; surface parameterization was revised to improve the forecast of strong wind; diagnostic scheme for temperature at 2 meter was modified to reduce the forecast bias against observation; chemical process was coupled into GRAPES_Meso system for air quality forecast; new version of Tiedtke shallow convection parameterization was introduced into GRAPES_Meso system.

4.3.3 Operationally available NWP products

In 2017, many variables which are outputs from the model integration are added to operationally available regional NWP products. A list of GRAPES_MESO model products is given in table 4.3.3.1.

Table 4.3.3.1 The List of GRAPES_MESO model isobaric surface Products (BRIB2 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·hPa·s	30		
37	Divergence of vapour flux	g/cm2·hPa·s	30		
38	Pseudo-equivalent potential temperature	K	30		
39	Radar reflectivity	dBz	30		
40	Strong weather threat index	-	1	--	
41	Convective available potential energy	J/kg	1	--	
42	Convective inhibition energy	J/kg	1	--	
43	Lifting index	K	1	--	
44	Condensation layer pressure	hPa	1	--	
45	K index	K	1	--	
46	Snow	m	1	surface	
47	0-1000m storm-relative helicity	M2/s2	1	0_1000m	
48	0-3000m storm-relative helicity	M2/s2	1	0-3000m	
49	Planetary boundary layer height	M	1	--	
50	Height of radar echo top	M	1	--	
51	Richardson number of surface layer	-	1	Surface	
52	Richardson number of PBL	-	1	Boundary layer	
53	Maximum of u10m in output interval	m/s	1	10m	
54	Maximum of v10m in output interval	m/s	1	10m	
55	0-1000m Vertical speed shear	1/s	1	0-1000m	
56	0-3000m Vertical speed shear	1/s	1	0-3000m	
57	0-6000m Vertical speed shear	1/s	1	0-6000m	
58	Radar composite reflectivity	dBz	1	--	
59	Simulated satellite brightness temperature of vapor channel	K	1	--	
60	Simulated satellite brightness temperature of infrared channel	K	1	--	
61	Maximum vertical speed in output interval	m/s	1	--	
62	The best lifting index	K	1	--	
63	Maximum radar composite reflectivity in output interval	dbz	1	--	
64	Hail index	--	1	--	
65	Shawalter index	K	1	--	
66	Wind index	m/s	1	--	
67	Height of 0 degree isothermal level	m	1	--	
68	Height of -20 degree isothermal level	m	1	--	

69	Down convective available potential energy	j/kg	1	--	
70	Storm strength index	J/kg	1	--	
71	Soil moisture	Kg/kg	1	0-0.1m below ground	
72	Soil moisture	Kg/kg	1	0.1-0.3m below ground	
73	Soil moisture	Kg/kg	1	0.3-0.6m below ground	
74	Soil moisture	Kg/kg	1	0.6-1.0m below ground	
75	Soil temperature	K	1	0-0.1m below ground	
76	Soil temperature	K	1	0.1-0.3m below ground	
77	Soil temperature	K	1	0.3-0.6m below ground	
78	Soil temperature	K	1	0.6-1.0m below ground	
79	Total index	K	1	--	
80	2m dew point temperature	K	1	2m	
81	Maximum ascending helicity	M^2/s^2	1	2000-5000m	
82	The whole layer precipitable water	Kg/m^2	1		

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

4.3.4.1 In operation

Specific content refer to 4.2.4.1.

4.3.4.2 Research performed in this field

Specific content refer to 4.2.4.2.

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

4.3.5.1 In operation

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

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

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

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

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

- Running cycle: 00UTC and 12UTC;

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

4.3.5.2 Research performed in this field

The double components ETKF initial perturbation method designed and tested in 2017. This method can increase initial perturbation energy and ensemble spread in lower layers, however, with the evolution of forecast lead time, Perturbation energy dispersion is not enough. The effects of model bias on the quality assessment of an ensemble prediction system indicate: The conclusions drawn from ensemble verification about the EPS are dramatically different with or without model bias. This is true for both ensemble spread and probabilistic forecasts.

A 3D bias damping method designed can reduce the systematic errors in model and improve the quality of ensemble forecast systems to a great extent. The GRAPES-REPS is severely under-dispersive before the bias correction but becomes calibrated afterwards, although the improvement in spread's spatial structure is much less; the spread-skill relation is also improved. The probabilities become much sharper and almost perfectly reliable after the bias is removed. Therefore, it is necessary to remove forecast biases before one can accurately evaluate an EPS since an EPS deals only with random error but not systematic error.

4.3.5.3 Operationally available EPS Products

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

http://www.nmc.cn/publish/nwpc/grapes-regional/index.html

Table 4.3.2 The list of Mesoscale EPS products in graphical format

Variables	**Unit**	**Layer**	**Level**	**EPS products**	**Probability threshold**
24-HR Accum. Precip.	mm	1	Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	

				PRBT	1, 10, 25, 50 ,100
12-HR Accum. Precip.	mm	1	Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 5, 15, 30 ,70
6-HR Accum. Precip.	mm		Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 4, 13, 25 ,60
3-HR Accum. Precip.	mm		Surface	Thumbnails	
				Ensemble Mean	
				Mode & Maximum	
				PRBT	1, 3, 10, 20 ,50
Sea Surf Pres	hPa		mean sea level	Ensemble Mean & Spread	
2m Temp	K		2 m above ground	Ensemble Mean & Spread	
10m Wind	m/s		10 m above ground	Ensemble Mean & Spread	
				PRBT	5.5,8, 10.8, 17.2, 24.5, 32.7
Convective Available Potential Energy	J/kg			Ensemble Mean & Spread	
				PRBT	200, 500, 1000, 1500, 2000, 2500
Convective Inhibition	J/kg			Ensemble Mean & Spread	
				PRBT	50, 100, 150, 200
Combined Radio Reflection Ratio	dbz			Thumbnails	
				Ensemble Mean & Spread	
				PRBT	5, 10, 20, 30, 40
K index				Ensemble Mean & Spread	
				PRBT	30, 35, 40, 45
Best Lifting Index				Ensemble Mean & Spread	
				PRBT	0, -2, -4, -6
0-1km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	8, 12, 16, 18
0-3km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	12, 16, 20, 24
0-6km Vertical Wind shear	m/s			Ensemble Mean & Spread	
				PRBT	20, 26, 32, 38
Down CAPE	J/kg			Ensemble Mean & Spread	
				PRBT	500, 1000, 1500, 2000
Hail Index				Ensemble Mean & Spread	
				PRBT	0.2, 0.5, 0.8, 1, 1.5

EPS METEOGRAM (Including 3-H Accum. Precip. 10m Wind 2m Temp 2m RH)				BOX & WHISKERS	

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

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

4.4.1 Nowcasting system

4.4.1.1 In operation

The application of FY-4A satellite data is improving the capability of monitoring and warning of disastrous weather. The FY-4A satellite was launched in December 2016 and became operational on May 1, 2018. It provides satellite data and derivative products for more than 80 countries and regions and 2,500 domestic users. The five-minute imager image products and the lightning flash products have been used through the MICAPS platform for real-time monitoring and forecasting of disastrous weather. Combining ground flash data and FY-4A cloud flash data, thunderstorm recognition is realized by using clustering algorithm. Based on it, tracking and prediction thunderstorm is realized by using Kalman algorithm and machine learning algorithm, which provide future 0-1 H information of lightning path and intensity.

Classification severe convective weather prediction and quantitative precipitation forecasting based on convection-allowing rapid update numerical analysis and prediction model outputs have been applied in operations. Using GRAPES mesoscale models from CMA, RMAPS from Beijing and SMB-WARMS from Shanghai, some new calibration method such as neighbourhood, time-lagged and super ensemble has been used to severe convective weather forecasting and QPF, which provide 1 day 8 times updated hourly thunderstorm, short-term heavy rainfall with 1-haccumulated precipitation over 20mm, hail and thunderstorm gale probability forecast.

4.4.1.2 Research performed in this field

The deployment and application of dual polarization radar is an important part of CMA to improve its weather forecast capability。New research shows that the double polarization radar can obtain the echo intensity, radial velocity and velocity spectrum width in the horizontal polarization direction of the precipitation system, and the parameters such as difference reflectivity factor, propagation phase shift, propagation constant difference, correlation coefficient and linear depolarization ratio can also be detected. By analyzing and inverting these parameters, we can judge more specific meteorological information such as the shape, size, phase distribution, spatial orientation and precipitation type of precipitation. Especially, the heavy rainfall and hail produced by mesoscale convective system have better recognition ability.

The radar-based data stream transmission is improving the temporal resolution of radar composite image in the Severe Weather Automatic Nowcasting system (SWAN). Prior to this, the large-scale radar composite image time resolution of 10 minutes. Through the design of virtual body sweep method, the adjacent observation of the 9 elevation into a chloroplast sweep file, using chloroplast sweep file for jigsaw processing. In the virtual body sweep synthesis strategy, a chloroplast sweep file is synthesized every two minutes by sliding time window for two minutes. Thus, the nationwide 3D radar mosaic is expected to achieve a time resolution of five or six minutes in 2019.

Machine learning is being used in nowcasting and very short-time prediction. The deep learning radar echo prediction is developed, and the extrapolation prediction time is extended to 2 hours. Using satellite data and numerical model outputs, the convective initiation prediction based on the machine learning methods is testing in CMA.

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

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

4.5.1.1 In operation

- **CUACE/Dust**

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

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

- **CUACE/haze-fog**

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

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

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

4.5.1.2 Research performed in this field

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

4.5.2 Specific Models (as appropriate related to 4.5)

4.5.2.1 In operation

- Environmental emergency response system (EERS):

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

- Regional fine-gridded environmental emergency response system:

- For regional EERS, the status is still maintained. The GRAPES_MESO with 10km resolution in horizontal, 51 vertical levels and 1houly output is used to drive the HYSPLIT model. Additionally, the ensemble GRAPES_MESO meteorological fields are used to force HYSPLIT, the new ensemble ATDM system can provide the regional probability forecast atmospheric dispersion products with 15 members. Regional Typhoon prediction system GRAPES-TYM

GRAPES-TYM was updated in the following two aspects: 1) the isothermal atmosphere reference atmosphere was replaced by a horizontally average of initial temperature profile, and 2) the radius of initial vortex intensity correction was reduced in order to reduce the effects to the analysis

- Global typhoon track prediction system.

TC vortex initialization scheme was implanted into GRAPES-GFS and sensitive experiments were finished on the key parameters that were used to construct TC vortex.

- Ocean wave models

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

	Global	Western North Pacific (WNP)	China Offshore(CO)
Domain	0º—360ºE， 78ºS—78ºN	90º—170ºE， 0ºN—51ºN	105º—130ºE， 7ºN—42ºN
Resolution	0.5º×0.5 º	1/6º×1/6º	1/15º×1/15º
Grid size	720×311	481×307	376×526
Forecast hour	240h	120h	72h
Atmospheric input	T639	GRAPES_TYM	GRAPES_TYM
Minimum water depth	2.5m	2.5m	2.5m
Time steps	3600s,480s,1800s, 30s	1800s，450s，900s，15s	300s，185s，150s，15s
Model physics	Wave propagation：ULTIMATE QUICKEST propagation scheme； Source term：Tolman and Chalikov source term package； Nonlinear interactions：Discrete interaction approximation； Bottom friction： JONSWAP bottom friction formulation.		

4.5.2.2 Research performed in this field

- Regional Typhoon prediction system GRAPES-TYM

An ocean and atmospheric coupled model was developed and tested; A unified Typhoon and Meso-scale model has been under tuning. Global typhoon track prediction system

- Global typhoon track prediction system

A new TC tracking method was implanted into GRAPES-GFS in order to define a weak TC center.

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

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

4.5.3 Specific products operationally available

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

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

- Regional Typhoon prediction system GRAPES-TYM:

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

- Global typhoon track prediction system

  TC tracks and wind speeds at 10m up to 120hrs.

- Ocean wave forecasting system.

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

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

4.5.4.1 In operation

- CUACE/Dust

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 center: http://eng.weather.gov.cn/dust/.

- CUACE/haze-fog

CUACE/haze-fog has been developed for the regional haze-fog forecast 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. CAUCE/Haze-fog has been operationally run twice a day in CMA since Sept 2012. It issues 84-hrs products of visibility, PM2.5 and some gas species. It can predict the timing and distribution of the regional haze-fog over 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 hours after their detection; 2) 24-hour average pollution concentration in 0-72 hours; 3) 0-24 hour, 0-48 hours and 0-72 hours accumulated deposition (wet & dry) distribution; 4) improved the time of arrival products.

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

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

4.5.4.2 Research performed in this field

CUACE/haze-fog has been performed re-running experiments since 2015. The horizontal resolution increased from 54km to 15km, physical parameterization scheme added aerosol and cloud radiative feedback effect, gas and aerosol of liquid phase reaction mechanism and it was optimized the emission source system and visibility computation scheme. It was tested in Air quality index (AQI), six primary pollutant concentration and visibility. The verification results showed that the experiment model was better than before. The forecast deviation reduced and the predict performance improved. So CUACE/haze-fog has been upgraded and operationally implemented in March 2016.

Based the analysis on model deviation, the study on using Kalman filtering method to rolling deviation correction and the technology research of the model application were developed. 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.

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

We have studied on the formation mechanism of particulate matter pollution and photochemical pollution and developed a composite pollution index products based on the emission source, the concentration of various pollutants and meteorological conditions.

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

The haze and heavy pollution weather medium-term probability forecast products have been developed since 2015.

- Environment emergency response products:

The global ensemble atmospheric dispersion forecast system is maintained in 2016, which based on 15 members of T639L61 ensemble numerical prediction system. And the global ensemble forecast products include the ensemble trajectories, the ensemble average and probability products of concentration and accumulated deposition in 0-72 hours.

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

The regional ensemble atmospheric dispersion forecast system is maintained in 2017, which based on 15 members of GRAPES_MESO ensemble numerical prediction system. And the regional ensemble forecast products of atmospheric dispersion include the ensemble trajectories, the ensemble average and probability products of concentration and accumulated deposition in 0-12 hours.

4.5.5.2 Research performed in this field

Based on the similarity method, we developed the probability mid-term forecasting products on haze and sever pollution weather.

According to haze and heavy pollution weather database, we have established a classical or extreme processing background databank combining the united elements and circulation.

By means of similarity analysing elements and relevance with circulation, it's screened effective circulation factor. corresponding analysis of the physical parameters by using the effective factor gradually filtered similarity analysis prediction method and reference the circulation factor and ten day pollution, the number of relevant degree, established objective forecast model and in combination with an ensemble forecast products to develop haze, heavy pollution mid-term and ten days weather daily probability forecast products.

4.5.5.3 Operationally available probabilistic prediction products

- **CUACE/Dust Product: 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, sand/dust indexes derived from FY-2D satellite data. The software SDSDVAS allows forecasters to display and analyze sand/dust storm products.

- **GRAPES-CUACE/Dust sand/dust storm numerical prediction model:** the wind erosion database was updated, while real-time soil moisture data were included. A trial forecast was made with the system, providing useful results.

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

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

- **Fog and haze probability forecast products:** We constructed the medium and long-term forecast factors and indicators of fog and haze in different regions, depending on the circular flow background of fog and haze generation and elimination, the physical quantity analysis of boundary layer, in addition, the characteristics of fine particle pollution and source intensity distribution in different regions of China. We researched and developed medium and long-term probability prediction test products for fog and haze in 1-15 days, using ECMWF ensemble forecast products for 1-15 days, in addition to, multiple linear stepwise regression method and artificial neural network machine learning technology, achieved good results in fog and haze process forecast in 2017.
- **TC track numerical prediction products:** The global TC track prediction system provides the following products (1) TC tracks to 120h; (2) maximum wind at surface;(3) vertical shear;(4)steering flow; (5)vorticity; and(6)divergence.
- **TC ensemble prediction system**: This system mainly provides the TC ensemble tracks and the strike probability.

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

4.6.1 In operation

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

4.6.2 Research performed in this field

The contribution of air-sea interaction on the extended-range prediction in the northern extratropical region has been analyzed with a coupled model form Beijing Climate Center and its atmospheric components. Under the assumption of the perfect model, the extended-range prediction skill was evaluated by anomaly correlation coefficient (ACC), root mean square error (RMSE) and signal-forecast error ratio (SER). The coupled model has better prediction skill than its atmospheric model, the air-sea interaction in July made a greater contribution, and the prediction skill of extratropical in the coupled model reaches 16–18 days in all month, while the atmospheric model reaches 10–11 days in January, April, and July and only 7–8 days in October, indicating that the air-sea interaction can extend the prediction skill of the atmospheric model by about 1 week. The errors of the coupled model and the atmospheric model reach saturation in about 20 days, suggesting that prediction skill is still less than 3 weeks. In the coupled model, the prediction skill of northern extratropics, Asia, mid-high latitudes of Eurasia, and western Pacific subtropical high regions was similar to each other.

4.6.3 Process and sort of the products in extended range forecast

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

4.6.4 Performance Evaluation

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

4.6.5 Operationally available NWP model and EPS ERF products

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

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

4.7.1 In operation

In recent years, a new generation coupled climate system model (BCC-CSM) has been developed in BCC. Seasonal model named BCC-CSM1.1m has been operational in application in 2016.

4.7.2 Research performed in this field

BCC/CMA is committed to carry out a series of dynamical-statistical seasonal precipitation prediction research and operational application, and establish the forecast system on dynamical and analogy skills (FODAS) in recent years, and carried out the improved the new forecast system based on dynamical and analogy capabilities (FODAS2.0) in 2017 and 2018. The system is based on the second-generation seasonal model in BCC (BCC-CSM1.1), NCEP_CFS2 and ECMWF_SYSTEM4, and by using the 74 circulation factors of BCC, 40 circulation factors of NOAA and optimal multiple factor regression method for correcting 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 74 in 2017. And the FODAS2.0 will be further developed and applied in the future. The predicted results of summer precipitation in 2018 are provided in March 2018. And the FODAS2.0 will be further developed and applied in the future. Based on the hindcast data of BCC Climate System Model BCC-CSM1.2, the anomalous circulation characteristics of intraseasonal variation of East Asian in Meiyu Period was evaluated by employing deterministic methods. The results show that the performance of the BCC-CSM1.2 is significantly good in the subtropical high over the Western Pacific (WPSH). In addition, we are planning to develop the multi-model ensemble prediction system.

4.7.3 Operationally available products

a) 30-day period prediction

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

b) seasonal and interannual prediction

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

5. Verification of prognostic products

5.1 Annual verification summry

5.1.1 The verification against analysis of operational model (T639)

The verification against analysis of operational numerical forecast model (GRAPES_GFS) in 2017 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 2017

Month	Valid time	Z(500)		W(250)			W(850)
		NH	SH	NH	SH	Tropics	Tropics
1	24	13.5	12.9	4.8	4.9	4.5	2.9
	72	37.9	30.8	10.4	10	7.5	5.4
	120	68.5	54.4	16	15	9	7.5
2	24	13.7	13.4	4.9	5.1	4.4	2.9
	72	37.6	34.4	10.5	10.6	7.5	5.8
	120	69.5	58	16.4	15.4	9.2	7.8

3	24	12.4	14.4	4.9	5.2	4.3	3.1
	72	34.7	38.6	10.1	11.7	7.1	6.3
	120	63.6	65.8	15.5	17.2	8.6	8.7
4	24	11.4	15.2	4.6	5.4	4.2	3.2
	72	29.6	39.9	9.4	11.2	7	6.5
	120	52.9	72	14.3	17.5	8.5	9.2
5	24	11	16.2	4.8	5.6	4.2	3.4
	72	29.5	45.9	10	12.3	7.1	7.2
	120	53.2	79.4	15	18.9	8.9	10
6	24	10.5	16.2	4.5	5.4	4.2	3.4
	72	27.8	44.3	10.1	11.9	7.1	7.3
	120	47.4	78.7	14.8	18	8.9	10.4
7	24	9.6	17.6	4.2	5.4	4.1	3.5
	72	25.8	47.9	9.4	12.4	7.4	7.5
	120	43.8	82	13.4	18.2	9.3	10.2
8	24	9.4	16.7	4.2	5.2	4.1	3.2
	72	25.3	46.8	9.6	12.1	7.4	7.2
	120	44.8	77.8	14	17.9	9.3	10
9	24	9.9	17.4	4.3	5.1	4	3.2
	72	26.9	46	9.8	11.6	7.2	6.9
	120	50.1	78.9	15.1	17.4	9.3	9.7
10	24	10.7	15.8	4.4	5	4.1	3.1
	72	32.6	42.4	10.6	11	7.1	6.3
	120	62.4	71.7	16.8	16.5	8.8	8.8
11	24	11.1	14.1	4.4	4.8	4.1	2.8
	72	31.9	37.5	10	10.7	7.1	5.8
	120	60.3	61.9	15.9	15.5	8.8	8
12	24	12.7	13	4.7	4.7	4.3	2.8
	72	35.2	34.2	10.4	10.2	7.4	5.5
	120	63	59.2	16.1	15.3	9.3	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 2017 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 2017

Month	Valid time	Z(500)				W(250)			
		N.A	Europe	Asia	Australia	N.A	Europe	Asia	Australia
1	24	15.7	17.9	23.6	14.8	5.8	6.3	5.6	7.9
	72	30.1	38.2	54.4	32.2	9.3	11.1	11.4	12.7
	120	52.6	69	100.2	60.2	13.6	16.7	17.7	19.2
2	24	15.8	17.9	24.1	14.7	6.4	6.7	5.6	8
	72	29.9	37.9	52.2	39.2	9.2	11.3	10.6	14.1
	120	49.2	69.9	91.8	74	13.2	17.1	17	19.9
3	24	14.9	16.7	20.9	14	7	6.7	4.7	7.6
	72	26.7	34.8	43.8	32.2	10	10.9	9.1	12.3
	120	44.1	61.8	77	57.6	13.2	15.8	14.3	17.2
4	24	15	16	19.3	13.3	7.2	6.6	4.5	7.7
	72	27.4	31.3	41.1	28.5	10.9	10.7	8.8	12.5
	120	46.1	54.5	72.5	47	14.7	15.4	13.4	17.2
	24	16	16.1	19.4	14.6	7.2	6.6	5	7.7

5	72	31.3	31.4	40.7	28	11.4	11	9.6	12.5
	120	49	52.9	71.2	51.2	15.9	15.8	14.9	17.6
6	24	14.8	15	19.5	11.5	7.5	6.8	6.6	6.8
	72	24.7	28.4	41.5	24.7	11.7	11.4	11.7	11.4
	120	38.1	46	66.6	39.7	15.8	15.7	16.2	15.6
7	24	15.3	15.6	18.7	11.1	6.9	6.5	6.6	6.4
	72	22.4	25.6	38.1	18.7	10.4	10.3	11.7	9.4
	120	32.3	40	61.8	34	13.1	13.6	16.4	13
8	24	14.9	15.6	18.8	12.1	6.7	6.4	6.6	6.4
	72	23.4	26.2	38.3	19.7	10.3	10.5	12.5	9.7
	120	37.2	44.3	67.9	32.5	13.5	14.9	18.1	13.5
9	24	15.3	16.3	20.3	11.3	6.4	6.2	6.1	6.4
	72	24.8	28.4	40.3	23.1	10	10.6	11.4	10.8
	120	42.4	50.2	73.7	38.9	13.8	15.7	18	15.5
10	24	14.5	16.1	19.7	13	5.5	5.8	5.3	6.5
	72	24.9	34.1	44.6	31.9	8.9	10.9	11.2	11.8
	120	45.5	64.5	85.2	61.4	13.4	16.9	18	18.7
11	24	13.6	16.1	20.1	12.4	5.5	5.9	5.2	6.9
	72	24.3	32.6	46.5	30.7	8.1	10.2	10.4	12
	120	44.5	60.3	79.5	54.8	12	15.6	16.7	17.1
12	24	16.4	18.9	21.8	14.2	6.1	6.5	5.1	7.2
	72	28.9	37.4	45.7	38.4	9.4	11.2	10.4	13.4
	120	52.4	64.6	81.7	65.5	13.5	16.8	15.9	20.6

5.1.3 Verification of CMA EPS

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

Table 5.1.3 Brier Score Skill (BSS) for CMA EPS (500 hPa height, 850 hPa Temperature) relative to an analysis in 2017

Month	**Threshold / Valid time**	**Z(500)**		**T(850)**	
		>climatology +1sd	**<climatology -1sd**	**>climatology +1sd**	**<climatology -1sd**
1	48	0.82	0.79	0.67	0.69
	72	0.73	0.70	0.60	0.59
	120	0.51	0.46	0.45	0.41
	168	0.28	0.25	0.33	0.26
2	48	0.83	0.81	0.70	0.68
	72	0.76	0.73	0.62	0.60
	120	0.57	0.56	0.55	0.45
	168	0.37	0.35	0.40	0.32
3	48	0.83	0.81	0.64	0.69
	72	0.74	0.71	0.55	0.60
	120	0.54	0.49	0.39	0.42
	168	0.36	0.31	0.28	0.26
4	48	0.78	0.79	0.66	0.64
	72	0.69	0.67	0.59	0.52
	120	0.49	0.46	0.48	0.34
	168	0.29	0.27	0.38	0.20
5	48	0.78	0.76	0.70	0.59
	72	0.67	0.64	0.64	0.47
	120	0.45	0.41	0.50	0.29

	168	0.24	0.22	0.38	0.13
6	48	0.71	0.71	0.72	0.61
	72	0.59	0.58	0.65	0.50
	120	0.39	0.36	0.54	0.33
	168	0.23	0.18	0.46	0.20
7	48	0.69	0.66	0.72	0.61
	72	0.58	0.51	0.65	0.51
	120	0.41	0.31	0.55	0.36
	168	0.25	0.12	0.47	0.25
8	48	0.72	0.70	0.75	0.60
	72	0.59	0.56	0.69	0.51
	120	0.39	0.35	0.58	0.35
	168	0.24	0.18	0.48	0.25
9	48	0.75	0.73	0.73	0.66
	72	0.63	0.61	0.67	0.58
	120	0.47	0.41	0.54	0.45
	168	0.25	0.22	0.41	0.35
10	48	0.80	0.78	0.68	0.69
	72	0.69	0.66	0.59	0.61
	120	0.51	0.44	0.44	0.47
	168	0.32	0.26	0.34	0.35
11	48	0.82	0.79	0.67	0.71
	72	0.73	0.70	0.59	0.64
	120	0.64	0.48	0.43	0.50
	168	0.35	0.29	0.29	0.35
12	48	0.80	0.78	0.63	0.64
	72	0.71	0.67	0.55	0.55
	120	0.51	0.45	0.41	0.41
	168	0.32	0.23	0.27	0.27

5.2 Research performed in this field

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

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

6.1 Development of the GDPFS

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

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

A new generation of Beijing Climate Center Climate Prediction System (BCC_CPS) will be tested and verified, based on a mid-resolution version with T106 horizontal resolution and 46 vertical levels and a high-resolution version with T266 horizontal resolution and 56 vertical levels. The new generation of BCC_CPS will be put into quasi-operation run in 2020, and it will provide sub-seasonal, seasonal, and interannual prediction products.

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

1) The vertical resolution of atmosphere components will be increased from 26 levels to 46 levels. Some key physical parameterization schemes will be modified. The updated climate model will be used in the new generation of BCC_CPS.

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

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

6.2.1 Planned Research Activities in NWP

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

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

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

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

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

6.2.2 Planned Research Activities in Nowcasting

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

6.2.3 Planned Research Activities in Long-range Forecasting

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

1) Build a high-resolution climate system model, in which the atmospheric component has a T266 horizontal resolution and 56 vertical levels, and the ocean component has $1/3^{o}$–1^{o} horizontal grid resolution.

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

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

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

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

6.2.4 Planned Research Activities in Specialized Numerical Predictions

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

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

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