National Meteorological Center,CMA
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JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2016

CHINA

NMC and NCC
China Meteorological Administration
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1. Summary of highlights

1.1 Developments of operational NWP

The global model forecast system GRAPES-GFS (0.25L60) version 2.0 has been put into operation run in June 2016. For the products consistency, the global model system T639L60 will still run in transition period. The regional model GRAPES-MESO had been updated to version4.1. Cloud Analysis Scheme modular had been put into the meso-scale operational system. The specialized numerical prediction system CUACE/haze-fog has been updated to 15km resolutions run. The high resolution system which reaches to 3KM and covers middle-east-china of GRAPES-MESO has been put into operational run in Sep 2016.

1.2 Developments of GRAPES

GRAPES-GFS (0.25L60) was tested and its performance was evaluated, the results showed that GRAPES-GFS was better than the current global NWP system (T639L60), and GRAPES-GFS has been put into operation in June 2016. GRAPES global 4DVar was tested with all observation, one month experiment showed that GRAPES global 4DVar was better than 3DVar, although there was still some results should be analysed in detail. A high resolution meso-scale GRAPES (3km grid length) which cover East China, was also tested in the flood season in 2015 with cloud analysis for the initial condition, GRAPES-3km had a good performance on the severe weather forecasting, such as tornado and heavy rainfall events.

2. Equipment in use

The total peak performance of IBM Flex System P460 is 1759 TFlops and the total storage capacity is about 6925TB. Three 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	527.10	527.10	391.69	77.24	51.80	77.24	26.35

(TFlops)							
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 NMIC in use are showed in table 3.1 according to one day data used by GRAPES-GFS on a batch experiment in December 2016.

Table3.1 Observation data for assimilation system

Data type	Mean	Data type	Mean	Data type	Mean
SYNOP	20968	AIREP/AMDAR	295364	NOAA15_AMSUA	69119
SHIP/BUOY	2478	SATOB (WIND)	228614	NOAA18_AMSUA	93875
TEMP	1456	AIRS	106130	METOP2_AMSUA	72646
GNSS(including COSMIC)	77337	NOAA19-AMSUA	81599	METOP1_AMSUA	96832
ASCAT	25284	FY3C-AMSUB	9755	NPP-ATMS	164915

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_GFS2.0)	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_MESO4.1)	03:40 (00Z_ ASSIM +60HR_.FCST)	03:40 ~ 05:00	IBM Flex P460
	16:40 (12Z_ ASSIM +60HR_.FCST)	16:40 ~ 18:00	IBM Flex P460
Ensemble Forecasts	07:00 (00Z_ASSIM+240HR_FCST)	07:00 ~ 09:00	IBM Flex P460

With 15 members 15 members (T639)	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）	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
Ensemble typhoon track forecasts with 15 members 15members(T639+ Bogus)	07:30 (00Z_120HR_FCST)	07:30～07:50	IBM Flex P460
	19:30 (12Z_120HR_FCST)	19:30～19:50	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_84HR_FCST）	00:10~04:10	IBM Flex P460
	12:00（12Z_84HR_FCST）	12:00~16:00	IBM Flex P460
GRAPES Rapid Analysis and Forecast System(GRAPES_RAFS)	01:20 (00Z_ASSIM+24HR_FCST)	01:20～01:45	IBM Flex P460
	04:20 (03Z_ASSIM+24HR_FCST)	04:20～04:45	IBM Flex P460
	07:20 (06Z_ASSIM+24HR_FCST)	07:20～07:45	IBM Flex P460
	10:20 (09Z_ASSIM+24HR_FCST)	10:20～10:45	IBM Flex P460
	13:20 (12Z_ASSIM+24HR_FCST)	13:20～16:45	IBM Flex P460
	16:20 (15Z_ASSIM+24HR_FCST)	16:20～16:45	IBM Flex P460
	19:20 (18Z_ASSIM+24HR_FCST)	19:20～19:45	IBM Flex P460
	22:20 (21Z_ASSIM+24HR_FCST)	22:20～22:45	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 at 0.25 degree horizontal resolution has been operational, replacing the previous GSI system since June 1st 2016. The observations used in the first version of GRAPES operational global 3D-Var system consist of conventional GTS observation, NOAA15 AMSUA, NOAA18 AMSUA, NOAA19 AMSUA, METOP-A AMSUA, AQUA, and GNSSRO. After the further validation, the assimilation of METOP-B AMSUA, NPP ATMS, FY3C GNOS and FY3C MWHS-2 was introduced in operations on October 14th 2016.

Two one-year trials are performed to evaluate the performance of GRAPES global 3D-Var system prior to the operational implementation. The results show that the RMSE of GRAPES global 3D-Var analysis is smaller than ERA-Interim reanalysis and NCEP FNL analysis for pressure field in most areas. The wind analysis of GRAPES global 3D-Var is worse in the Southern Hemisphere and Tropics. For humidity field, GRAPES global 3D-Var is much drier than ERA-Interim and NCEP FNL data especially in the middle and high troposphere.

4.2.1.2 Research performed in this field

Further research are being made to improve the operational 3D-Var system in the fields of humidity analysis and satellite assimilation. Firstly, the correction for radiation dry bias in radiosonde data is performed which gives the positive contribution on the humidity analysis. Secondly, the normalized unbalanced pseudo-relative humidity is investigated as a new humidity control variable. The preliminary results show that it reduces the positive humidity bias. But the impact of the new humidity control variable on the global analysis with the operational configuration is small. Moreover, the assimilation of NOAA18 AMSUB, NOAA19 AMSUB and METOP-A AMSUB is under development. It results in the improvement on 3D-Var analysis. But the forecast skill is slightly reduced.

In the operational 3D-Var system, the bias correction coefficients of satellite data are calculated off-line which fails to deal with the drift of observation bias. The adaptive bias correction of satellite data is being developed which uses the on-line samples from the previous 10 days to compute the bias correction coefficients.

The assimilation of Chinese FY satellite data is also an urgent work. The FY3C MWHS-2 118 GHz radiance data have been quality controlled. The assimilation results show a positive impact when only conventional observations are assimilated in the control experiment. The impact is neutral when full observations are all assimilated.

The background error covariance modelling scheme has been reformulated. In the new scheme, the balance constraint between stream function and velocity potential and the constraint between velocity potential and mass field are taken into account as well as the original geostrophic balance constraint. The impact of the new scheme is slightly positive.

A lot of efforts have been put into the development of global 4D-Var system. The work is ongoing to develop a pre-operational 4D-Var suite with 0.25° outer loop resolution. A three-month trial has been performed. 4D-Var with a single outer loop has a better performance than 3D-Var in most of areas. But the 4D-Var forecast skill in the tropical area is worse. It is expected that the improvement of satellite bias correction and linearized physics should give the contribution on the tropical analysis.

A series of linearized physical parameterization scheme has been developed to improve the representation of perturbed fields in the linear model. It consists of vertical diffusion, sub-grid scale orography gravity wave drag, large-scale condensation and cumulus convection schemes. Currently, the linear physics have an obvious impact on 4D-Var analysis but not always positive.

To accelerate the convergence in the multiple outer loop configuration, the information from the previous minimization is used to precondition the next minimization in the L-BFGS algorithm. In the one-month experiments, the preconditioned L-BFGS leads to quicker convergence of 4D-Var minimization. It contributes to a significant reduction in 4D-Var run-time. The Lanczos algorithm is also being developed following the scheme used in the ECMWF IFS system. It is expected that the preconditioned Lanczos algorithm is the operational candidate.

Now a weak constraint Jc term has been developed in GRAPES global 4D-Var system. It has an equivalent performance as the explicit digital filter and reduces the computational cost. But it is also found that the 4D-Var analysis is sensitive to the weighting factor used in the Jc term. Further work is focused on the tuning of the weighting factor and the use of the moist energy norm as the inner product.

We have started research into using the ensemble samples in the error covariance estimates used in 3 and 4D-Var. The preliminary results show that the vertical correlation from the EDA samples is beneficial.

A hybrid variational/ensemble data assimilation algorithm using the alpha control variable has been developed and tested with the current VAR software framework. The development of an ensemble transform Kalman filter (ETKF) system is underway. It will generate the background perturbations and give us the covariance required.

4.2.2 Model

4.2.2.1 In operation

Medium-range system GRAPES GFS has been put into operation to replace the previous system $T_L639L60$ on June 1, 2001. GRAPES GFS runs with a horizontal resolution of 0.25° and 60 vertical levels (up to 3 hPa), and time step is 300s. 10-day prediction is made twice a day, i.e. at 00:00 and 12:00 UTC respectively. Its physical processes Include the Rapid Radiative Transfer Model for GCMs, longwave and shortwave radiation schemes (Mlawer et al., 1997; Clough et al., 2005; Iacono et al., 2008), the Simplified Arakawa Schubert cumulus convection scheme (Pan and Wu, 1995; Han and Pan, 2011), the Medium Range Forecast boundary layer scheme (Hu zhijin, et a.,1986;1988), a double moment cloud microphysics scheme (Hong and Lim, 2006), the Common Land Model land surface scheme (Dai et al., 2003), and a prognostic cloud scheme (Sundqvist ,1978; 1989).

4.2.2.2 Research performed in this field

In GRAPES global model, Predictor-Corrector SISL scheme is implemented to solve the problems including the large off-center coefficient in SISL scheme which causes only first order accuracy of dynamics and too much damping for the short waves, and extrapolation in Lagrange trajectory calculation and Nonlinear terms, which produces noises and leads instability. 3D reference stat is realized to replace 1D reference stat and tested preliminarily. A scalable high-order nonhydrostatic multi-moment constrained finite volume dynamical core is been developing, and a high order slope constrained BGS limiter is realized to reduce the numerical oscillations and the horizontally-explicit and vertically-implicit (HEVI) scheme is used as the efficient time integration scheme. The coupling of convection and microphysics and consistency between cloud cover and condensate are optimized, and consistent treatment of evaporation and condense is realized. A soil resistance term is implemented to reduce the ground evaporation, and the scale factor is considered in the calculation of canopy interception fraction. Over ocean, the scheme for roughness lengths is improved and salinity effect on saturated specific humidity is included.

4.2.3 Operationally available Numerical Weather Prediction 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. 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	10^{-1} C	4	500,700,850,925

difference					
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	
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 solar radiation	W m**-2 s	1	surface	
upward long- wave radiation flux(surface)	W m**-2 s	1	surface	
Terrain height	Gpm	1	surface	
Dew point temperature	K	30	10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000	
Temperature Advection	K/s	30		
Vorticity Advection	1/s2	30		
Dew point temperature difference	°C	30		
Water vapour flux	g/cm·hPa·s	30		
Divergence of vapour flux	g/cm2·hPa·s	30		
Pseudo-equivalent potential temperature	K	30		
radar reflectivity	dBz	30		
Strong weather threat index	-	1	Surface	
Convective available potential energy	J/kg	1	Surface	
Convective inhibition energy	J/kg	1	Surface	
Lifting index	K	1	Surface	
Condensation layer pressure	hPa	1		
K index	°C	1	mean sea level	
Radar composite reflectivity	dBz			
Simulated satellite brightness temperature of vapor channel	K	1	Surface	
Simulated satellite brightness temperature of infrared channel	K	1	Surface	

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

For gridded Daily maximum Temperature， minimum Temperature，maximum RH and minimum RH, the period validity was expended from 10-day to 15-day.

4.2.4.2 Research performed in this field

Method same as short-range forecast was used. Specific content refer to 4.3.4.2.

4.2.5 Ensemble Prediction System (EPS)

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: 32 km (T639) up to day 15.

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. The main development in 2016 is organized as follows:

(1) **The development and improvement of the singular vectors (SVs) calculation**: the SVs are calculated respectively according to different targeted regions (i.e. the Northern Hemisphere extratropics: 30^{o}N–80^{o}N, and the Southern Hemisphere extratropics: 30^{o}S–80^{o}S); with the optimized GCR calls in the adjoint model and the increased computational nodes, the

computation time of SVs is reduced from 75 minutes to 55 minutes.

(2) **The development and improvement of the initial perturbations generator**: the initial perturbations are not just derived from the SVs, but from the combination of the SVs and the evolved SVs so as to introduce more large-scale perturbation structures which are contained in the evolved SVs.

(3) **The development and improvement of stochastic parameterizations**: apart from the SPPT (Stochastically Perturbed Parameterization Tendencies) scheme, the SKEB (Stochastic Kinetic Energy Backscatter) scheme is developed to further account for the model uncertainty.

（4）**The implementation of the real-time emulation system for the operational GRAPES-GEPS**: the implementation of the real-time emulation system for the operational GRAPES-GEPS has been accomplished; the numerical model of this real-time emulation system is the GRAPES model with the horizontal resolution of $0.5^o * 0.5^o$ and the integration time of 10 days; the introduced perturbation techniques consist of the SVs method to perturb the initial fields and the SPPT scheme to perturb the model itself; there are 41 members in total with a control forecast and 40 perturbed forecasts; besides, a dynamically upscaling approach for the high-resolution analysis fields from the operational GRAPES-3DVAR (horizontal resolution: $0.25^o * 0.25^o$) is developed to produce lower-resolution initial conditions for the 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.

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	Layer	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 an incremental grid-point data analysis system with 10km horizontal resolution and 50 vertical levels the same as the GRAPES_Meso model. The data assimilated include the conventional GTS data、GPS/PW and FY_2E. The analysed variables include zonal and meridonal winds, nodimensional pressure and specific humidity.The first guess is from the operational 6-hour prediction of T639 global model with the digital filter for initialization.

4.3.1.2 Research performed in this field

Data assimilation improvements of GRAPES-MESO model included : 1) developing global and regional unified assimilation system; 2) using multi-scale analyses to obtain the small-scale information in regional analysis; 3) implementing radar radial wind assimilation in regional analysis system; 4)setting up real-time Cloud Analysis Scheme system.

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: self-adjusting time step method was introduced to improve model instability; diagnostic work was carried on to evaluate the 2 meters temperature error; numerical experiments using the real data were conducted to test Tiedtke shallow convection parameterization; the coupled scheme between dynamic and physics was revised.

4.3.3 Operationally available NWP products

In 2016, 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)

<table>
<tr><th>No.</th><th>Variable</th><th>unit</th><th>Layer</th><th>Level(hPa)</th><th>Area</th></tr>
<tr><td>1</td><td>Geopotential height</td><td>Gpm (geopotential meters)</td><td>30</td><td rowspan="12">10, 20, 30, 50, 70, 100, 125,150, 175,200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000</td><td rowspan="12">horizontal resolution：0.1*0.1
Grid points：751*501
15°N ~65°N 70°E ~145°E</td></tr>
<tr><td>2</td><td>Temperature</td><td>K</td><td>30</td></tr>
<tr><td>3</td><td>U-wind</td><td>m/s</td><td>30</td></tr>
<tr><td>4</td><td>V-wind</td><td>m/s</td><td>30</td></tr>
<tr><td>5</td><td>Vertical velocity</td><td>m/s</td><td>30</td></tr>
<tr><td>6</td><td>vorticity</td><td>s-1</td><td>30</td></tr>
<tr><td>7</td><td>divergence</td><td>s-1</td><td>30</td></tr>
<tr><td>8</td><td>Specific humidity</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>9</td><td>Relative humidity</td><td>%</td><td>30</td></tr>
<tr><td>10</td><td>Cloud water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>11</td><td>Rain water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
<tr><td>12</td><td>Ice water mixing ratio</td><td>Kg/kg</td><td>30</td></tr>
</table>

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	--
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 during output interval	m/s	1	10m
54	Maximum of v10m during 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 during output interval	m/s	1	--	

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

Hourly corrected gridded meteorological elements forecast within 24h was put in quasi-operation. It based on twice a day gridded forecast and hourly gridded observation data.

4.3.4.2 Research performed in this field

Advection-extrapolating method and error-function correcting method based on historical data statistics were used in hourly corrected forecast.

4.3.5 Ensemble Prediction System

4.3.5.1 In operation

The GRAPES-based regional operational ensemble prediction system (REPS) based on V4.2.0 model (GRAPES-REPS-V2.0) has been running since Mar. 2016.. The system configurations are as follows:

- Time range: 0-96h forecast;
- Domain: 70-140°E, 15-60° N;
- Number of models used: one model (GRAPES-MESO V4.2.0 with 15km horizontal resolution and 49 vertical levels);
- Number of members: 15 members; 14 perturbed members (perturbations produced by Ensemble Transform Kalman Filter method) plus one control run;
- Initial condition perturbation method: Ensemble Transform Kalman Filter (ETKF);
- Perturbation of physical process: Different combinations of two PBL schemes and four cumulus schemes and Stochastically Perturbed and Parameterization Tendencies (SPPT) scheme；
- Running cycle: 00UTC and 12UTC;
- Integration time: 96h for both 00UTC and 12UTC.

4.3.5.2 Research performed in this field

The GRAPES-MEPS ensemble calculates the initial condition perturbations using the ensemble transform Kalman filter (ETKF). A T639 global ensemble provides lateral boundary conditions to this regional ensemble. The perturbations using the ETKF for the regional ensemble contain more detail on small scales and less power on large scales. Thus a Multiple Scale Blending (MSB) perturbations method has been operationally implemented. Aside from the ICs perturbations, the multiple-parameterization scheme and Stochastically Perturbed Parameterization Tendencies (SPPT) scheme were employed in GRAPES-MEPS to describe the model uncertainty. In this system, 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.

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)

4.4.1 Nowcasting system

4.4.1.1 In operation

In 2015, SWAN (Severe Weather Automatic Nowcasting system) updated from version 1.6 to 2.0, with a significant change in the aspects of algorithm, data resource and function. Four new algorithms, including 3DVAR wind retrieval from Doppler radar, rain cluster divisional QPE, the operational probabilistic short–duration heavy rainfall forecasts and the hail identification from Doppler radar. New data was added to the SWAN, such as lightning and upper air sounding data, which provided new methods of monitoring and nowcasting. New interface was designed for the SWAN 2.0, with new functions were invented. For example, the module of Subjective guiding forecast products of severe weather was designed, remaindering forecasters the potential severe weather areas. A new function of calculating statistic data in a specified area can show the cumulative precipitation in different time windows.

Beijing Meteorological Bureau has developed a Rapid-refresh Multi-scale Analysis and Prediction System — Integration (RMAPS-IN). With the strategy of blending, it has a better forecast performance in the 0-12hrs than the extrapolated and NWP alone. High time and space resolution (10min and 1km) products, including precipitation, temperature and wind field, etc., could be provided. The system has been in operation in the flood season of 2015, proved to be an effective and efficient system.

4.4.1.2 Research performed in this field

Some researches were performed in the field of monitoring and nowcasting to enhance the function of Nowcasting and Very Short-range Forecasting Systems in 2015.

In order to improve the capacity of severe weather forecast in 6-12hrs, the probabilistic severe weather forecast algorithm was developed. Based on the principle of ingredients based forecasting methodology, it can provide the forecasting results of different severe weather, including hail, heavy rain and thunderstorm gale, etc. in the 6-12hrs using tens of convective parameters.

The algorithm of 3DVAR wind retrieval from Doppler radar can provide the wind filed with a high-resolution of 2km in different heights, which can provide detail information in the storm for the forecasters. Other products, such as vorticity and divergence, may also derive from the wind filed.

Rain cluster divisional QPE, which can provide more accurate precipitation estimation using the Doppler radar data and AWS rainfall data, divided different rain clusters and estimated their precipitation discriminately. Different coefficients was decided according to their reflectivity. As various rainfall types, stratiform cloud precipitation and convective cloud precipitation, were distinguished, it can provide better QPE results, especially for the heavy rain.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

Grapes Rapid Analysis and Forecast System (RAFS) is an quasi-operational system with a horizontal resolution of 10 km and 50 vertical levels. The prediction domain is from 70°E to 145°E and from 15°N to 65°N and the grid space is 751×501. This system updates its data assimilation every 3 hours in China domain and provides 30-hour forecasting products every 3 hours. The system uses T639 real-time field database to provide its background, while the observations include real-time GTS data (radiosondes, AIREP/AMDAR reports, GMS derived winds, SHIP and SYNOP data, etc.)、radar VAD data、GPS/PW、 FY_2E and GPS/RO occultation retrieval of temperature profile. The products for making assimilation analysis for such variables as wind, temperature, pressure, humidity, and the products on severe convection weather potential forecast (CAPE, K index, et al) were made available in such 3 formats: Grads, MICAPS, and GIF.

4.4.2.2 Research performed in this field

- The errors of GRAPES-RAFS system were evaluated;
- real-time Cloud Analysis Scheme system was set up;

4.5 Specialized numerical predictions

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. No changes in 2016.
The V2.0 forecast modeling system run twice a day operationally in CMA. It issues 84-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):

The global environmental emergency response system is composed of T639L61 and off-line HYSPLIT. Additionally, the ensemble T639L61 meteorological fields are 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 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	0.5°×0.5°	1/6°×1/6°	1/15°×1/15°
Grid size	720×311	481×307	376×526
Forecast hour	240h	120h	72h
Atmospheric input	T639	GRAPES_TYM	GRAPES_TYM
Minimum water depth	2.5m	2.5m	2.5m
Time steps	3600s,480s,1800s, 30s	1800s，450s，900s，15s	300s，185s，150s，15s
Model physics	Wave propagation：ULTIMATE QUICKEST propagation scheme； Source term：Tolman and Chalikov source term package； Nonlinear interactions：Discrete interaction approximation； Bottom friction： JONSWAP bottom friction formulation.		

4.5.2.2 Research performed in this field

- Regional Typhoon prediction system GRAPES-TYM

  A Dynamical Initialization Scheme for initial vortex and further tuning for model physics was conducted to improve track and intensity forecasts of TCs. A high resolution (3km) forecast system for TCs in 48h waring area was developed and put into realtime running in order to improved precipitation and high wind forecasts during TCs landfall.

- 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.

4.5.3 Specific products operationally available

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

  A new TOA products has been designed and revised. The new TOA products are tested in 2016.

- 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 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 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.

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 was used into operational in 2016, which based on 15 members of T639L61 ensemble numerical prediction system. And the new global ensemble forecast products of atmospheric dispersion are used in 2016, including 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 used into operational in 2016, which based on 15 members of GRAPES_MESO ensemble numerical prediction system. And the new regional ensemble forecast products of atmospheric dispersion are used in 2016, including 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.
- **TC track numerical prediction products:** The global TC track prediction system provides the following products(1) TC tracks to 120h;(2) maxmum 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)*

4.6.1 Models

4.6.1.1 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.

4.6.1.2 Research performed in this field

Based on the indices of Standard Verification System (SVS) for Long-Range Forecasts (LRF) recommended by WMO (2006), both deterministic and probabilistic forecast of atmospheric circulation and climate variables of BCC Climate System Model BCC-CSM1.2 was assessed. Moreover, the model's performance on climate phenomenon prediction on the timescale of seasonal to sub-seasonal (S2S), such as MJO, BSISO, AO and ISV was analysed, which plays an important role in the source of predictability of extended range.

Based on the hindcast and real-time forecast datasets of BCC-CSM1.2, the forecasting performance of atmospheric blocking was investigated. The medium-range ensemble forecasts performed well in simulating the frequencies of Euro-Atlantic (EA) and Pacific (PA) blocking, especially with lead time within 10 days. Compared with observations, the model underestimates the blocking frequency in the middle and latter half of the forecast range. In addition, the predictive bias of onset and frequency of EA blocking is significantly higher than PA blocking, which may be caused by the systematic errors of 500-hPa geopotential height.

4.6.2 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.

4.6.3 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.

4.6.4 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 (LRF) *(30 days up to two years)*

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. 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.

4.7.3 Operationally available EPS LRF 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 (T639) in 2016 is shown in the following table 5.1.1.

Table 5.1.1 RMSE of T639 model (500 hPa height Z and 250 hPa and 850 hPa wind speed W) against analysis field in 2016

Month	Valid time	Z(500)		W(250)			W(850)
		NH	SH	NH	SH	Tropics	Tropics
1	24	12.8	13.9	5.4	5.6	5.3	3.1
	72	35.5	38.3	10.7	12.1	8.2	6.4
	120	63.9	63.3	15.6	17.2	9.8	8.5
2	24	12.1	13.7	5.1	5.4	5.5	3.1
	72	33.5	38.1	9.8	11.6	8.4	6.5
	120	60.6	64	15.1	16.7	10	8.8
3	24	11.2	14.9	5.4	5.7	5.2	3.3
	72	33.2	44.7	10.3	12.9	7.9	7.1
	120	58.9	74.3	15	18.6	9.1	9.5

4	24	10.8	16.5	5.2	5.6	4.9	3.5
	72	30.3	50.5	10.1	13.1	7.4	7.8
	120	56.1	85.6	15.2	19	8.8	10.5
5	24	10.4	15.9	5.4	5.3	4.8	3.3
	72	29.5	45.5	10.6	12	7.2	7.5
	120	56.6	77.4	16.1	17.7	8.7	10.3
6	24	10.4	17.5	5.3	5.4	4.9	3.5
	72	27.4	49.2	10.3	12.6	7.5	7.9
	120	48.5	81.3	14.8	18.5	9	10.8
7	24	10.3	17.6	5.7	5.8	5	4.7
	72	25.2	47.5	10.7	13.1	7.6	10
	120	43.8	80.4	14.5	18.7	8.8	13.5
8	24	10.3	17.9	5.3	5.4	5.2	3.6
	72	28	49.8	10.8	12	8.1	8.1
	120	49.2	87.4	15.4	18.8	9.3	11.4
9	24	10.1	16.9	5.2	5.2	5.1	3.3
	72	28.2	46.2	10.6	11.7	7.7	7.3
	120	51.7	80.3	15.8	17.9	9.1	10.3
10	24	10.4	15.2	5	5.3	5	3.3
	72	29.9	44.5	10.4	11.7	7.5	7.1
	120	54.3	76.6	15.3	17.2	8.9	9.7
11	24	11.2	14.5	5	5.4	5.1	3.1
	72	32.4	39.7	10.2	11.4	7.7	6.5
	120	61.3	67.6	16	16.8	9.4	9
12	24	12.5	13.3	5.1	5.2	5.3	3
	72	35.4	35.2	10.5	10.6	7.9	6.1
	120	64.9	58.5	16.4	15.5	9.5	8.2

5.1.2 The verification against observations of operational numerical forecast model (T639)

The verification against observations of operational numerical forecast model (T639) in 2016 is shown in the following table 5.1.2.

Table 5.1.2 RMSE of T639 model (500 hPa height Z and 250 hPa wind speed W) against observations in 2016

Month	Valid time	Z(500)				W(250)			
		N.A	Europe	Asia	Australia	N.A	Europe	Asia	Australia
1	24	16	17.7	15.6	19.4	7.6	6.7	5.6	7.6
	72	38.8	34.5	28.6	35.8	13	11.3	9.1	12.1
	120	61.3	62.3	50	47.2	17.9	18.3	13.7	18.2
2	24	17.1	20.3	15.1	21	7.2	6.5	5.6	6.2
	72	40.8	35.1	27.9	36.1	12.5	10.9	8.9	10.2
	120	63	73.8	50.1	49	16.5	17.6	13.5	14.2
3	24	17.9	16.6	14	18	7.8	6.1	6.5	6.8
	72	42.9	40.9	28.7	30.9	12.6	12.2	10.4	11.4
	120	61.2	66.7	48.9	41.3	17	16.6	14.1	15.1
4	24	15.3	13.4	14.6	17.8	7.4	5.3	7.3	6.8
	72	33.2	32.2	27.8	35.1	11.9	10.1	11.1	12.3
	120	56.2	60.3	46.8	53.5	16.8	15.9	15.6	15.5
5	24	13.9	13.1	15.4	16.1	7.7	5.6	7.3	7.4
	72	28.5	27.1	29.8	35.9	13	10.4	11.5	11.8
	120	47.6	52.5	48.7	58.1	17.5	17.4	15.4	17.9
	24	11.7	12.6	14.4	16.6	6.7	6.1	7.3	7

6	72	22.7	25.4	25.4	30.8	11	11.2	11.8	12.7
	120	37.4	41	36.8	67.6	15.1	15.3	15.5	18.1
7	24	11.6	12	16.3	19.4	8.5	9.1	9	9.7
	72	23.2	21.3	25.8	37.4	12.5	11.6	12.3	13.8
	120	34.8	39.7	35.2	53.8	15.7	15.8	15.2	16.1
8	24	10.5	10.8	15.6	15.7	6.1	6	6.3	6.7
	72	22.5	22.9	27.2	29.8	10.2	11.2	10.7	10.6
	120	35	48.4	39.6	53.1	13.9	17.7	14.9	16.1
9	24	13.3	14.3	14.5	19.1	6.7	6.2	6.1	7
	72	28.8	24.9	25.6	39.3	11.9	11.4	10.1	11.3
	120	48.1	50.5	41.3	59.7	18	18.5	13.5	15.3
10	24	14.7	11.8	14.1	16.5	6.7	6	5.3	6.7
	72	30.6	27.5	25.1	31.9	11.9	11.3	8.4	11.1
	120	44.2	51.6	41.8	56.8	16.2	17.5	12	16.2
11	24	17.2	20	14.5	18.3	7.2	6.3	5.6	7
	72	35	37	27.5	32	12	11.4	8.9	10.5
	120	57.2	65.4	44.7	46.6	17.4	18.3	12.8	13.3
12	24	15.3	13.8	14.7	13.9	7.3	5.5	5.5	6.9
	72	37.8	32.7	29.6	26.7	12.9	11.6	9.1	9.9
	120	70.2	60.3	48.6	35.4	19.7	17.6	13.2	14

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 2016

Month	**Threshold / Valid time**	**Z(500)**		**T(850)**	
		>climatology +1sd	**<climatology -1sd**	**>climatology +1sd**	**<climatology -1sd**
1	48	0.82	0.80	0.66	0.65
	72	0.73	0.71	0.57	0.56
	120	0.52	0.48	0.41	0.42
	168	0.35	0.33	0.28	0.33
2	48	0.84	0.80	0.72	0.66
	72	0.76	0.70	0.63	0.57
	120	0.60	0.50	0.50	0.44
	168	0.42	0.31	0.39	0.33
3	48	0.83	0.80	0.69	0.63
	72	0.74	0.70	0.62	0.55
	120	0.57	0.51	0.51	0.41
	168	0.41	0.36	0.40	0.32
4	48	0.80	0.79	0.68	0.63
	72	0.72	0.69	0.61	0.53
	120	0.52	0.48	0.49	0.37
	168	0.32	0.25	0.37	0.21
5	48	0.80	0.77	0.67	0.60
	72	0.70	0.66	0.60	0.49
	120	0.48	0.45	0.46	0.32
	168	0.29	0.28	0.36	0.22
6	48	0.74	0.73	0.70	0.60
	72	0.64	0.60	0.62	0.51

	120	0.47	0.40	0.50	0.36
	168	0.32	0.23	0.39	0.24
7	48	0.68	0.66	0.69	0.63
	72	0.57	0.51	0.64	0.55
	120	0.39	0.29	0.53	0.42
	168	0.25	0.17	0.44	0.33
8	48	0.71	0.70	0.71	0.67
	72	0.61	0.56	0.65	0.59
	120	0.42	0.39	0.54	0.47
	168	0.26	0.23	0.45	0.38
9	48	0.75	0.73	0.75	0.71
	72	0.63	0.58	0.68	0.64
	120	0.42	0.40	0.57	0.50
	168	0.24	0.23	0.46	0.40
10	48	0.80	0.79	0.72	0.69
	72	0.70	0.69	0.65	0.62
	120	0.53	0.51	0.52	0.51
	168	0.36	0.35	0.40	0.40
11	48	0.82	0.80	0.69	0.70
	72	0.73	0.69	0.62	0.62
	120	0.55	0.50	0.49	0.49
	168	0.38	0.32	0.38	0.38
12	48	0.82	0.80	0.67	0.67
	72	0.73	0.69	0.58	0.57
	120	0.53	0.45	0.43	0.39
	168	0.32	0.27	0.32	0.26

5.2 Research performed in this field

- Application of a bias correction scheme for 2 meter temperature in numerical model forecast.
- Application of neighborhood spatial verification method on precipitation evaluation and assessing hourly precipitation forecast skill with the Fraction Skill Score
- Update new verification methods in GRAPES Evaluation Tools (GET)

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 Global Forecast System (GRAPES-GFS) will be put into operational run with 25km horizontal resolution and 60 levels in vertical by the end of 2016. The GRAPES-based regional ensemble system will be upgraded with multi-scale blending method and SPPT method .The new operational short-term REPS system will be upgraded in 2016 with a blending initial perturbation method, SPPT stochastical physics perturbation and a new post processing system will be implemented.

The model version of the second generation of Beijing Climate Center Climate Prediction System (BCC_CPS) will be updated, and the new generation of BCC_CPS will be put into quasi-operation run by the end of 2018 with T106 horizontal resolution and 46 levels in vertical. Also, a higher resolution climate system model BCC_CSM2 (T266 horizontal resolution, 56 levels) is being developed and will be tested in the short-term climate predictions.

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, and GRAPES global 4DVar is planned to put into operation before 2018.
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 microphysics scheme.
4) To set up the GRAPES global and regional ensemble NWP systems, based on SVs and ETKF respectively.

6.2.2 Planned Research Activities in Nowcasting

More attention will be put on the severe convective weather, especially the storm gale, the hail, and the tornado.

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) Further increase the horizontal resolution and the vertical levels of the atmospheric model and other model components.
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 two-momentum cloud and

microphysics scheme, cumulus parameterizations scheme, atmospheric boundary scheme, and shallow convection scheme, and so on.

3) Data assimilation techniques will be further improved to 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: carry out the research of meteorological fields down-scaling, 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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