WMO REGIONAL SPECIALIZED METEOROLOGICAL CENTER

WITH ACTIVITY SPECIALIZATION ON ATMOSPHERIC SAND

AND DUST STORM FORECASTS BEIJING

(RSMC-ASDF BEIJING)

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Contents

1. Introduction

Sand and Dust storms (SDS) cause devastating damages to properties and human health every spring in Asia. Under the major influence of global climate changes and weather conditions over the Asian dust source regions and the minor influence of anthropogenic desertification, the source strength of Asian SDS was estimated to be 800 Mt year^{-1} with very high spatial and temporal variability from year to year. Recently there has been an increasing concern over the formation and transport of soil dust aerosol and its contribution to the earth-climate system, essentially to the impact of a severe form of soil dust aerosol in the atmosphere – SDS. Because of its economic and social impacts, it is critical to understand the source strength, transport and deposition of soil dust and to establish the SDS forecasting and early warning (EW) capacity in the world to reduce its impact. Within this context, an ambitious plan to establish a global SDS forecasting and early warning system has been formulated by WMO (World Meteorological Organization) to improve the global forecasting ability for SDS around the world.

On 12-14 September 2004, an International Symposium on Sand and Dust Storms was held in Beijing, China, hosted by the China Meteorological Administration. It was followed by a World Meteorological Organization Experts Workshop that produced a proposal to create a WMO Sand and Dust Storm Project jointly coordinated by the WMO Global Atmosphere Watch Programme and the WMO World Weather Research Programme. The proposal was approved by the steering body of the WWRP in 2005. More than forty member countries expressed interest in participating in activities to improve capacities for more reliable sand and dust storm monitoring, forecasting and assessment. A Steering Committee for the Sand and Dust Storm Project was formed. In 2006, in a meeting in Shanghai, China, it proposed the development and implementation of a Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS).

In May 2007, the 15th Congress of the WMO approved the launching of the SDS-WAS system with the mission to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations and information to users through an international partnership of research and operational communities. The SDS-WAS system, an international framework linking institutions involved in sand and dust research, operations and delivery of services, addresses the following objectives:

1) Provide user communities with access to forecasts, observations and information on sand and dust storms through regional centers connected to the WMO Information System and the World Wide Web
2) Identify and improve sand and dust products through consultation with the operation and user communities
3) Enhance operational sand and dust forecasts through technology transfer from research to application
4) Improve forecasting and observation technology through coordinated international research and assessment
5) Build capacity of different countries to utilize sand and dust observations, forecasts and analysis products to meet public needs
6) Build bridges with other communities conducting aerosol related studies (air quality, biomass burning, etc.)

SDS-WAS is an international network of research institutes, national operational centres and users organized through regional nodes assisted by SDS-WAS regional centres (Fig.1). It is coordinated by the SDS-WAS Steering Committee which is supported by the WMO Secretariat and reports to CAS through the WWRP and GAW programmes.

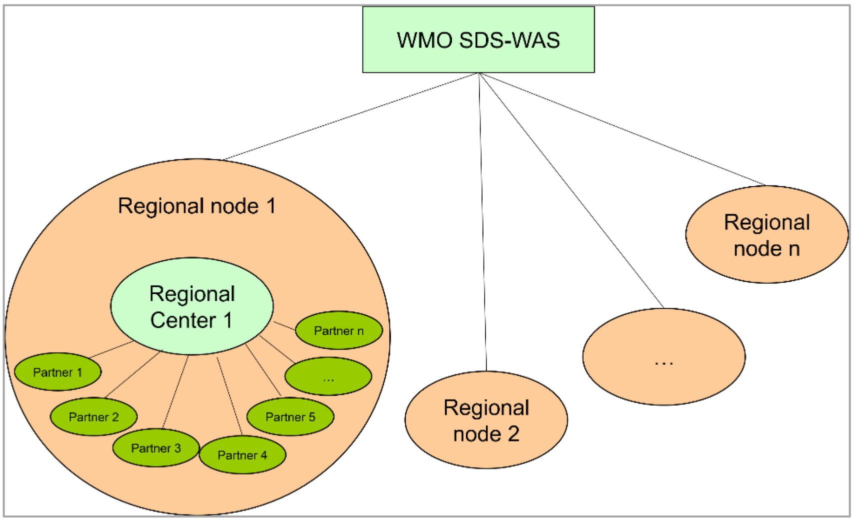

Fig.1 The international network of SDS-WAS

In June 2008, the 60th Executive Council session (EC-LXI) of WMO welcomed the initiatives towards the development of SDS-WAS to assist Members to gain better access to services related to sand and dust storms prediction and warning advisories through capacity building and improved operational arrangements. It also welcomed the establishment of the two SDS-WAS regional centres in China and Spain in support of the corresponding SDS-WAS nodes. EC-LXI further requested the

Commission for Basic Systems (CBS) to collaborate with the Commission for Atmospheric Sciences (CAS) to develop operational procedures to determine the future role of the centres with the appropriate operational and research capabilities. At the fourteenth session of the Commission for Basic System (CBS-14), March 2009, the Commission requested appropriate experts in CBS to review the draft SDS-WAS Implementation Plan "to clarify the future of the SDS-WAS centres (and nodes) in the context of the WMO Global Data-Processing and Forecasting System (GDPFS) and Regional Specialized Meteorological Centre (RSMC) structures", and recommended using its RSMC designation process for the establishment of the SDS-WAS centres, to ensure operational sustainability; At CBS-15, September 2012, the Commission noted the results of the work of the ad hoc joint CAS-CBS Task Team on Sand and Dust Storm Warning Assessment Systems, the Commission agreed that there is a need to incorporate the mandatory functions and criteria for the designation of RSMC with activity specialization on Atmospheric Sand and Dust storm Forecasts (RSMC-ASDF) in the current version of the Manual on the GDPFS, and therefore proposed an amendment to the Manual on the GDPFS.

The Commission was presented with the nomination of the centre in Barcelona (Spain) to act as an RSMC-ADSF for the Northern Africa (north of Equator), Middle East and Europe at its CBS-15 session, with the nomination of the centre in China (Beijing) to act as an RSMC-ADSF for the region consisting of Asia and the Central Pacific at its CBS-16 session and noted that those centres complies with the mandatory functions and recommended its formal designation. The World Meteorological Organization at its EC-65 and EC-69 sessions endorsed the formal designation of the RSMC-ADSF Barcelona and RSMC-ADSF Beijing respectively.

2. Forecast Models

CMA Operational Regional Dust Forecast Model (CUACE/Dust), an integrated atmospheric chemistry modelling system applied to dust (see special issue at http://www.atmos-chem-phys.net/special_issue81.html), was first established in 2002 and has been operationally run for dust forecasts in China Meteorological Administration (CMA) since 2004 and for the WMO SDS-WAS Asia Node-Regional Centre since 2007. Since 2017, CUACE has been being the operational modle of RSMC-ASDF Beijing.

CUACE has been designed as a unified chemistry module to be easily coupled with atmospheric models through a common interface. Its aerosol module utilizes a size-segregated multi-component algorithm for different types of aerosols including dust, sea salt, black and organic carbon, nitrate and sulphate (Gong, Barrie et al. 2003;

Zhou, Gong et al. 2008; Zhou, Gong et al. 2012). A detailed desert distribution with soil texture data base and dust particle-size distributions measurements from nine major deserts for China was adopted to the Model (Gong, Zhang et al. 2003; Zhang, Gong et al. 2003). One of the unique features of the CUACE/Dust is the implementation of a 3D-Var data assimilation system using both satellite and surface observations in near real-time to improve the initial conditions and hence the forecast results (Niu, Gong et al. 2008). A scoring system has been developed where observations from various sources concerning dust aerosol, i.e. surface observations of sand and dust storms and satellite retrieved Infrared Difference Dust Index (IDDI; (Wang, Zhang et al. 2008), are integrated into a Geographic Information System (Wang, Zhang et al. 2008).

Functional Blocks of Forecasting System: CUACE/Dust has been designed as a unified chemistry module to be easily coupled onto any atmospheric models on various temporal and spatial scales. Through a common interface to communicate with a host model, CAUCE/Dust has four functional blocks: (1) an emission processor, (2) a gas phase chemistry, (3) an aerosol algorithm and (4) a data assimilation system.

Aerosol Module in CUACE/Dust: The aerosol module currently used in CUACE is a size-segregated multi-component algorithm for different types of aerosols including dust, sea salt, BC/OC and sulfate (Gong et al., 2003a) with major aerosol processes in the atmosphere such as the generation, hygroscopic growth, coagulation, nucleation, condensation, dry depositions, scavenging and aerosol activations. Since most mineral aerosol is primarily emitted from dry land surface in coarse mode (Zhao et al., 2003), the processes of coagulation, nucleation, condensation and aerosol activations have been omitted for mesoscale dust simulation and forecast in CUACE/Dust.Particle size distribution plays an important role in aerosol microphysics and its large scale transport processes. Studies (Zhang et al., 2003) show that the dominant mass of the mineral aerosols in Northeast Asia are of a diameter from 2 to 20μm which accounts for about 53%–68% of the total mineral dust. It may shift slightly to coarse mode in heavy dust storms near the source regions and to fine mode in receptor regions. Consequently, the dust aerosol size spectra in CUACE/Dust have been divided into 12 size bins with a radius range of 0.005–0.01, 0.01–0.02, 0.02–0.04, 0.04– 0.08, 0.08–0.16, 0.16–0.32, 0.32–0.64, 0.64–1.28, 1.28–2.56, 2.56–5.12, 5.12–10.24, 10.24–20.48μm, respectively.

Dust Emission Schemes and Soil Erosion Database: There are two dust emission schemes built in CUACE/Dust: (1) by Marticorena and Bergametti (1995), Alfaro etal. (1997), Alfaro and Gomes (2001) (hereinafter referred to as MBA) and (2) by Shao (2001, 2004). Both of these schemes require a comprehensive soil erosion database containing deserts and semi-deserts distributions, soil grain-size, soil moisture content, snow cover, land use and surface roughness length. For East Asia, parameters and data sets to drive these two schemes have been derived and compared (Zhao et al., 2006) . In the current operational CUACE/Dust, the MBA scheme is used. A detailed desert distribution and soil texture data base for China was given (Gong et al., 2003b) and the snow cover was retrieved from NOAA17 AVHHR at the resolution of 0.02.

Meteorology, Transports and Data Assimilation: The key parameters from a host model to drive CUACE/Dust are the 3-D winds, boundary-layer turbulence, surface fluxes, cloud and precipitation as well as the soil moisture contents. They determine not only the production of dust aerosol but also its long-range transports. In the current CUACE/Dust, a non-hydrostatic version of MM5 is used as the meteorological driver with a horizontal resolution of 54 km to cover Asia and eastern part of Europe (Fig.2) and 31 vertical sigma-levels up to 10hPa.

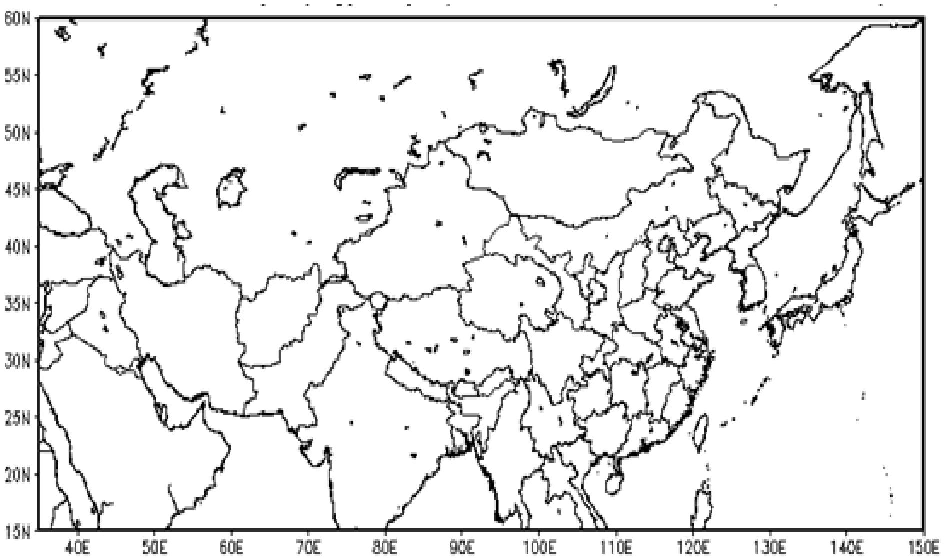

Fig.2 The domain of CUACE/Dust (15-60N,35-150E)

Meteorological forecasts at six hours' interval from T639L60, an operational global medium range spectrum model at the resolution of 0.281 in CMA, are interpolated to formulate the meteorological initial, boundary and lateral conditions.

A number of improvements have been made to the host MM5 model to provide more reasonable parameters to drive the dust forecasts. A Multi-dimensional Positive Definite Advection Transport Algorithm (MPDATA) (Smolarkiewicz, 2006) has been introduced as the advection scheme for all tracers due to its stability, consistence and conservation for positive definiteness. The excess numerical diffusion produced by this scheme is corrected by reapplying the scheme in which the velocity would be replaced by an anti-diffusion velocity field derived analytically from the truncation error analysis of the upstream scheme. A nonscillatory option can also be applied to assure monotonicity. Two iterations would make the MPDATA second-order accurate in time and space.

Vertical diffusion in sub-grid scale is another important progress controlling the transports of tracers, especially in PBL. A nonlocal vertical diffusion scheme has been adopted in CUACE/Dust which is an improved approach from local-k method based on local gradients of wind and potential temperature. The new method overcomes the deficiencies for highly unstable conditions where the local gradients cannot model the transport by large eddies representing the bulk property of the whole PBL (Hong and Pan, 1996).

One of the unique features of CUACE/Dust is the implementation of a three dimensional data assimilation model that uses the observations of the surface monitoring networks and FY-2C SDS retrieval data (Hu et al., 2008; Niu et al., 2008). The assimilated output has been used as the real time initial dust concentrations in the forecasting system.

3. Product Dissemination

According to the current GDPFS Manual - Designation and Mandatory Functions of Regional Specialized Meteorological Centres with Activity Specialization in Atmospheric Sand and Dust Storm Forecasts (Annex1), RSMC-ASDF Beijing has carried out the following real-time functions:

- Prepare regional forecast fields using CUACE/Dust continuously throughout the year, on a daily basis;
- Generate forecasts of the following minimum set of variables:
  - Dust load (kg•m–2)
  - Dust concentration at the surface (µg•m–3)
  - Dust optical depth at 550 nm (-)
  - 3-hour accumulated dry and wet deposition (kg•m–2).

The CUACE/Dust model operational run twice a day, respectively 00 hours:06:30-08:15(UTC) and 12 hours:18:30-20:15(UTC).

From 2017 to 2019, a total of 25 failures occurred in the dust Operational system, of which 12 were caused by HP machine, 11 were caused by data problems, 2 were caused by SMS server failures, 1 was caused by modle integration errors, and 1were caused by modle system problems.The overall operation of the model is stable, and the integration error of the model itself is only one time.

Dust forecast products have been filed since July 6, 2006. From 2006 to 2012, the daily amout of data is 75M and from 2018 to 2019, with a daily amount of data of 4.15G.

The RSMC-ASDF Beijing Web Portal(http:// http://eng.nmc.cn/sds_was.asian_rc/) has been designed to allow the users to access to the SDS forecasting products which are not only generated by CUACE/Dust from China but also by ADAM3 model from Korea, MASINGAR model from Japan, SILAM model from Finland，MACC model from ECMWF, and a dust forecast model from NCEP(Table 1-3), as well as to the sources of the basic information on CUACE/Dust system. An explanatory note will be issued on the web portal when it is in operational run.Also WMO members could order the SDS forecasting products from RSMC-ASDF Beijing by WMO WIS through GISC-Beijing.

Additionally, the data sharing ftp (ftp.nmc.cn) was established in late 2018, where member countries could exchange observations and numberical forecast data with each other. Until now, daily data files of all numerical models and ensemble forecast on portal site since January 1, 2018 have been uploaded. Further historical forecast data could be requested via sds@cma.gov.cn.

Table 1 Information of forecast products on the portal site

Parameter	**Area**	**Models**	**Resolution**	**Forecast range**	**Time steps**	**Frequency**
Dust load (kg m^{-2})	15-60 °N, 35-150 °E	CMA	0.5 °	3 days	3 hours	1 /day
		KMA	0.5 °			
		JMA	0.5 °			
		NCEP	1 °			
		ECMWF	0.5 °			
Dust concentration at the surface (μg m^{-3})	15-60 °N, 35-150 °E	CMA	0.5 °	3 days	3 hours	1 /day
		KMA	0.5 °	3 days		
		JMA	0.5 °	3 days		
		NCEP	1 °	3 days		
		ECMWF	0.5 °	3 days		
		FMI	0.5 °	5 days		
		Ensemble	0.5 °	3 days		
Dust optical depth at 550 (nm)	15-60 °N, 35-150 °E	CMA	0.5 °	3 days	3 hours	1 /day
		KMA	0.5 °	3 days		
		JMA	0.5 °	3 days		
		NCEP	1 °	3 days		
		ECMWF	0.5 °	3 days		

		FMI	0.5 °	5 days		
Three-hour accumulated dry and wet deposition (kg m^{-2})	15-60 °N, 35-150 °E	CMA KMA JMA NCEP ECMWF	0.5 ° 0.5 ° 0.5 ° 1 ° 0.5 °	3 days	3 hours	1 /day

Table 2 Information of observation products on the portal site

Parameter	**Area**	**Frequency**
FY-4A IDDI	15-60 °N, 35-150 °E	24 /day
Visibility	15-60 °N, 35-150 °E	8 /day
Dusty weather phenomena	15-60 °N, 35-150 °E	8 /day

Table 3 Information of verification products on the portal site

Parameter	**Area**	**Models**	**Forecast range**	**Time steps**	**Frequency**
Forecasted surface-layer dust concentrations vs observed dusty weather phenomena	15-60 °N, 35-150 °E	CMA, KMA, JMA, NCEP, ECMWF, FMI, Ensemble	1 day	3 hours	1 /day

4. Overview of Asian SDS Events during 2017-2018

Summary of all dust events occurred in China durning 2017-2018 was showed in Table 4. In 2017, nine dust events occurred in China with eight Blowing and Floating Dust (BFD) processes and a SDS process, which was lower than the historical average. Compared with 2017, five more dust envents occurred in China. Among them, there were twelve BFD processes, a SDS process, and an intense SDS process. The first dust event in 2018 was the BFD process occurred from February 8 to 9. The most influential event was the BFD process occurred from March 26 to 29, affecting northwestern and northern China and northeastern, central and western Huanghuai region. The most intensive event was the active SDS process occurred from April 1 to 3 in central and southern Xinjiang Basins, Xilinhot of Inner Mongolia and the right bank of New Balhu. During late November and early December, a wide-ranging BFD process occurred in central and eastern regions of North China and Huanghuai region, which was relatively rare in the same period in previous years.

Additonally, a severe SDS process struck north-western parts of India, including megacities like Jaipur, Delhi, Agra, Lucknow, on 2 and 3 May 2018, causing around

35, 4, and 73 people dead in Rajasthan, Uttarakhand, and Uttar Pradesh, respectively, and more than 400 people injured. Another SDS process occurred in Khuzestan located at the southwest of Iranian, bordering Iraq and the Persian Gulf on February 18-19, 2018. The wind speed measured ~50 km h^{-1} during the storm. The concentration of dust in the cities of Abadan and Khorramshahr was about 66 times higher than the permitted limit, and the horizontal visibility in these cities decreased to about 100 m.

Table 4 Summary of dust events occurred in China durning 2017-2018

No.	Time Period	Grade	Affected Area
201701	25-26 Jan	BFD[1]	BFD occurred in western Gansu, Ningxia and western Inner Mongolia; SDS occurred in Zhongwei and Zhongning of Ningxia.
201702	19-21 Feb	BFD	BFD occurred in western Gansu, southern Xinjiang and western Inner Mongolia; SDS occurred locally in southern Xinjiang and Inner Mongolia.
201703	12 Mar	BFD	BFD occurred in eastern Xinjiang and southern Xinjiang Basin, western Gansu and western Inner Mongolia.
201704	23 Mar	BFD	BFD occurred in southern Xinjiang Basin, Hexi Corridor of Gansu, western Inner Mongolia and northern Ningxia.
201705	17 Apr	BFD	BFD occurred in western Inner Mongolia, Hexi Corridor of Gansu, and northern Ningxia; SDS occurred locally in western Inner Mongolia.
201706	19 Apr	BFD	BFD occurred in southern Xinjiang Basin, central and western Inner Mongolia and central Gansu.
201707	3-7 May	SDS[2]	BFD occurred in southern Xinjiang Basin, central and western Gansu, Ningxia, Inner Mongolia, northern Shaanxi, northern and central Shanxi, northern Hebei, Beijing, western Jilin, southwestern Heilongjiang, Shandong, Jiangsu, Hubei and northern Hunan; SDS occurred in parts of Inner Mongolia; Severe SDS occurred locally.
201708	28-29 May	BFD	BFD occurred in western Inner Mongolia, western Gansu and southern Xinjiang Basin; Severe SDS occurred locally in Inner Mongolia.
201709	28-29 Dec	BFD	BFD occurred in southern Xinjiang Basin, northern Qinghai, most part of Gansu, western Inner Mongolia and northern Ningxia.
201801	8-9 Feb	BFD	BFD occurred in central and western Inner Mongolia, Gansu, northeastern Qinghai, Ningxia, central and northern Shaanxi, most parts of Shanxi, central and southern Hebei, northern Henan and western Shandong; Severe SDS occurred locally in Inner Mongolia.

201802	14-17 Mar	BFD	BFD occurred in central and southern Xinjiang Basin, central and western Inner Mongolia, Gansu, northern Qinghai, Ningxia, central and northern Shaanxi, southern Shanxi, central and southern Hebei, Henan, western Shandong and northern Hubei. SDS occurred locally in central and southern Xinjiang Basin and Inner Mongolia.
201803	18-20 Mar	BFD	BFD occurred in southern Xinjiang Basin, central and western Inner Mongolia, most parts of Gansu, Northeastern Qinghai and Ningxia; SDS occurred locally in southern Xinjiang Basin and northeastern Gansu.
201804	26-29 Mar	BFD	BFD occurred in central and southern Xinjiang Basin, northern Qinghai, central and western Gansu, northern Ningxia, most parts of Inner Mongolia, central and southern Heilongjiang, most parts of Jilin, western Liaoning, Beijing, Tianjin, most parts of Hebei, eastern Shanxi, central and northern Henan and western Shandong. SDS occurred locally in southern Xinjiang Basin and central of Gansu.
201805	1-3 Apr	Severe SDS	BFD occurred in central and southern Xinjiang Basin, northern Gansu, Ningxia, central and western Inner Mongolia, southern Heilongjiang, western Jilin, northern Shaanxi, eastern Shanxi, most Hebei, most Henan and western Shandong; SDS occurred locally in southern Xinjiang Basin and central of Inner Mongolia; Severe SDS occurred locally in southern Xinjiang Basin.
201806	4-6 Apr	SDS	BFD occurred in central and southern Xinjiang Basin, northern Qinghai, central of Gansu, Ningxia, central and western Inner Mongolia, northern Shaanxi, northern Shanxi and northern Hebei; SDS occurred locally in southern Xinjiang Basin, central of Gansu, central and western Inner Mongolia and northern Hebei; Severe SDS occurred locally in western Inner Mongolia.
201807	9-10 Apr	BFD	BFD occurred in central and western Inner Mongolia, central of Gansu, Ningxia, northern Shaanxi, most parts of Shanxi, southern Hebei, northern Henan and western Shandong; SDS occurred locally in western Inner Mongolia.
201808	13-14 Apr	BFD	BFD occurred in central of Inner Mongolia, northern Shanxi, Beijing, southern Hebei and northern Henan, SDS occurred locally in western Inner Mongolia.
201809	16-17 Apr	BFD	BFD occurred in central and eastern Inner Mongolia, southern Heilongjiang, western Jilin and northern Liaoning.

201810	21-23 May	BFD	BFD occurred in northern Gansu, central and western Inner Mongolia, northern Ningxia and northern Hebei; SDS occurred locally in western Inner Mongolia.
201811	24-26 May	BFD	BFD occurred in central and southern Xinjiang Basin, northern Qinghai, western Gansu, central and western Inner Mongolia, Ningxia, central and northern Shaanxi, most parts of Shanxi and northern Henan; SDS occurred locally in southern Xinjiang Basin and western Inner Mongolia.
201812	17-21 Oct	BFD	BFD occurred in southern Xinjiang Basin, Northwest Qinghai, western Gansu, central and western Inner Mongolia. SDS and Severe SDS occurred locally in southern Xinjiang Basin.
201813	25-27 Nov	BFD	BFD occurred in most parts of Xinjiang, Northeastern Qinghai, most parts of Gansu, Ningxia, northern Shaanxi, most parts of Inner Mongolia, central of Heilongjiang, western Jilin, Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, northern Anhui, northern Hubei; SDS and occurred locally in southern Xinjiang Basin, central of Gansu and western Inner Mongolia.
201814	1-3 Dec	BFD	BFD occurred in central and southern Xinjiang Basin, central and western Gansu, central and western Inner Mongolia, Ningxia, most parts of Shaanxi, Beijing, Tianjin, Hebei, Shanxi, northern Henan and western Shandong; SDS occurred in parts of southern Xinjiang Basin and western Inner Mongolia; Severe SDS occurred locally.

[1] BFD, Blowing and Floating Dust process

[2] SDS, Sand and Dust Strom process

5. Forecast Validation

Figure 3 showed a qualitative comparison with the overlapping of observed dusty weather phenomenon and forecasted dust surface concentrations by each model and mean ensemble forecast during the wide-ranging process occurred in late November and early December. Results showed that most of the single model and mean ensemble forecast could capture the spatial distribution of the process at 6:00 (UTC) on November 26, 2018. But model from NCEP largely underestimated observations in locations with a dust storm.

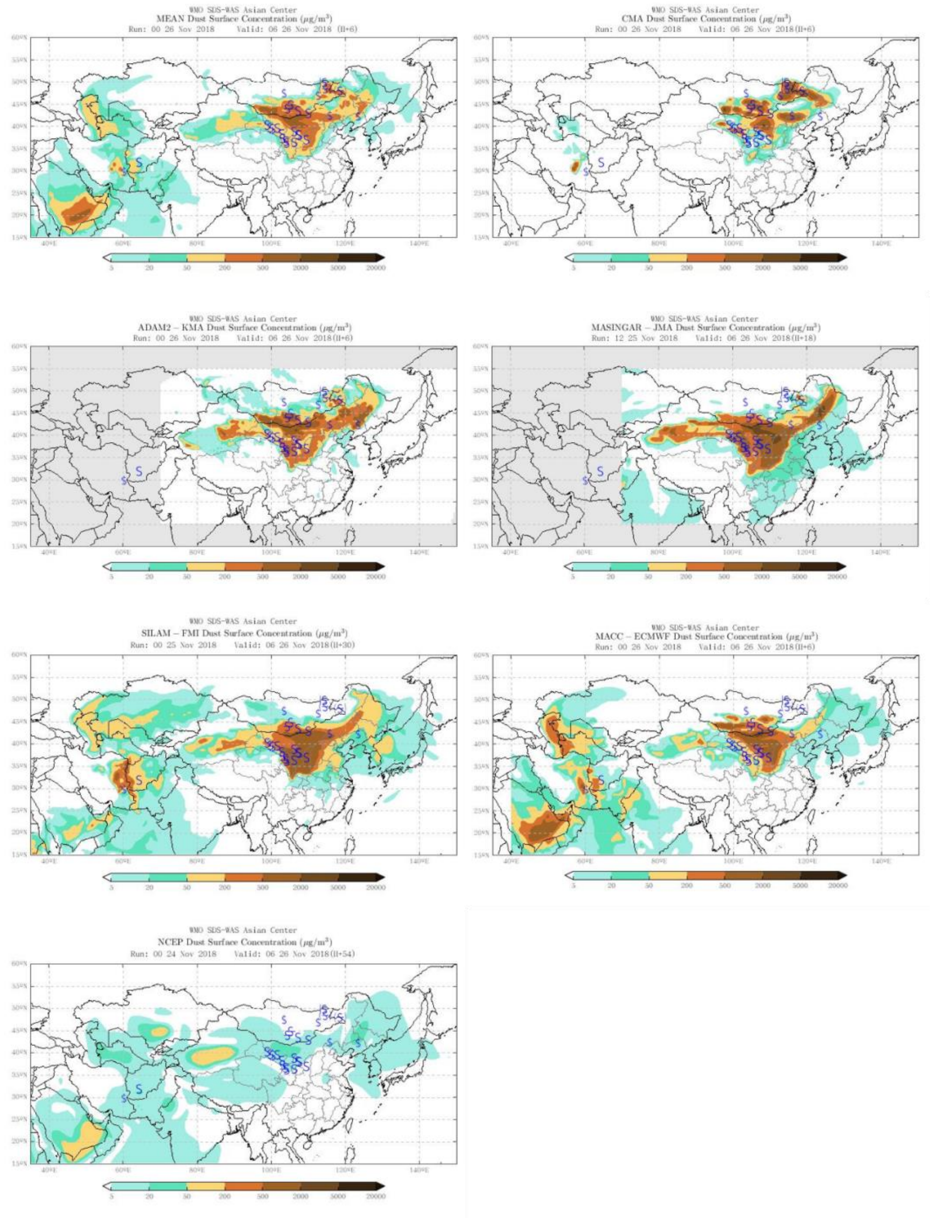

Fig. 3 Overlapping of observed dusty weather phenomenon and forecasted dust surface concentrations (μg m^{-3}) by each model and mean ensemble forecast at 6:00 (UTC) on November 26, 2018

Due to the lack of observation on dust concentration, we compared the time series of observed PM_{10} concentration and forecasted dust concentration by the mean ensemble during a case occurred on April 3-6, 2018, in the city of Yinchuan which is located on the dust transport path (Figure 4). Results showed that the trend of forecasted dust concentration matched well with that of observed PM_{10} concentration with a high correlation coefficient of 0.63. The forecasted occurrence time of the case coincided with observation, but the forecasted peak and end time were 3 hours later than observation. However, the magnitude of the forecasted peak value was much larger than that of the view.

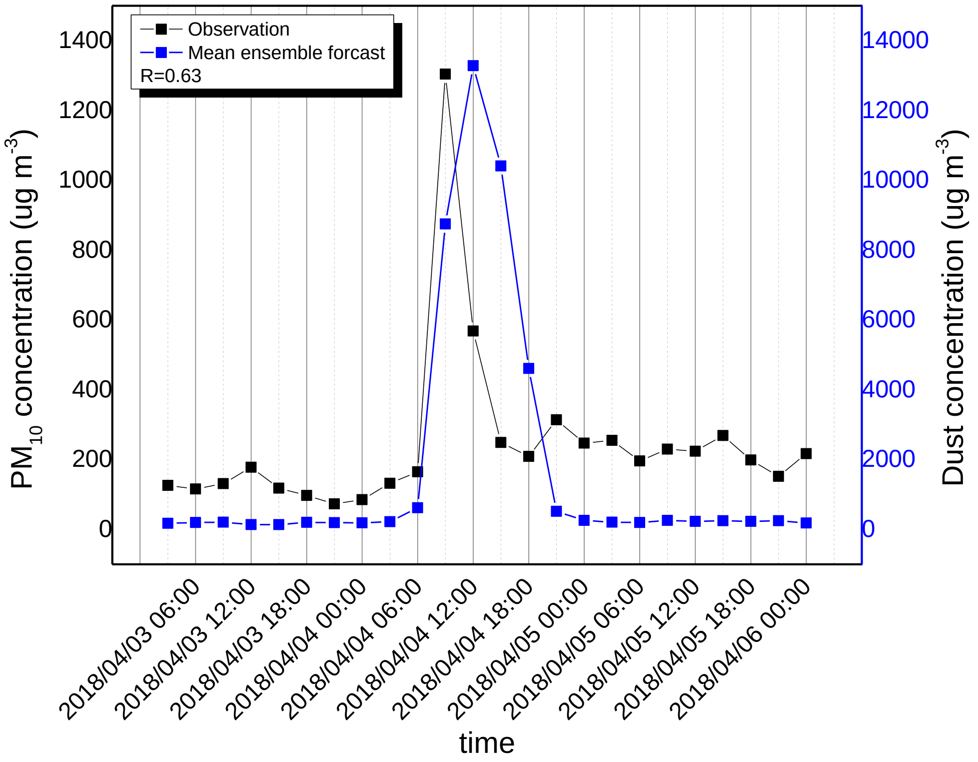

Fig. 4 Time series of observed PM_{10} concentration (μg m^{-3}) and forecasted dust concentration (μg m^{-3}) by a mean ensemble in the city of Yinchuan (38.5 °N, 106.3 °E), Ningxia province during April 3-6, 2018

6. Recent Developments

1) FY-4A/AGRI has more spectral bands (increased from 5 in FY-2 to 14), which will greatly improve object detection (e.g., dust, cloud, aerosol, snow, fire and water bodies) and quantitative retrievals. FY-4A/AGRI will also enhance dynamic monitoring. FY-4A/AGRI's regional observation mode can provide a regional scan each minute. The FY-4A/AGRI dust product can provide dust mask and IDDI (Infra-red Difference Dust Index) which is a semi-quantitative parameter for dust

loading each hour for full disk and 15 minutes for a regional scan. In 2018, the FY-4A/AGRI dust product was assimilated in CUACE/Dust model successfully, which significantly promoted the accuracy of the model and could be as the validation for forecast results.

2) Preliminary gridding observed dust surface concentration dataset in China has been made based on surface site PM_{10} concentration observation, the ratio of dust to PM_{10} concentration and size distribution of dust aerosols using Cressman interpolation method.

3) Multi-model ensemble forecast system for surface concentration of Asian dust has been established based on numerical models from CMA, KMA, NCEP, and ECMWF. As a partial result of ensemble forecast system, the mean ensemble forecast has been shown on the portal site.

4) The format of all products on the portal site has been unified.

5) A data sharing international ftp has been established, and its accounts have been dispensed to member countries. Daily data files of all dust forecast models and ensemble forecast are consistently uploaded.

6) A new version of the portal site（http://www.asdf-bj.net） has been designed and discussed on the 6th Meeting of WMO SDS-WAS RSG for Asia. It will be launched in 2019.

7. International Activities and Training

1) The 9th International Workshop on Sand / Dust storm and Associated Dustfall (http://dustworkshop9.net/) was held in Tenerife, Spain, from 22 to 24 May 2018. Three experts from RSMC-ASDF Beijing participated in the meeting and exchanged the latest research results with experts from 37 countries.

The dustworkshop9 is a scientific forum to analyze and discuss the state of the art research on dust, its connections to air quality, environmental impacts and climate. The dustworkshop9 developed by seven different sessions which cover broad topics of dust: Sources and transport of dust, Dust impacts, Dust composition and properties, Dust, radiation and clouds, Dust and the ocean, Dust at different scales and Dust forecast and services.

2) The 4th meeting of WMO SDS-WAS Steering Committee was held in Laguna, Canary Islands, Spain, from 25 to 26 May 2018. Zhang Xiaoye form CAMS, CMA

was elected as new chair of the Steering Committee of SDS WAS.

SDS-WAS was established in 2007 responsing to the intention of 40 WMO member countries to improve capabilities for more reliable sand and dust storm forecasts. Research forecasting products from atmospheric dust models may considerably contribute to risk reduction in many areas of societal benefit. More than 15 organizations currently provide daily dust forecasts in different geographic regions (https://www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html).

3) The 6th Meeting of the Asian Regional Steering Group of WMO Sandstorm Early Warning Advisory and Assessment System (WMO SDS-WAS RSG for Asia) and the International Dust and Aerosol Workshop were held in Tsukuba, Japan, from 19 to 21 November 2018.

Experts from participating countries reported on various fields of sand storm research and operational center development and discussed the current status, challenges, and future work of WMO SDS-WAS. The meeting agreed that member states need to strengthen cooperation in scientific research and business, and focus on data assimilation and sharing, dust monitoring, model performance evaluation, regional centers website construction, dust training and technical exchanges with other regional operational centers.

4）Each year, RSMC-ASDF Beijing in cooperation with WMO RTC Beijing and Nanjing jointly organize several training courses on NWP model products and interpretation, FY Satellite application, aeronautic meteorolgocial services, and SDS forecasting products application is one of very important components of those courses.

8. Users

The RSMC-ASDF Beijing conducts regular monitoring of website access. The results (Table 6) show the number of page views and unique visitor.

Table 6 Overview of web access in 2018

Season	**Page views**	**Unique visitor**
Jan. – Mar.	9405	864
Apr. – Jun.	15402	1422
Jul. – Sep.	25340	2566
Oct. – Dec.	17523	1291
Total	67670	6143

9. Publications

An Linchang, Che Huizheng, Xue Min, et al., 2018. Temporal and spatial variations in sand and dust storm events in East Asia from 2007 to 2016: Relationships with surface conditions and climate change. *Science of The Total Environment*, 633: 452-462.

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Zhang Tianhang, Zhang Hengde, Zhang Bihui, et al., 2018. Multi-model ensemble forecast system for surface-layer $PM_{2.5}$ concentration in China. Signal and Information Processing, Networking and Computers. ICSINC 2018, Singapore, Springer, 550:462-470