



WMO REGIONAL SPECIALIZED METEOROLOGICAL CENTER
FOR ATMOSPHERIC SAND AND DUST STORM FORECASTING

BEIJING

(RSMC-ASDF BEIJING [HTTP://WWW.ASDF-BJ.NET/](http://www.asdf-bj.net/))

ANNUAL REPORT

2023-2024

2025

TABLE OF CONTENTS

1. Model introduction	1
2. Model evaluation	2
3. Data sharing	4
4. System implementation	4
4.1 Operational Status of the CMA CUACE Dust Model	4
4.2 Analysis of Operational Failure Types	5
4.3 Website Access	5
5. Technical progress	7
5.1 Integrating machine learning with multi-numerical models	7
5.2 Modeling for the source apportionments of PM10	8
5.3 Stone coverage effects	9
5.4 Seasonal dust forecasting	10
6. International Activities	11
6.1 The 9th WMO SDS-WAS Asian Regional Steering Committee meeting	11
6.2 The first International Day of Combating Sand and Dust Storms	12
6.3 WMO 10th SDS-WAS Asian Regional Steering Committee meeting	13
7. Authors	13

1. Model introduction

The WMO Regional Specialized Meteorological Center for Atmospheric Sand and Dust Storms currently operates six operational dust models, supplemented by a multi-model ensemble system. Key forecast parameters include surface dust concentration, 550nm AOD, total dust load, and 3-hour dry/wet deposition. The following section details the specific configurations and parameters of each modeling system employed at the center.

Table 1. Key parameters of the operational dust models at RSMC-ASDF BEIJING

Parameter	Area	Models	Resolution	Forecast range	Time steps	Frequency
Dust load ($\text{kg}\cdot\text{m}^{-2}$)	10-60°N, 30-150°E	CMA	0.5°	7 days	3 hour	2 /day
		KMA	0.5°	5 days	3 hours	2 /day
		JMA	0.5°	3 days	3 hours	1 /day
		NCEP	0.5°	5 days		
		ECMWF	0.5°	3 days		
		FMI	0.2°	7 days		
Dust concentration at the surface ($\mu\text{g} \cdot \text{m}^{-3}$)	10-60°N, 30-150°E	CMA	0.5°	7 days	3 hour	2/day
		KMA	0.5°	5 days	3 hours	2/day
		JMA	0.5°	3 days	3 hours	1 /day
		NCEP	0.5°	5 days		
		ECMWF	0.5°	3 days		
		FMI	0.2°	7 days		
		Ensemble	0.5°	3 days		
Dust optical depth at 550 (nm)	10-60°N, 30-150°E	CMA	0.5°	7 days	3 hour	2 /day
		KMA	0.5°	5 days	3 hours	2 /day
		JMA	0.5°	3 days	3 hours	1 /day
		NCEP	0.5°	5 days		

		ECMWF	0.5°	3 days		
		FMI	0.2°	7 days		
Three-hour accumulated dry and wet deposition (kg·m ⁻²)	10-60°N, 30-150°E	CMA	0.5°	7 days	3 hour	2 /day
		KMA	0.5°	5 days	3 hours	2 /day
		JMA	0.5°	3 days	3 hours	1 /day
		NCEP	0.5°	5 day ³		
		ECMWF	0.5°	3 days		
Further information						
Web portal	http://www.asdf-bj.net					

2. Model evaluation

In the spring of 2023, most models demonstrated reasonably good performance, with the exception of NCEP. Due to its prevalence of anomalously low values, NCEP was excluded from the evaluation. Overall, based on the spatial distribution of PM₁₀ averages, the outputs from CMA, KMA, and the Ensemble model aligned more closely with observations.

However, in some instances—such as over Inner Mongolia—CMA, JMA, and the Ensemble model overestimated surface dust concentrations relative to actual measurements. Conversely, KMA tended to underestimate dust levels in the Taklamakan Desert. Throughout the spring, CMA's forecasts of dust concentrations in certain regions, particularly the Southern Xinjiang Basin and western Inner Mongolia, showed remarkable consistency with observations. Other operational models also exhibited high accuracy and reliability in China's major dust source regions.

In downstream areas such as Beijing, Hebei, and Shandong, however, the predicted dust intensity tended to weaken progressively, leading to a growing discrepancy between forecasts and observations—a pattern similarly seen in models such as FMI.

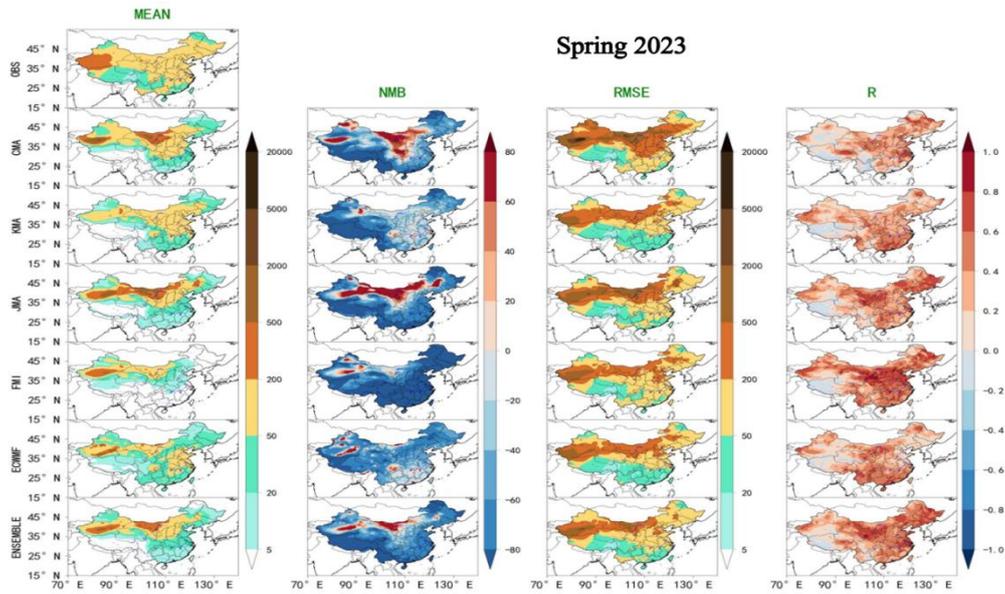


Figure 1. Model performances in the spring of 2023

During the spring of 2024, the outputs from CMA and JMA showed closer agreement with observations. However, these models occasionally overestimated surface dust concentrations in Xinjiang and Inner Mongolia. In contrast, the KMA model consistently produced lower values than observed in the Taklamakan Desert, Gansu Province, and Northeast China. Furthermore, the FMI and Ensemble models significantly underestimated dust concentrations in downstream areas, including North China, the Huanghuai region, and Northeast China.

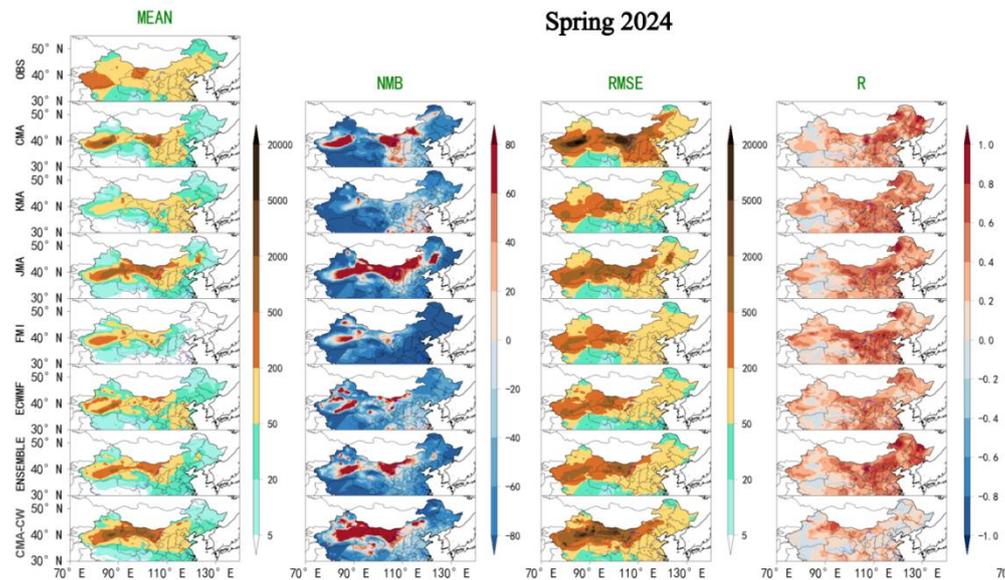


Figure 2. Model performances in the spring of 2024

A typical dust event in 2024 was selected for model evaluation. Overall, the four dust models produced relatively consistent predictions regarding the initial dust source regions and the subsequent transport pathways. Nevertheless, substantial

discrepancies were observed in key aspects such as the intensity of dust emission, the magnitude of downstream transport, and the occurrence of secondary dust uplift from source regions. The CMA and JMA models demonstrated commendable accuracy in simulating areas of high dust concentration, while KMA showed notable excellence in forecasting the extent of dust-affected areas in downstream regions. A notable limitation, however, was the systematic underprediction of secondary dust uplift from Mongolian source regions, which was observed across all models to varying degrees.

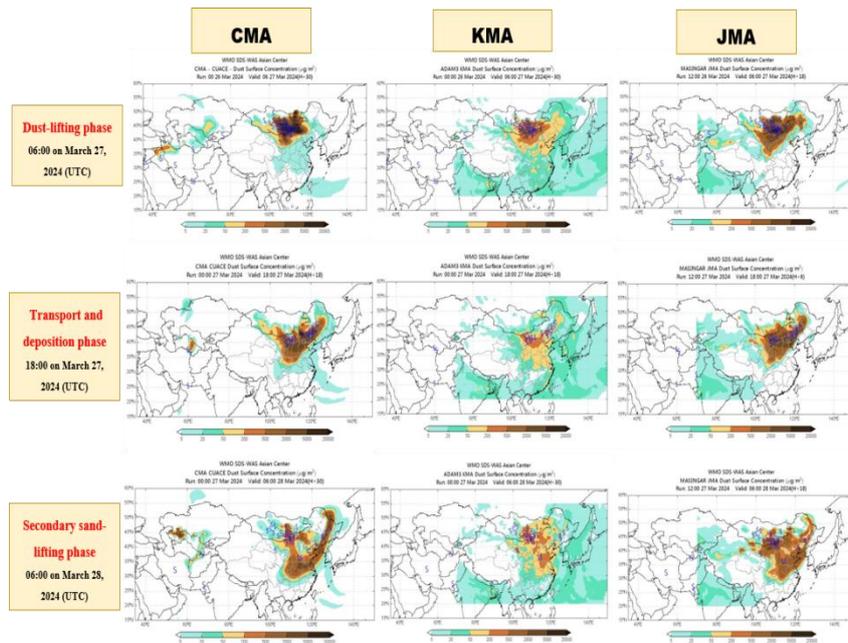


Figure 3. Model performances in a typical dust event in 2024

3. Data sharing

RSMC-ASDF Beijing launched an international data-sharing FTP site (<ftp.nmc.cn>) in early 2019. The platform provides daily access to Asian regional forecast outputs from dust numerical models operated by CMA, KMA, JMA, ECMWF, NCEP, and FMI, along with PM₁₀ concentration observations from selected sites in Mongolia. Member countries maintain full administrative control over their respective directories while being granted download-only access to directories of other members. The system currently offers 3 TB of storage capacity, with planned expansions to be implemented according to operational demands.

GISC-Beijing also runs an archiving and retrieval system, providing access to the CMA CUACE Dust model.

4. System implementation

4.1 Operational Status of the CMA CUACE Dust Model

From 2023 to 2024, the CMA CUACE Dust model experienced a total of seven operational failures, including:

- 4 failures caused by data issues,
- 1 failure due to an upstream model malfunction,
- 1 failure resulting from hardware (machine) issues, and
- 1 failure caused by full disk space.

Overall, the model itself operated stably, with no instances of numerical overflow occurring.

4.2 Analysis of Operational Failure Types

The primary operational failures were caused by data issues, accounting for 57%, mainly due to the absence of FY-4A data, which led to system failures.

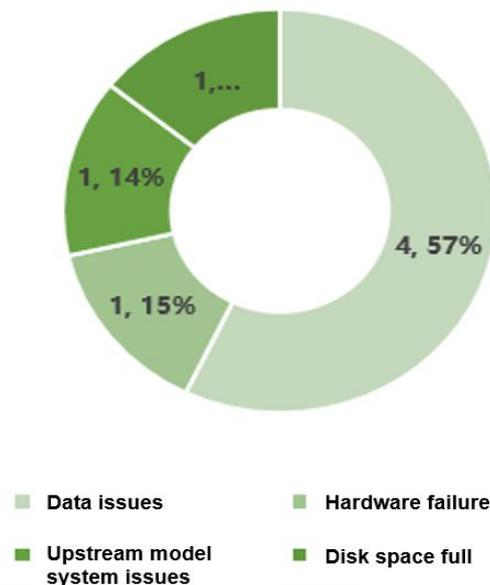


Figure 4. Operational Performance of the CUACE Dust Model in 2023–2024

4.3 Website Access

RSMC-ASDF Beijing routinely monitors its website traffic. The statistical results (Table 2) show the total page views and number of unique visitors.

Analysis of the pie chart reveals that in 2023, the annual visit count reached 180,000, with the primary traffic sources being China, followed by India, South Korea, the United States, and Japan. Visits from China significantly outnumbered those from all other countries combined. In 2024, the total number of visits saw a slight increase over the previous year but remained generally stable at around 180,000. The ranking

of the top five visiting countries stayed unchanged, with the traffic distribution continuing to be dominated by China.

This pattern confirms that the portal has been effective in supporting dust monitoring, forecasting, and early warning operations. However, the heavy concentration of visits from China also indicates a need to enhance international promotion efforts. Expanding the global user base would further strengthen the role of WMO RSMC-ASDF Beijing in dust disaster prevention and mitigation worldwide.

Table 2. Overview of web access in 2023

Season	Page views (PV)	Unique visitor (UV)
Jan. – Mar.	46671	39343
Apr. – Jun.	77539	67070
Jul. – Sep.	26015	22554
Oct. – Dec.	35780	32268
Total	186005	161235

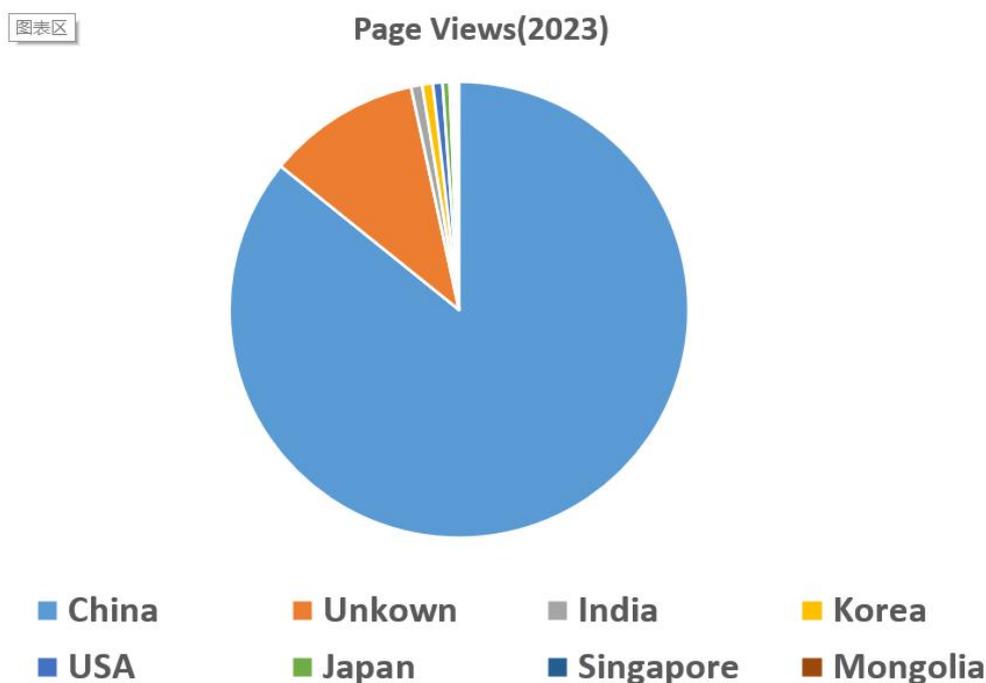


Figure 5. Statistics on the number of visits to RSMC-ASDF BEIJING in 2023

Table 3. Overview of web access in 2024

Season	Page views (PV)	Unique visitor (UV)
Jan. - Mar.	58302	49786
Apr. - Jun.	59157	51822
Jul. - Sep.	34780	31316
Oct. - Dec.	36886	33730
Total	189125	166654

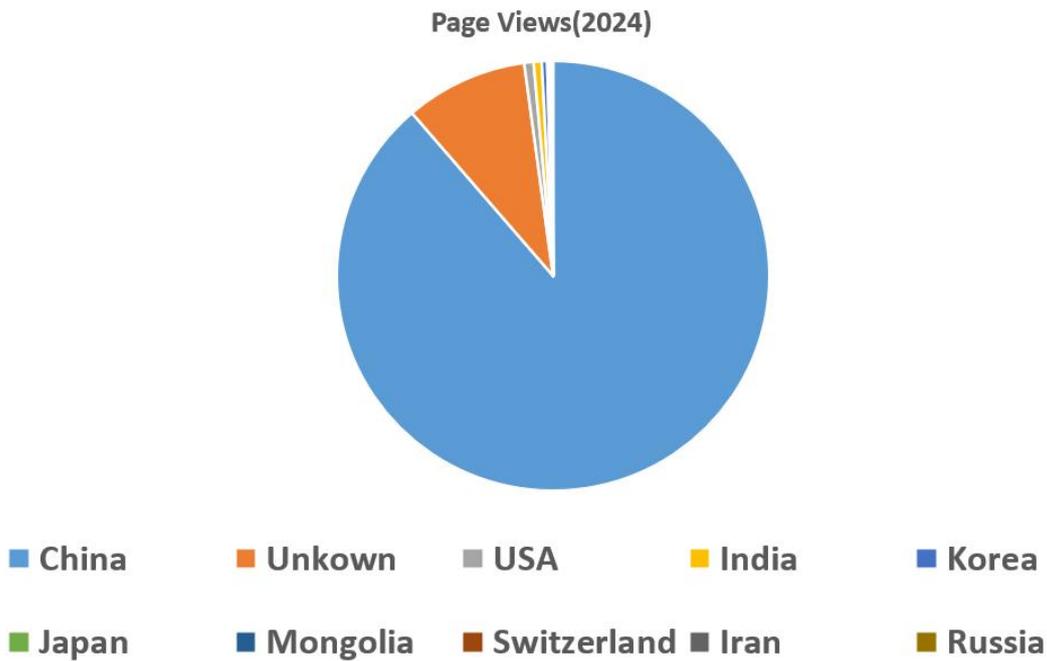


Figure 6. Statistics on the number of visits to RSMC-ASDF BEIJING in 2024

5. Technical progress

5.1 Integrating machine learning with multi-numerical models

An integrated dust concentration correction model (ML-SDC) was developed by CMA researchers which significantly improved forecasting accuracy and stability by combining multi-source numerical models with machine learning. Evaluation using datasets from February to May 2023 demonstrated that ML-SDC outperformed traditional numerical models, conventional ensemble correction methods, and single machine learning models in terms of correlation coefficient (R), root mean square error (RMSE), and mean absolute error (MAE) (Figure X). For 3–72-hour forecasts, ML-SDC improved the correlation coefficient from approximately 0.5 to 0.78, reduced RMSE from over 140 $\mu\text{g}/\text{m}^3$ to 91.49 $\mu\text{g}/\text{m}^3$, and lowered MAE from over 60

$\mu\text{g}/\text{m}^3$ to $36.91 \mu\text{g}/\text{m}^3$. Spatially, ML-SDC maintained stable performance in dust source regions and complex terrain, achieving correlation coefficients of 0.75–0.78, and significantly reducing RMSE (by $55.75\text{--}147.4 \mu\text{g}/\text{m}^3$) and MAE (by $40.89\text{--}64.08 \mu\text{g}/\text{m}^3$). For extreme events, such as the March 20–23, 2023 severe dust storm, ML-SDC accurately captured the entire event's progression, effectively characterizing the spatiotemporal distribution of dust concentrations.

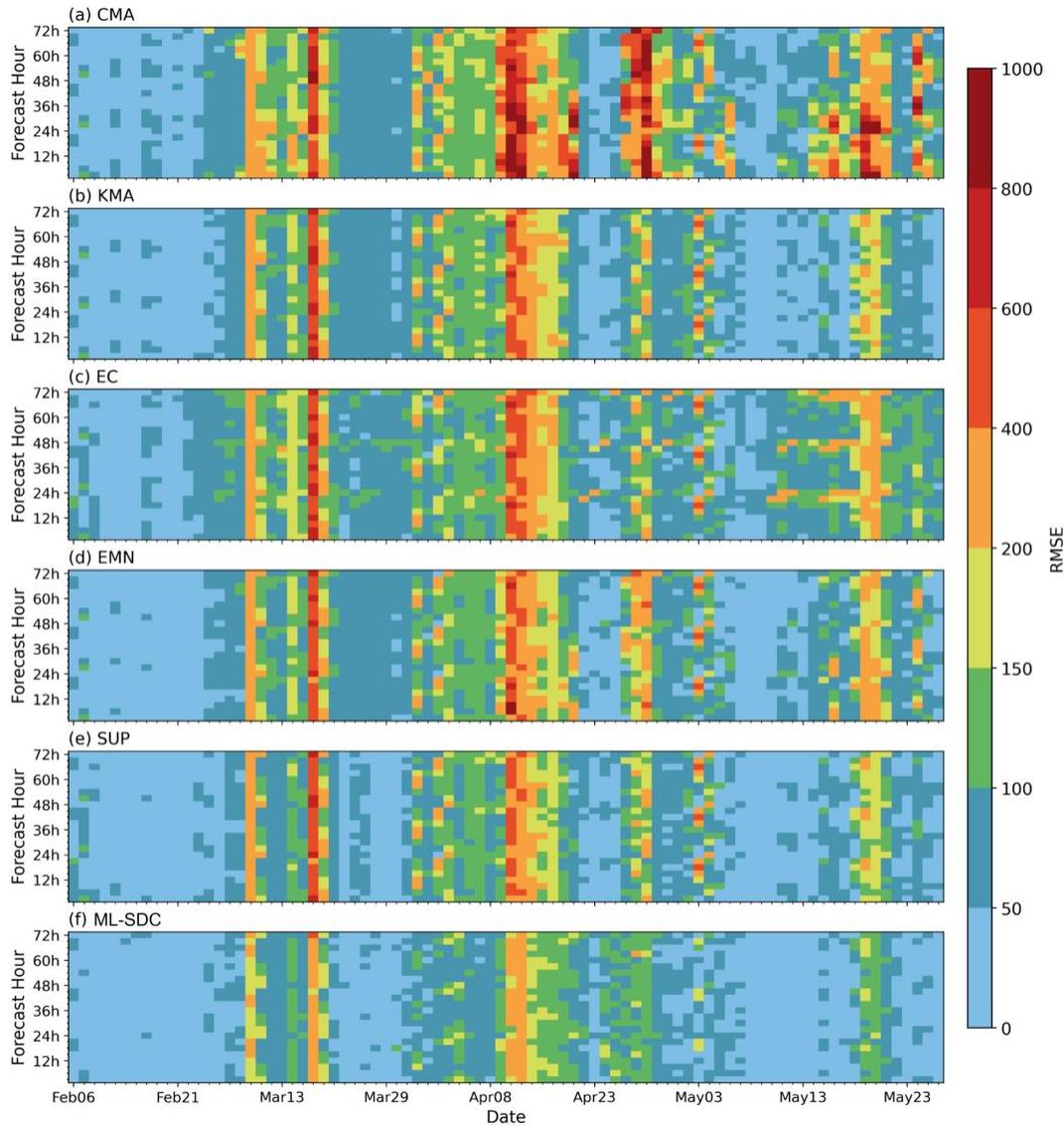


Figure 7. The daily area-averaged RMSE ($\mu\text{g}\cdot\text{m}^{-3}$) evolutions of the 3–72 h SDC forecasts from the (a) CMA, (b) KMA, (c) EC, (d) EMN, (e) SUP and (f) ML-SDC from February to May 2023

5.2 Modeling for the source apportionments of PM₁₀

A tagged tracer method was employed to quantify emissions from distinct dust source regions and to assess their contributions to surface dust concentrations. In this approach, the dust numerical model is augmented with sets of non-reactive tracer

species, each uniquely "tagged" to represent dust emitted from a specific geographic region. These tracers undergo the same physical processes as the primary dust species—such as advection, diffusion, dry/wet deposition. By tracking the evolution of each tagged tracer throughout the simulation, the model can apportion the total surface dust concentration into contributions originating from each predefined source region. This technique enables detailed source-receptor analysis, supporting policy decisions and mitigation strategies targeting major dust-emitting areas.

The Gobi deserts in Mongolia were the most important sources of sand and dust in East Asia, with the highest dust emissions, contributing more than 60% to the PM₁₀ concentrations over East-Central China, Japan, and South Korea (Figure 8). The dust emission from Inner Mongolia was about 1/3 of that in Mongolia, and contributed 20-30% to PM₁₀ concentrations over East-Central China, Japan, and South Korea. Few dust aerosols from Taklimakan and Eastern Xinjiang could be transported to the areas further than its surrounding area. Anthropogenic emissions contributed less than 5% to the PM₁₀ concentrations over most part of East Asia during the SDS events.

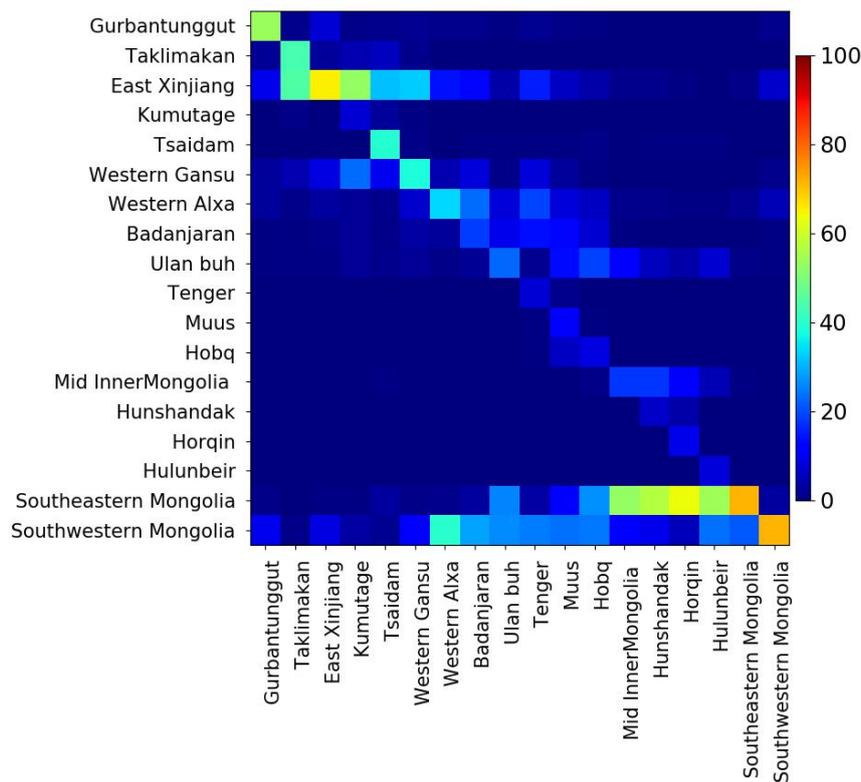


Figure 8. The contributions of the dust emissions to the average PM₁₀ concentrations in the 18 dust source regions during SDS events (x axis is the receptor regions and y axis is the dust emission sources).

5.3 Stone coverage effects

More than 50% of Earth’s deserts are covered with stones, which suppress SDSs. Since dust particles influence climate change, studying these surfaces is crucial. For the first time, a SDS simulation scheme including a stony surface effect was tested by Sekiyama et al. (2023). The mathematical formulation of the stony surface effect was based on observations in East Asia and data from the SoilGrids 2.0 set. The meteorological and dust simulations were performed from 0000 UTC on 29 April 2017 to 0000 UTC on 7 May 2017. They reproduced fewer dust storms in areas with higher stone coverage and more in areas with lower coverage. This simulation result was consistent with SYNOP observations from weather stations in China and Mongolia (Figure 9). In addition, satellite measurements for air pollution also supported these observations and simulation results. This study is the first successful investigation of the stony surface effects on dust storm simulations using a realistic stone coverage map.

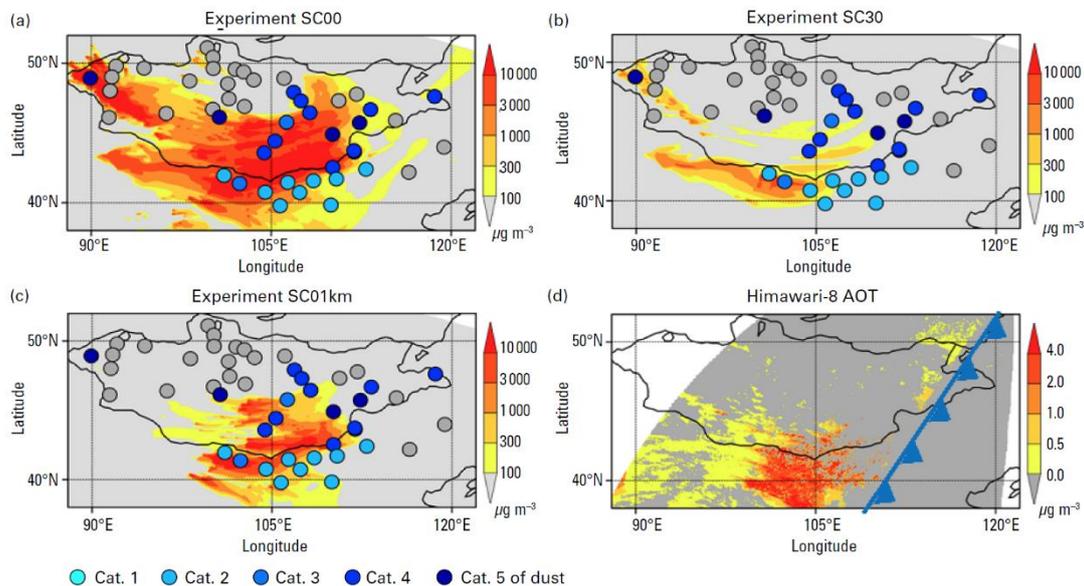


Figure 9. Modelled surface dust concentrations ($\mu\text{g m}^{-3}$) and SYNOP observatory dust reports (blue circles) at 0900 UTC on 3 May 2017 for (a) the stone-free experiment, (b) the 30% uniform stone-coverage experiment, and (c) the 1 km gridded stone coverage experiment. The 30% stone coverage is the average for the Gobi Desert. The gray circles indicate the observatories that reported anything but dust events. (d) The aerosol optical thickness observation from the Himawari-8 satellite at the same time with the approximate location of the cold front.

5.4 Seasonal dust forecasting

The Korea Meteorological Administration (KMA) has incorporated a sand and dust emission process into its operational climate prediction model (the Global Seasonal Forecasting model version, GloSea6). Since August 2022, KMA has been operating a real-time system for calculating dust PM_{10} concentrations, which are taken into account in Asian dust forecasts. In 2023, using the model’s output, KMA produced

information for Asian seasonal dust forecasting in the Republic of Korea during spring, categorizing it as “above normal”, “near normal” and “below normal” compared to the mean value of the GloSea6’s climate period (1993 to 2016). The observed mean number of Asian dust days during the spring of 2023 in the Republic of Korea was 19, placing it in the “above normal” category. The predicted value was 9.78, also falling into the “above normal” category. The spatial pattern of the predicted data indicates an increase in the number of Asian dust days in the southern region of the Republic of Korea, with most areas classified as “above normal”, consistent with the observed results (Figure 10). This outcome verifies the capability of GloSea6 in generating output to produce information for Asian dust seasonal forecasting in spring. KMA has established the capability to perform Asian seasonal dust forecasting at any time by continuously producing Asian dust forecast information.

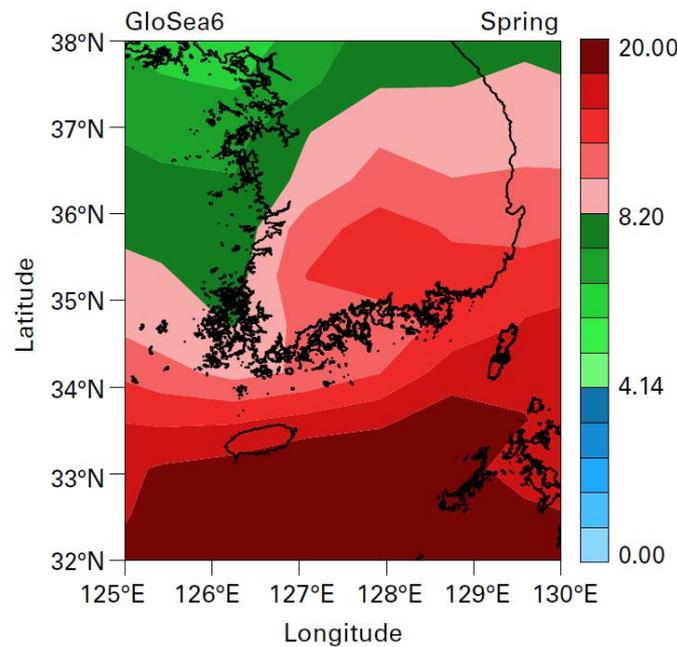


Figure 10. Spatial distribution of predicted Asian dust days in the Republic of Korea for the spring of 2023. The three contour colours represent three categories for Asian seasonal dust forecasting: “above normal” (red), “near normal” (green) and “below normal” (blue).

6. International Activities

6.1 The 9th WMO SDS-WAS Asian Regional Steering Committee meeting

From October 30 to November 1, 2023, the WMO 9th SDS-WAS Asian Regional Steering Committee meeting was held in Tokyo, Japan. Hosted by the Japan Meteorological Agency(JMA), the meeting gathered over 30 experts and scholars from 6 member countries, namely China, Japan, South Korea, Mongolia, Kazakhstan, and India, who participated both online and offline. Each of the six countries provided

an update on their recent national sand and dust storm monitoring, forecasting, and research activities in their national reports. And Sara Basart, representative from WMO introduced the situation surrounding SDS, mentioning the recent intensification of efforts against sand and dust storms in the UN.



Figure 11. The 9thWMO 9th SDS-WAS Asian Regional Steering Committee meeting

6.2 The first International Day of Combating Sand and Dust Storms

On July 12, 2024, the WMO Regional Association II and the RSMC-ASDF jointly held a seminar themed "International Day against Sand and Dust Storms - Sand and Dust Storm Monitoring and Forecasting". Nearly 50 experts from WMO Secretariat, Japan, Saudi Arabia, Iran, and CMA attended the meeting. On behalf of the Asian Sand and Dust Storm Forecasting Regional Specialized Meteorological Center (ASDF -RSMC Beijing), Zhang Bihui from the CMA briefly reviewed the establishment and development history of the Asian Dust Center, introduced the recent technological research, operational services, and future work plans. Experts from Japan, Saudi Arabia, and Iran respectively shared the progress of their work. The participating experts discussed the application of artificial intelligence technology in sand and dust storm forecasting, the needs for developing early warning systems for sand and dust storms in Western Asia, and explored issues such as the construction of sand and dust sub-centers in Western Asia.

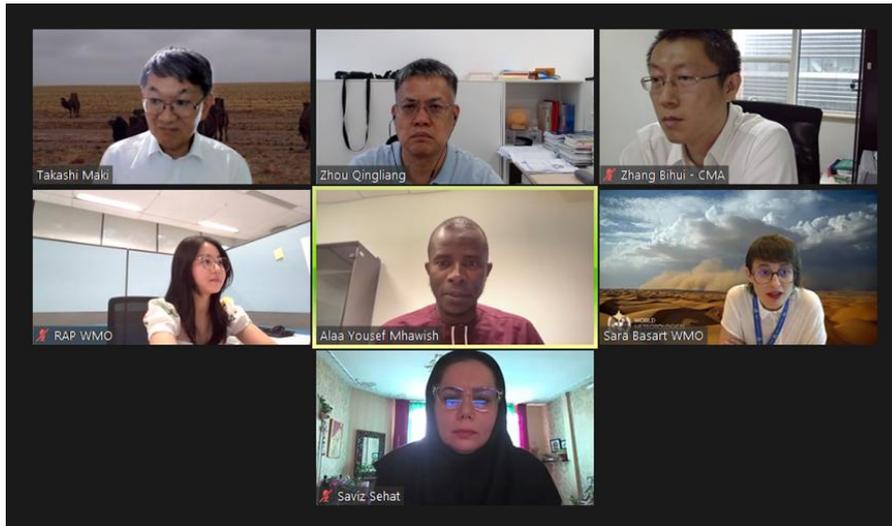


Figure 12. WMO 9th SDS-WAS Asian Regional Steering Committee meeting

6.3 WMO 10th SDS-WAS Asian Regional Steering Committee meeting

From September 23 to 24, 2024, the WMO 10th SDS-WAS Asian Regional Steering Committee meeting, alongside the Workshop on sand and dust storm, was convened in New Delhi, India. Hosted by the India Meteorological Department, the event gathered over 40 experts and scholars from China, Japan, South Korea, Mongolia, India, and other countries, participating both online and in person. Five member countries provided their updates on recent national sand and dust storm monitoring, forecasting, and research activities in their national reports.

From Gulf Cooperation Council (GCC) node and Pan American node, they reported current progress from each node. The RSG welcomed and consider future cooperations.

7. Authors

Hailin Gui, Cong Hua, Ran Xu, Jikang Wang, Yanzhe Zhao, National Meteorological Centre (NMC) , CMA

Yitao Wang, Jikai Hu, CMA Earth System Modeling and Prediction Centre (CEMC) , CMA

Chunhong Zhou, Chinese Academy of Meteorological Sciences (CAMS) , CMA

Hyun-Suk Kang, National Institute of Meteorological Sciences, KMA

Takashi Maki, Meteorological Research Institute, JMA