**WMO/WWRP**

SAND AND DUST STORM

WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

**TECHNICAL REPORT ON ASIAN REGIONAL CENTRE**

March 2015

# Contents

# 1  Background

## 1.1 Motivation for Dust Forecasting in Asia

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 (Zhang et al., 2003b), the source strength of Asian SDS was estimated to be 800 Mt/year (Zhang et al., 1997) with very high spatial and temporal variability from year to year (Gong et al., 2006a). 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 economical 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 14th 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. 1-1). 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.
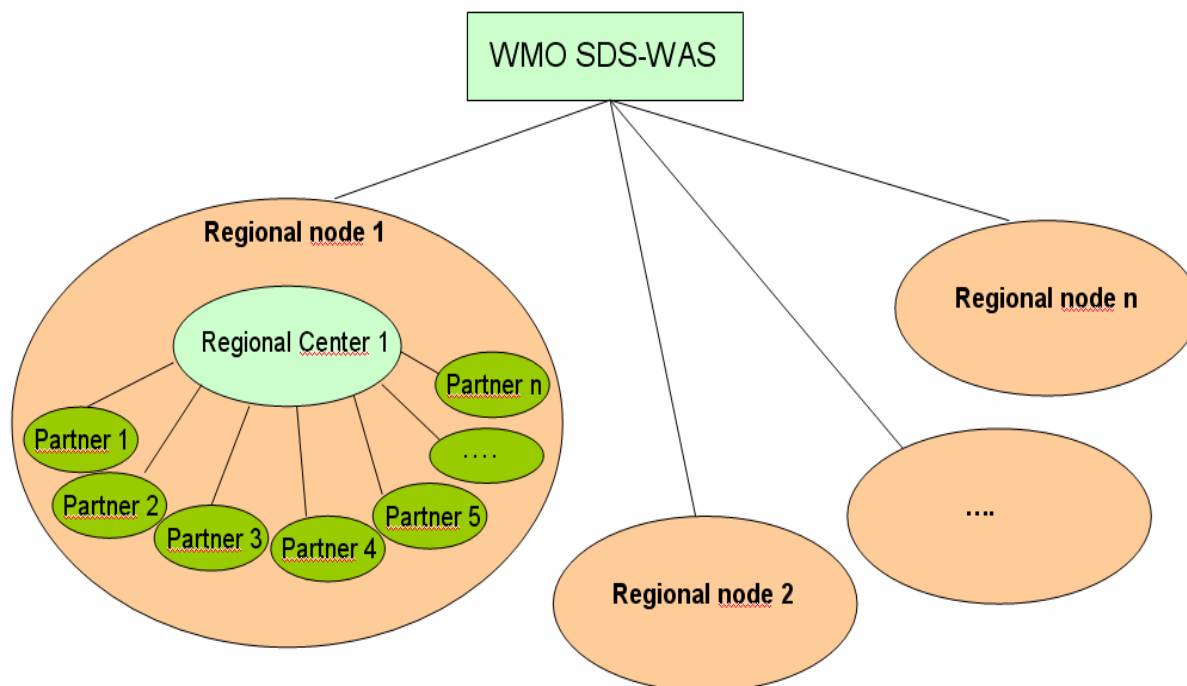
Fig.1-1 The international network of SDS-WAS

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.

### 1.2 History of Asian Regional Centre

In May 2007, the 14th WMO Congress endorsed the launching of the SDS-WAS. Two Regional Nodes were established with the support of    two Regional Centres, the Asian Regional Centre and the African Regional Centre.

The Asian Regional Centre (Asian-RC) supports a node in a global network of SDS-WAS research and operational partners implementing SDS-WAS objectives in the Asian region. The Host Country of Asian-RC is China (CMA). The Member Countries include Korea, Japan, Mongolia and Kazakhstan. The Asian-RC works under the guidance of regional RSG of SDS WAS.    The first meeting of the Asian Node "SDS Regional steering group was held in Beijing in October 2008, the second in Seoul, October 2009, and the third in Japan in March 2012. The major objective of Asian-RC is to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts through an international partnership in research and operations.

Since 2011, WMO has been encouraging CAS and CBS efforts to specify an optimal concept of transferring research on numerical dust forecasting to operational activity. (16th WMO Congress, 2011), and achieve rapid transition from research to operational forecasting (61st Executive Council, 2011). At this moment, there are three SDS forecasting systems  in operation  at three organizations in Asia including the Model of Aerosol Species in the Global Atmosphere (MASINGAR) in JMA (Tanaka et al. 2003) providing global SDS forecasts, the Asian Dust Aerosol Model – ADAM (Park and In, 2003) in KMA, and an integrated atmospheric chemistry modelling system applied for dust (CUACE/Dust)  in CMA providing SDS forecasts for Asia (Zhou et al., 2008, and see also special issue in Atmospheric Chemistry and Physics at

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). Researches have shown that the existing dust forecasting models possess a certain degree of skills to forecast a general picture of a dust episode in Asia.

## 2    Forecasting Models in Asian Node

Within the Asian node, there are one global and two regional models for operational running to do the dust forecast. In order to facilitate the development of the forecasting techniques and to improve the forecast accuracy within Asia Nodes, exchange of the output of model forecast and their inter-comparisons are of great importance. Results of forecast within Nodes (China, Korea and Japan, at the present) have been shared and mutually referred via web-portal of the regional node centre (http://eng.weather.gov.cn/dust/ ) with CAS framework of SDS WAS. Ad-hoc members who will be involved in model comparisons have been recommended at the RSG. the current coordinators are T. Maki (JMA), Jong-Chul (KMA) and Zhou Chunhong (CMA), respectively. The working group will work continuously in future possible RSMC-ASDF under the CBS framework of SDS-WAS.

### 2.1  JMA Operational Global Dust Forecast Model

The Japan Meteorological Agency (JMA) has been providing the "Aeolian Dust Information" to the general public via its website (http://www.jma.go.jp/en/kosa/ ) since January 2004. The former operational numerical dust forecast in JMA was based on the Model of Aerosol Species in the Global Atmosphere (MASINGAR) (Tanaka et al. 2003), which is directly coupled with the MRI/JMA98 AGCM. JMA has updated the operational dust forecast model (MASINGAR-mk2) to be based on the latest global climate model MRI-AGCM3 (Yukimoto et al. 2012) since November 2014. The model is coupled with the Scup coupler library (Yoshimura and Yukimoto 2008). MASINGAR mk-2 treats five aerosol species: non-sea-salt sulfate, BC, OC, sea-salt, and mineral dust. The operational version of MASINGAR mk-2 calculates the emission flux of dust as a function of the friction velocity, soil moisture, soil type, snow cover and vegetation cover. Dust particles are logarithmically divided into 10 discrete size-bins from 0.1 to 10 µm in radius. Horizontal resolution of the MASINGAR mk-2 is set as TL 159 (about 120 km). JMA has a plan to upgrade horizontal resolution of the model to TL319 (about 60km) from 2016. JMA also has a plan to introduce data assimilation technique (LETKF) into MASINGAR mk-2 from 2019.

### 2.2  KMA Operational Regional Dust Forecast Model

The Asian Dust Aerosol Model (ADAM) in the Korea Meteorological Administration (KMA) was developed in 2003 as an operational forecasting model (http://web.kma.go.kr/eng/weather/asiandust/forecastchart.jsp). It was first modified to ADAM1 based on dust source regions in northern China. It is a Eulerian dust-transport model that includes specifications of dust source regions, delineated by a statistical analysis of WMO dust-reporting data and statistically derived dust emission conditions in sand, gobi, loess and mixed soil surfaces. The dust emission flux is assumed to be proportional to the fourth power of the friction velocity due to modifications of land use types in each source-grid region. It uses the suspended particle size distribution parameterized by the several log-normal distributions of the soil particle-size distribution in the source regions, based on the concept of minimally and fully dispersed particle-size distribution. Later it was still modified to ADAM2, with enhanced ability to deliver timely and quality sand and dust storm forecasting to all Asian countries that might be affected by dust storms(Park, Choe et al. 2010b). ADAM2 model utilizes a Normalized Difference Vegetation Index (NDVI) obtained from spot vegetation data.

### 2.3  CMA Operational Regional Dust Forecast Model

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. 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).

## 3    Forecasting Capacity and Effect in Asian-RC

Within the Asian Regional Centre (Asian-RC), CUACE/Dust forecasting system has been operationally run  in support of Asian node research and operational partners implementing SDS-WAS objectives in Asian region since 2007. The forecast capacity, activities and effect are described in details in  this section.

### 3.1 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.

### 3.1.1    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.

### 3.1.2    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.

### 3.1.3    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. 3-1) and 31 vertical sigma-levels up to 10hPa.
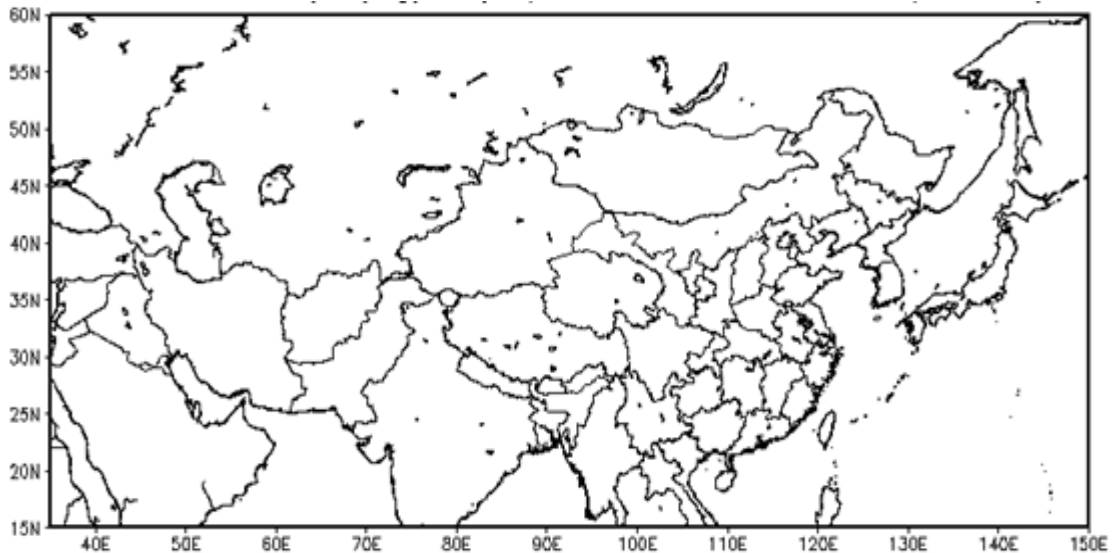
Fig.3-1 The domain of CUACE/Dust (15-60N,35-150E)

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.

## 3.2 Threat Score System for Verification of Dust forecast Effect

In order to evaluate the performance of the dust forecasting effect, a threat scoring system was developed where observations from various sources concerning dust aerosol in Asian-RC had been integrated into a GIS (Geographic Information System) (Wang et al., 2008). Surface regular weather phenomena which can directly indicate the occurrence of a SDS and satellite retrieved IDDI (Hu et al., 2008) with a value above 20 defined as a SDS was used to construct the observational truth of a SDS or non-SDS. However, both surface SDS record and satellite retrieved IDDI were separately mapped into a 1°x1°grid, and the IDDI index was used only when there was no surface monitoring data in that grid.

### 3.2.1   Grid to Grid Spatial Validations Including Threat Score

Ground-based observations from the normal meteorological stations and data from FY-2C satellite were used to verify the SDS forecasts from the modelled concentration of DM40 (dust particle matter with a

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diameter less than 40 μm) (Zhou et al., 2008). Compared to the weather monitoring network, the measurements made at the SDS stations are more quantitative but quite limited in spatial coverage (Figure 1). For spatial validation of the model, the weather monitoring network is used. However, these weather stations represent only a few locations in SDS source regions where most SDS events occur. This disadvantage could be partly overcome by using satellite data.

Grid to grid validation is used in our SDS validation system (Wang et al., 2008). Ground-based observation data and the SDS data retrieved from FY-2C satellite were assigned to the grid in areas with no ground station. A GIS (Geographical Information System)-based validation system was developed to compare forecasting and observation data on all 1º×1º grids.

The method for dichotomous forecast (Wilks, 1995) of SDS and non-SDS was used in this study. As the reference of PM10 concentration given by Wang et al. (Wang et al., 2008),  200 μg m-3 is the concentration threshold for distinguishing a SDS event from a non-SDS event. The SDS category used includes all categories of SDS weather from meteorological observations. For satellite observations, it implies that the IDDI index of SDS is higher than or equal to 20 (Hu et al., 2008). Threat score (TS), false alarm ratio, miss ratio, accuracy and bias score were calculated from contingency table.

Threat score (TS) : $\quad TS = \dfrac{NA}{NA + NB + NC}$ $\qquad$ (1)

Missing ratio : $\quad PO = \dfrac{NC}{NA + NC}$ $\qquad$ (2)

False alarm : $\quad NH = \dfrac{NB}{NA + NB}$ $\qquad$ (3)

Bias : $\quad B = \dfrac{NA + NB}{NA + NC}$ $\qquad$ (4)

Forecast accuracy : $\quad EH = \dfrac{NA + ND}{NA + NB + NC + ND}$ $\qquad$ (5)

NA、NB、NC、ND are defined in the  following table3-1：

Table 3-1: SDS contingency table

| Forecast \ Observation | Yes | No |
|---|---|---|
| Yes | NA | NC |
| No | NB | ND |

Note NA: Hits, NB: False alarms, NC: Misses, ND: Correct rejections

### 3.2.2   Station Temporal Validation
The validation method used for this section is described in the table below:

Table 3-2: Definitions of common model validation metrics

| Validation metrics | Formula | Range | Ideal Score |
|---|---|---|---|
| Mean Bias Error (BE) | $MBE = \dfrac{1}{n}\sum_{i=1}^{n}\left(m_i - o_i\right)$ | $-\infty$ to $+\infty$ | 0 |
| Root Mean Square Error (RMSE) | $RMSE = \sqrt{\dfrac{1}{n}\sum_{i=1}^{n}\left(m_i - o_i\right)^2}$ | 0 to $+\infty$ | 0 |

| Correlation coefficient (r) | $r = \dfrac{\sum\limits_{i=1}^{n}\left(m_i - \overline{m}\right)\left(o_i - \overline{o}\right)}{\sqrt{\sum\limits_{i=1}^{n}\left(m_i - \overline{m}\right)^2}\cdot\sqrt{\sum\limits_{i=1}^{N}\left(o_i - \overline{o}\right)^2}}$ | -1 to 1 | 1 |
| --- | --- | --- | --- |

<div align="center">Note: o<sub>i</sub> and m<sub>i</sub> are respectively observed and modelled values

i, n is the number of data pairs and (-) denotes the mean value</div>

The BE captures the average deviations between two datasets with negative values indicating underestimation and positive overestimation of the model. The RMSE combines both the bias and the standard deviation. It is largely dominated by the largest values due to squaring. Especially in cases where prominent outliers occur, the usefulness of RMSE is questionable and the interpretation becomes difficult. The r indicates the extent to which temporal and spatial patterns in the model match those in the observations.

### 3.3  Data Used in the Validation of Dust Forecast Effect
### 3.3.1     Routine SDS Observational Data

Figure 3-2 shows the distribution of the weather stations in East Asia. Most stations are located in the areas with strong economic growth .However, in the Gobi desert and sandy land areas, where is the sources of SDS, the distribution of weather stations is very sparse. In the meteorological records, four categories of SDS events including suspended dust (with horizontal visibility less than 10000m and very low wind speed), blowing dust (with visibility reduced to 1000–10000 m), sand and dust storm (with visibility less than 1000 m) and severe sand and dust storm (with visibility less than 500 m) are usually reported in the daily observation. The last three categories of dust events all result from strong winds, the near real-time SDS observation data with 3-h interval at these stations were obtained through a data transfer system.
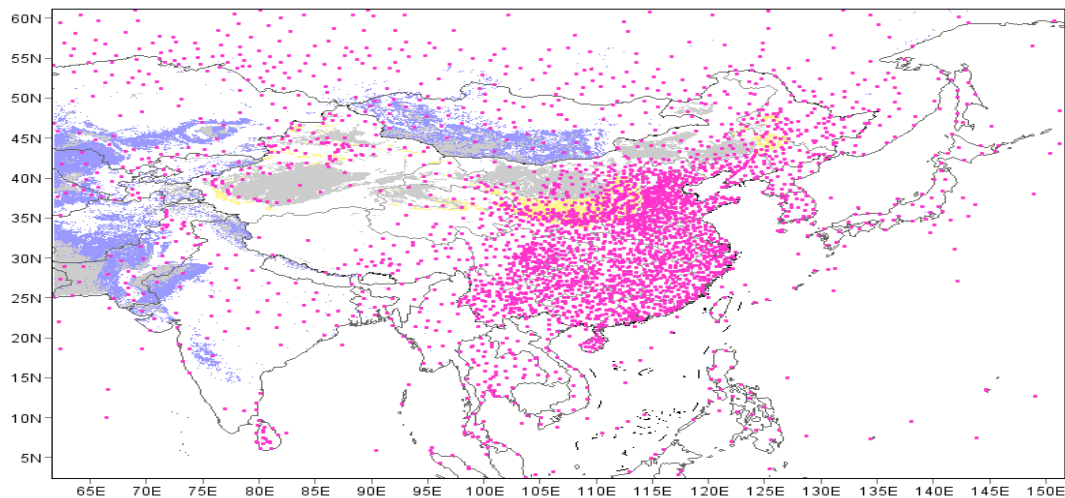


<div align="center">Fig.3-2 Routing meteorological observation stations</div>

### 3.3.2     PM Mass Concentration Data

To obtain the dust particle concentrations during SDS events, CMA, JMA and KMA have established a PM monitoring network that can be used for SDS validation. CMA SDS monitoring network  consists of 29 stations located in or near SDS source regions in northern China (Fig.3-3)   24 of  which have been monitored PM10 (particles with a diameter of less than 10 μm) observations  since 2003 andeleven of  which are  equipped with instruments to measure visibility. At 19     stations Tapered Element Oscilating Microbalance (TEOM, model 1400a, Rupprecht and Patashnick) instruments operated at a controlled flow rate of 4 L/min were used to record continuously the PM10 mass concentrations averaged over 5 min periods, GRIMM instruments were used in  5  otherstations for PM10, PM2.5 and PM1 observation. At eleven stations 5-min visibilities were also observed automatically on-line using FD-12 (Vaisala). After experimental running of the SDS monitoring network in 2003, the PM10 and visibility observation data started to be transferred to the CMA information centre in real-time from 2004.

Ten of SDS stations have been established through Sino-Korean cooperation (marked in blue in Fig.3-3). The observation data are shared between CMA and KMA at these stations. CMA also supported the establishment of 3 SDS stations (Underkhaan, Arvaikheer and Gobi-Altai) in Mongolia and 1 station (Kuygan) in Kazakhstan in 2009 and 2010 through bilateral cooperation.
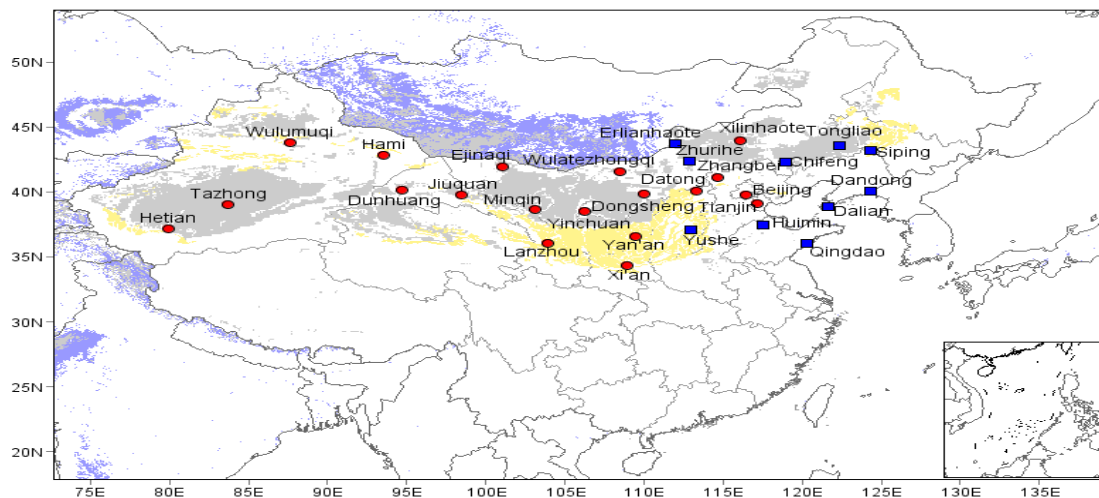


Fig.3-3 Sand and dust storm observation stations of CMA
With ten of which established through Sino-Korea cooperation (marked in blue ).

There are 29 SDS observation stations in KMA located in South Korea (Fig.3-4).

There is also a PM10 monitoring station network in MOE for SDS and air quality observation (Fig.3-5).
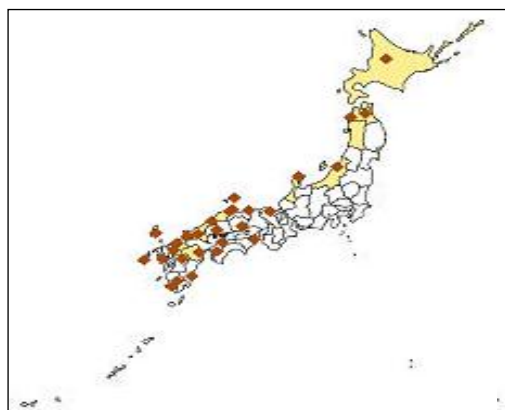


Fig.3-4(left) Sand and dust storm observation stations in KMA
Fig.3-5 (right) PM10 monitoring in Japan

### 3.3.3    Ground-Based AOD Data

The China Aerosol Research Network (CARSNET) is a ground-based network for monitoring aerosol optical properties (Fig.3-6) that uses the same type of instruments as AERONET (Che et al., 2009). CARSNET includes 20 sites located in northern and north-western China that were first established by CMA in 2002 for dust aerosol monitoring. This network has expanded its number of stations to more than 60 that are operated not only by CMA but also by local meteorological administrations, institutes, and universities throughout China. This has become a national resource for the study of aerosol optical properties  in different regions in China and the  validation of  satellite retrievals and numerical models of aerosols.
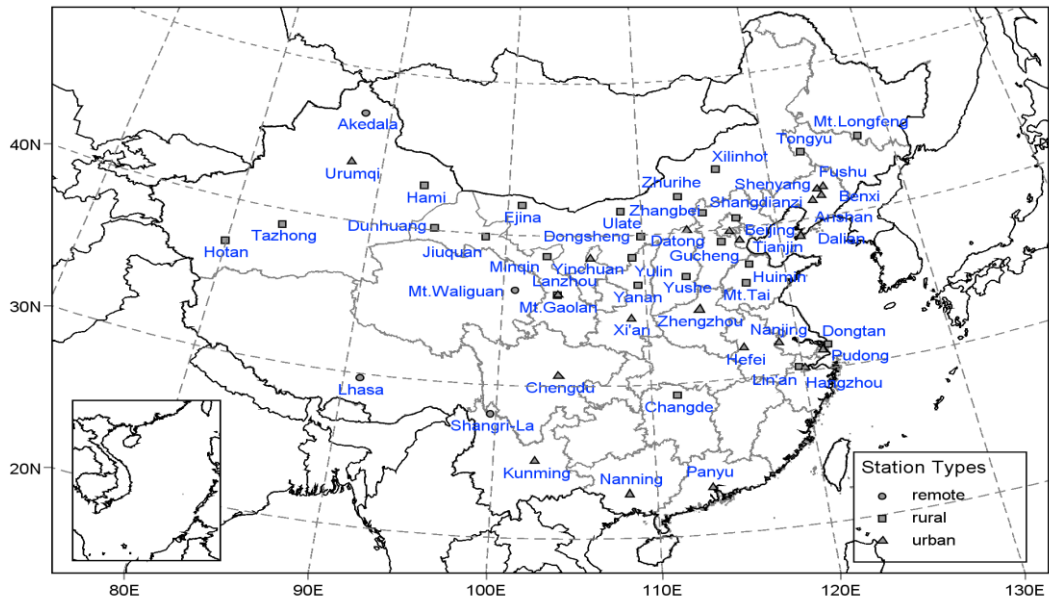
Fig.3-6. CARSNET stations of CMA with ground-based AOD observation

There are 3 sky radiometer stations in KMA and 3 sun photometer stations in JMA for aerosol optical properties observation (Fig.3-7).
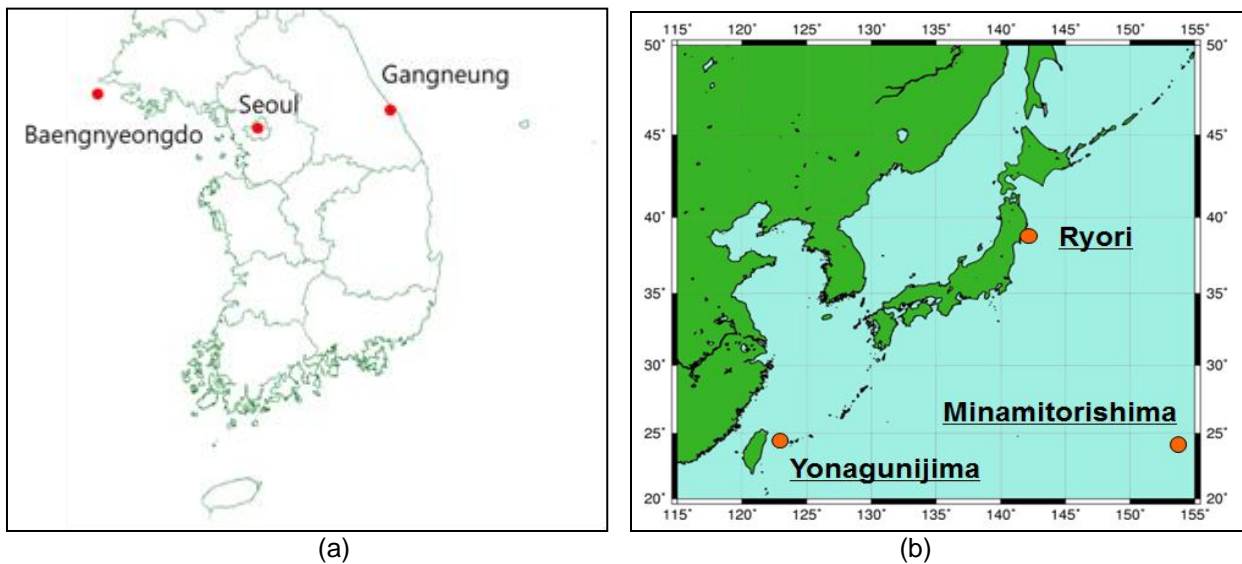


(a)                                          (b)

Fig.3-7 AOD stations in KMA (a) and JMA (b).

### 3.3.4    Satellite Remote-sensing Data

An operational retrieval algorithm for the sand/dust storm (SDS) from FY-2C/2D satellites was developed by CMA. This algorithm, called Dust Retrieval Algorithm from Geostationary Imager (DRAGI), is based on the optical and radiative physical properties of SDS in mid-infrared and thermal infrared spectral regions as well as the observation of all bands in the geostationary imager, which include the Brightness Temperature Difference (BTD) in split window channels, Infrared Difference Dust Index (IDDI) and the ratio of middle infrared reflectance to visible reflectance. It also combines the visible and water vapour bands observation of the geostationary imager to identify the dust clouds from the surface targets and meteorological clouds. The output product is validated by and related to other dust aerosol observations such as the synoptic weather reports, surface visibility, aerosol optical depth (AOD) and ground-based PM10 observations. Using the SDS-IDD product and a data assimilation scheme, the dust forecast model CUACE/Dust achieved a substantial improvement in SDS prediction (Fig.3-8).
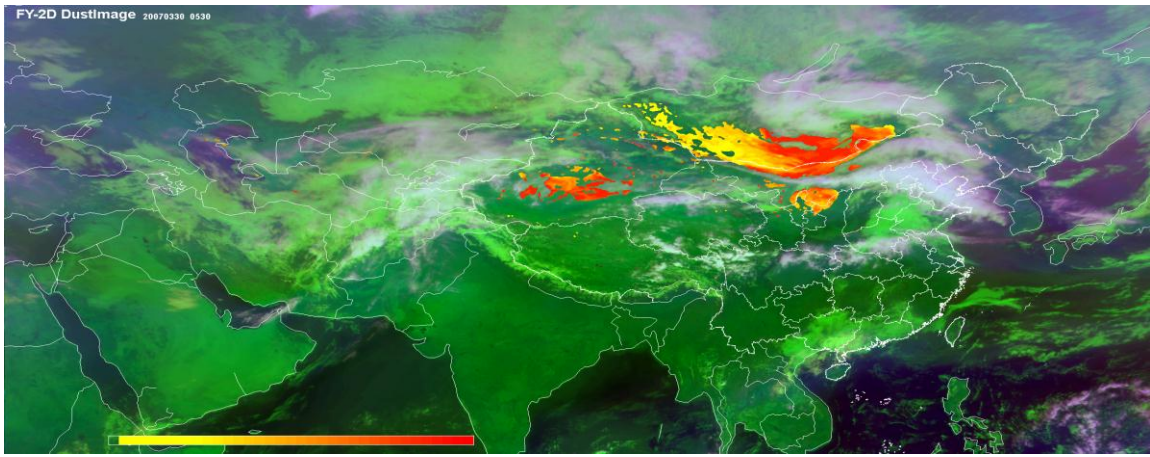
Fig.3-8 IDDI image from FY-2D satellite at 5:30 (UTC), March 30, 2007

Asian dust index products are also provided by KMA COMS and JMA NTSAT satellites (Fig.3-9).
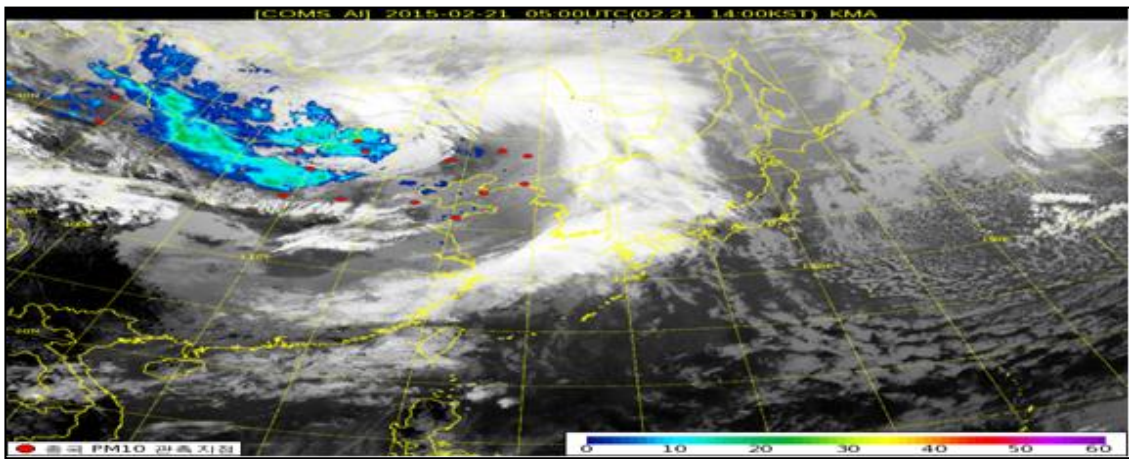


(a)
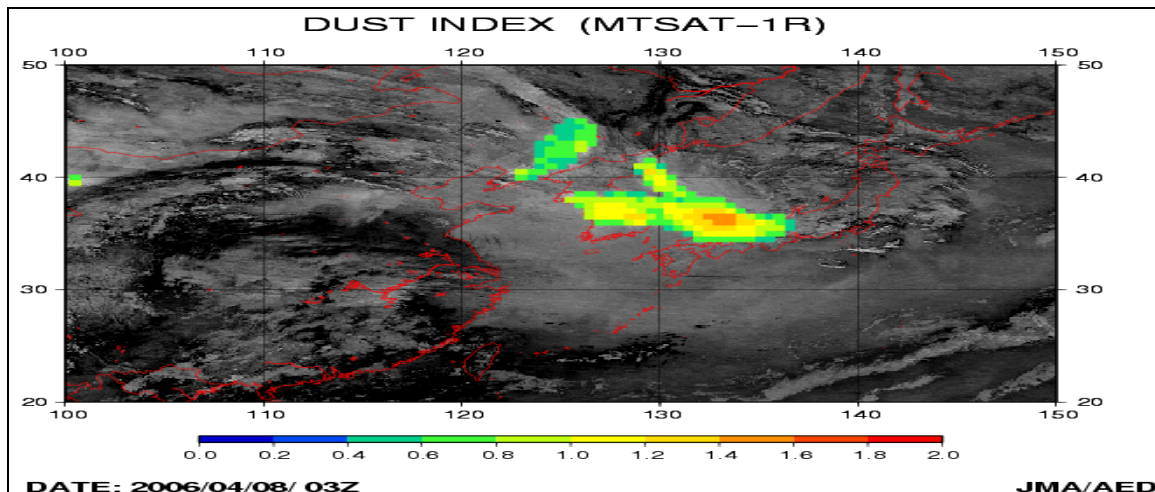


(b)

Asian dust index products are also provided by KMA COMS(Fig.3-9a) and JMA MTSAT satellites (Fig.3-9b). JMA estimates Asian dust index is from MTSAT infrared split window (11 μm and 12 μm) measurement. JMA has a plan to upgrade Asian dust related products (Asian dust index and aerosol optical depth) retrieved from Himawari-8 from 2015.

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### 3.3.5 Lidar Data

Lidars are useful tools for measuring vertical distributions of mineral dust continuously, and the data from the lidars are useful for validation/assimilation of dust transport models. Research-based lidar network observations of Asian dust were initiated in 1990's by lidar researchers in Japan, China and Korea. The routine lidar network observation of Asian dust using polarization-sensitive lidars was started in 2001. Currently, polarization-sensitive lidars are continuously operated in 20 locations in East Asia including two stations in the dust source area in Mongolia. The network, named AD-Net, is an Asian component of GAW Aerosol Lidar Observation Network (GALION) and is approved as a contributing network to the WMO GAW program (http://www-lidar.nies.go.jp/AD-Net/). Data from the lidar network were used in validation of chemical transport models (Uno et al., 2006). Studies on assimilation of ground-based lidar-network data were also conducted, and it was demonstrated that the data assimilation was useful not only for better reproducing dust concentration but also for better estimating emission in the source areas (Sugimoto and Uno, 2009). Although the number of the lidar stations in the dust source areas is not sufficient for data assimilation of dust forecast models, the data from the current AD-Net (and other lidars in the region) are useful for validation of the forecast models and for the data assimilation for reanalysis of dust phenomena and model improvement. The use of low-cost ceilometers for measuring dust would be effective for increasing the number of observations in dust source areas. Studies on capability of ceilometers are being conducted in AD-Net and also on the WMO framework (Fig.3-10).
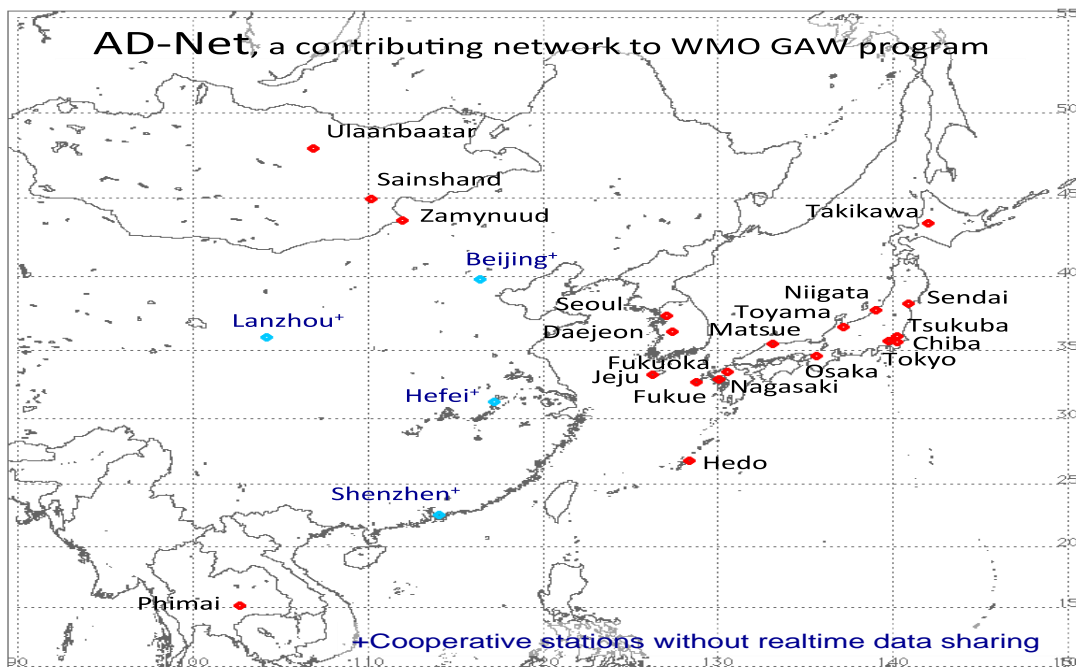


Fig.3-10 Lidar Network in East Asia(AD-Net)

### 3.4 SDS Forecasting Effects
### 3.4.1 Daily Threat Score and Accuracy of CUACE/Dust Forecasting Results

**Validation Results in Spring 2006** The spatial validation results show that in spring 2006 the daily-averaged TS values were 0.31, 0.23 and 0.21 for 24h, 48h and 72h forecasting, respectively. During SDS periods, TS values dramatically increased, with the highest value of 0.63 for 24 h forecasting on March 12, when a large SDS event occurred. The SDS forecasts maintained high accuracy with an average value of 0.88. Validation in different regions indicates the model performed better in China's far western province of Xinjiang, with an averaged TS value of 0.4. On each grid, comparison between forecast and observation in spring was also carried out every day. The temporal validation on each grid was also calculated. Results show that TS was high in the areas around deserts, Gobi deserts and sandy lands that are SDS sources. Averaged TS in source regions like the Taklimakan and Mongolian Gobi deserts was greater than 0.7. In downwind regions including most of Northern and North-eastern China, TS ranged from 0.3 to 0.5. TS for 85% severe SDS processes by three FTs were above the spring average value with 61% ones with relatively high scores. TS for 84% of all the 31 SDS processes were also above the spring

average score. In most areas, the bias scores were around 1, but in North Xinjiang the model often has false positives, or false alarms. North Tibet and South China are often missed by the forecasting system.

Another version of the model without data assimilation was also run in the spring of 2006. Validation results show that without assimilation there was   less satisfactory performance in SDS forecasts, with TS of 0.22 for 24 h forecasting. A detailed comparison of these results is presented in Niu et al. (Niu et al., 2008) (Fig.3-11).
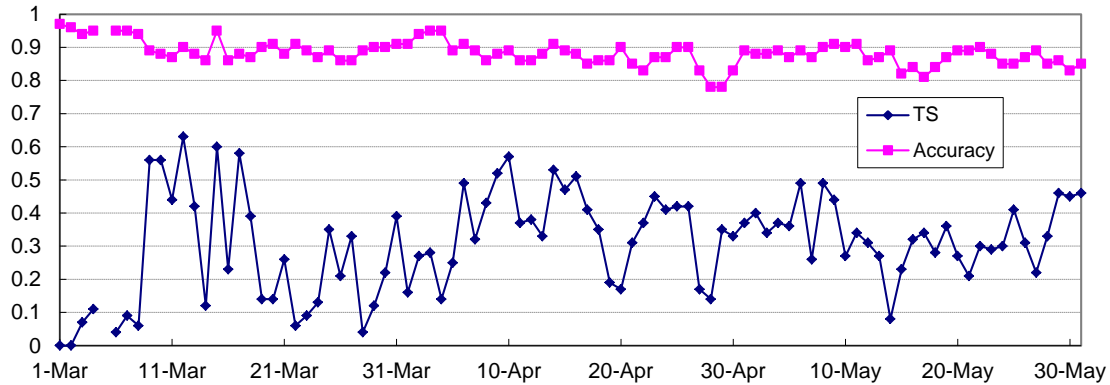


Fig. 3-11 Daily threat score and accuracy values in spring 2006 for 24 h forecasting

**Validation Results in Spring 2007**  The spatial validation results show that in spring 2007 the daily-averaged TS value was 0.25 for 24 h forecasting (Figure 13), which was lower than that in 2006 due to less SDS events occurring in spring 2007. There was only one strong SDS event from Mar. 30 to Apr. 2 with a TS value of 0.64 on Mar. 30.  In addition, the TS values were relatively high in other SDS events, which indicate the positive forecasting ability of CUACE/Dust to SDS events. The average accuracy value was 0.89 in spring 2007(Fig.3-12).



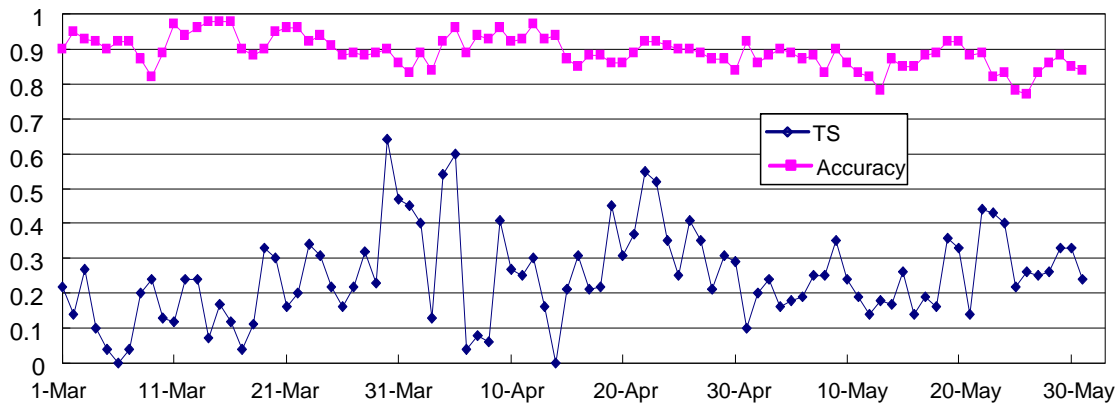Fig.3-12 Daily threat score and accuracy values in spring 2007 for 24 h forecasting

**Validation Results in Spring 2008**  The spatial validation results show that in spring 2008 the daily-averaged TS value was 0.26 for 24 h forecasting (Figure 14), which was similar to that in 2006. The highest TS value was 0.61 on  Mar. 18 when a strong SDS event occurred. The average accuracy value was 0.9 in spring 2008 (Fig.3-13)
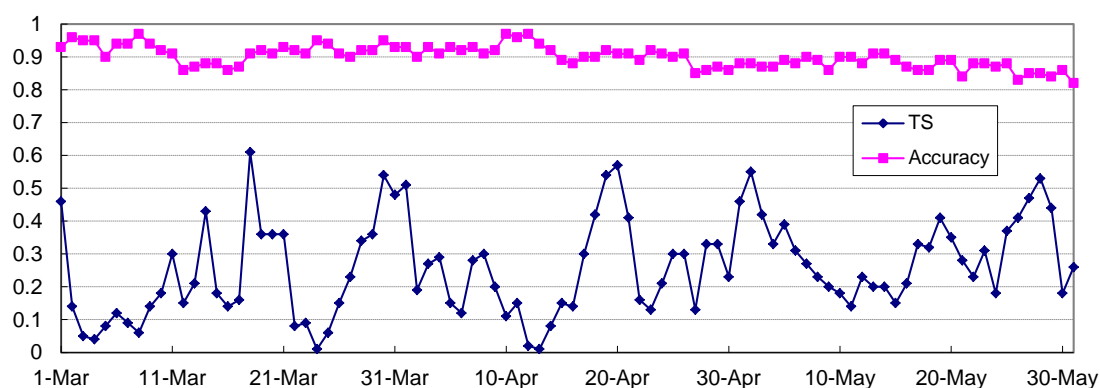
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Fig.3-13 Daily threat score and accuracy values in spring 2008 for 24 h forecasting

### 3.4.2    PM10 Station Validations

PM10 concentration data monitored by the CMA dust/sand storm monitoring network were also used to verify the surface dust concentration forecasts made by the CUACE model in recent three years on a station basis and in a quantitative manner, the results of which are shown in tables 3 to 5. In general, the dust model performs well in forecasting such concentration, with relevance factors of 3-year seasonal model forecasts and observations being 0.83, 0.83 and 0.69 respectively. Validations show a negative systematic bias with the model forecasting at the same time (Table3-3, 3-4, 3-5).

Table3-3  Some of PM10  stations statistics Parameter in China from  March to May in 2012

| Station(ID) | Mean Bias Error (BE) | Root Mean Square Error (RMSE) | Correlation coefficient (r) |
|---|---|---|---|
| Tazhong (51747) | -224.99 | 117.35 | 0.89 |
| Hetian (51828) | -345.87 | 87.67 | 0.52 |
| Hami (52203) | -195.39 | 69.75 | 0.89 |
| Dunhuang (52418) | -107.34 | 45.31 | 0.83 |
| Erjina (52267) | -80.84 | 67.02 | 0.88 |
| Jiuquan (52533) | -38.81 | 24.50 | 0.94 |
| Minqin (52681) | -111.99 | 85.29 | 0.88 |

Table3-4 Some of PM10  stations statistics Parameter in China from  March to May in 2013

| Station(ID) | Mean Bias Error (BE) | Root Mean Square Error (RMSE) | Correlation coefficient (r) |
|---|---|---|---|
| Tazhong(51747) | -307.75 | 123.98 | 0.81 |
| Hetian(51828) | -54.39 | 70.04 | 0.92 |
| Hami(52203) | -130.93 | 26.79 | 0.64 |
| Dunhuang(52418) | -169.09 | 77.27 | 0.72 |
| Erjina(52267) | -104.12 | 91.98 | 0.88 |
| Jiuquan(52533) | -362.96 | 93.50 | 0.80 |
| Minqin(52681) | -25.46 | 74.80 | 0.95 |

Table3-5 Some of PM10  stations statistics Parameter in China from  March to May in 2014

| Station(ID) | Mean Bias Error (BE) | Root Mean Square Error (RMSE) | Correlation coefficient (r) |
|---|---|---|---|
| Tazhong(51747) | -494.31 | 162.87 | 0.86 |
| Hetian(51828) | -770.00 | 106.19 | 0.52 |
| Hami(52203) | -479.71 | 64.57 | 0.62 |
| Dunhuang(52418) | -376.38 | 90.60 | 0.79 |
| Erjina(52267) | -165.03 | 77.97 | 0.92 |
| Jiuquan(52533) | -440.32 | 87.15 | 0.59 |
| Minqin(52681) | -503.68 | 96.18 | 0.52 |

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The analysis of selected stations in Tazhong and Hami in Xinjiang and Ejinain in Inner Mongolia shows (Fig.3-14) that the model forecast dust concentration   agrees with the observed evolution, indicating that the model is in a position to forecast the occurrence and peak concentration of a strong dust process, with the latter tending to be lower than what actually happens. However, a weak dust process would put the model in a poor position. For example, from March to May in 2014, the model failed to perform well in several processes of weak dust passing over the Tazhong Station in Xinjiang and the Erjina Station in Inner Mongolia (Fig.3-15, Fig.3-16).
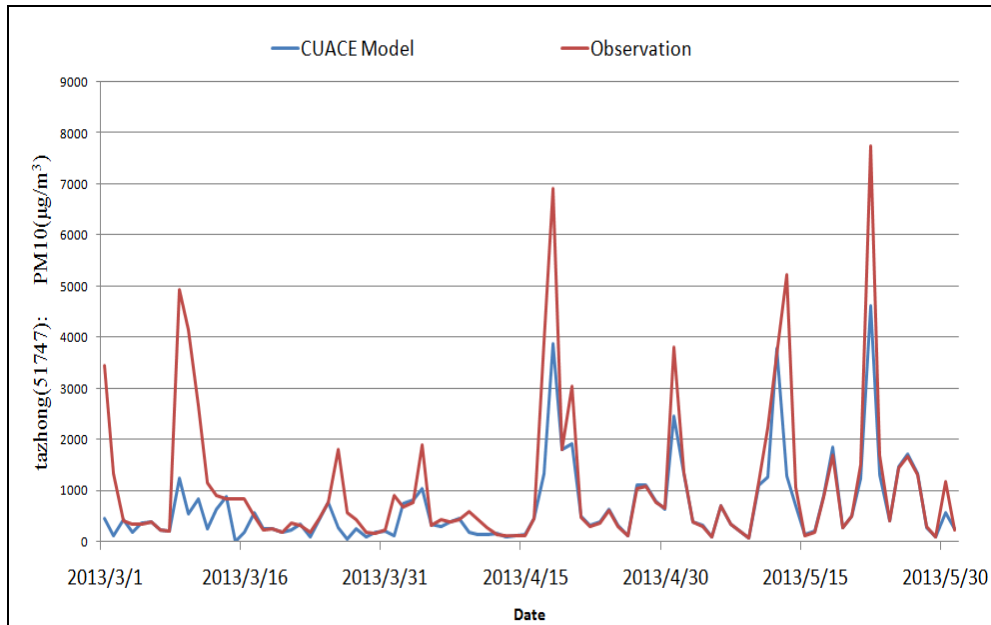


Fig.3-14  The Comparison of PM10 between CUACE/Dust forecasting and Observation
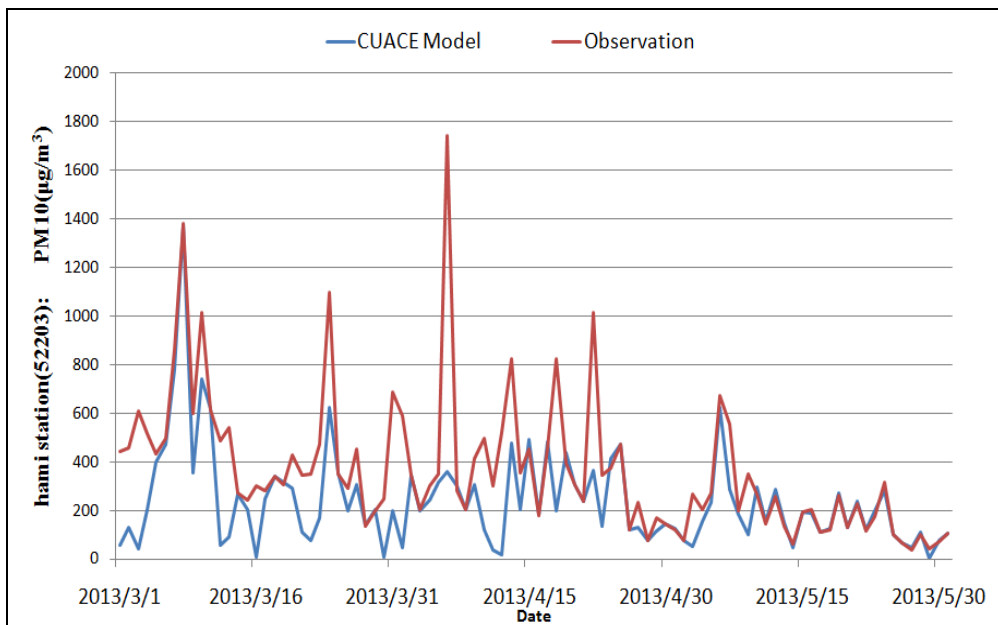at Tazhong(51747) station  in China  from March to May in 2013



Fig.3-15 The Comparison of PM10 between CUACE forecasting and Observation
at Hami(52203) station in China  from March to May in 2013
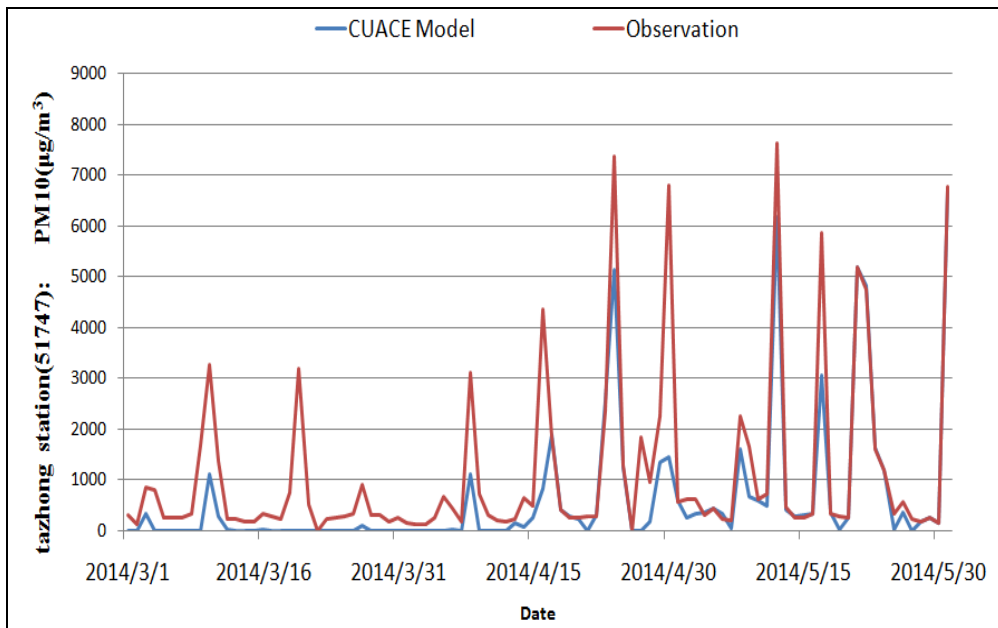
Fig.3-16 The Comparison of PM10 between CUACE forecasting and Observation at Tazhong(51747) station in China from March to May in 2014
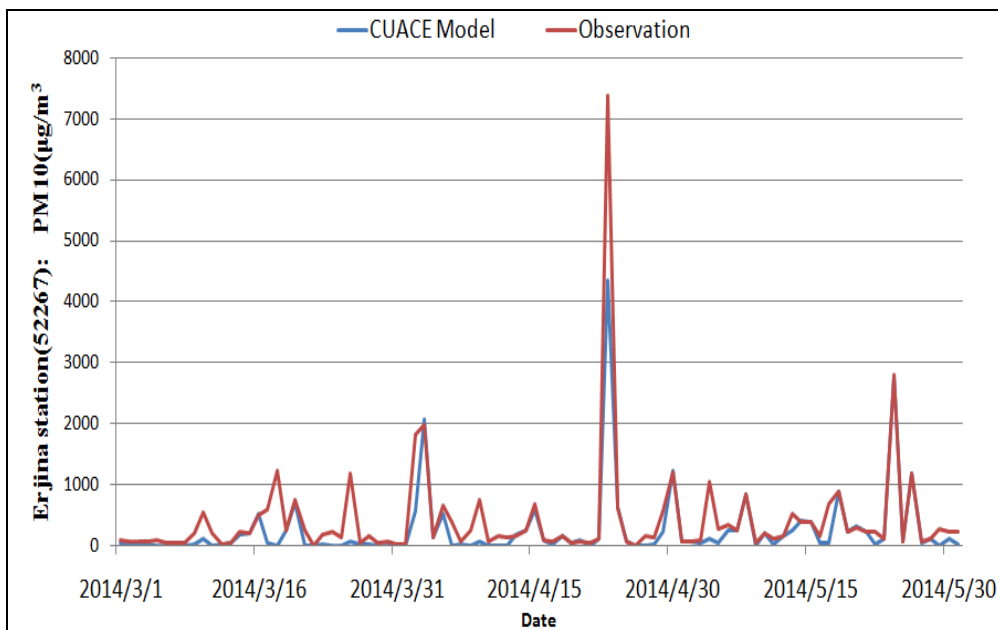


Fig.3-17 The Comparison of PM10 between CUACE forecasting and Observation at Erjina(52267) station in China from March to May in 2014

### 3.4.3 AOD Station Validations

The optical depth of dust reflects the attenuation of dust aerosol to sunlight. In a dust process, the optical depth of atmosphere does reflect the dust concentration. When verified, the model optical depth takes the maximal value of the day, with the actual optical depth being a daily average. An optical depth based forecast by CUACE and observations made at the station located in Banner Erjina in western Inner Mongolia in the spring of 2014 both point to such an evolution (Fig.3-18) that a local observed concentration registering a significant increase is reflected in the model, with the forecast output being much weaker than what actually happens.

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Fig.3-18  The Comparison of 550nm AOD between CUACE forecasting and Observation at Erjina(52267) station in China from March to May in 2014
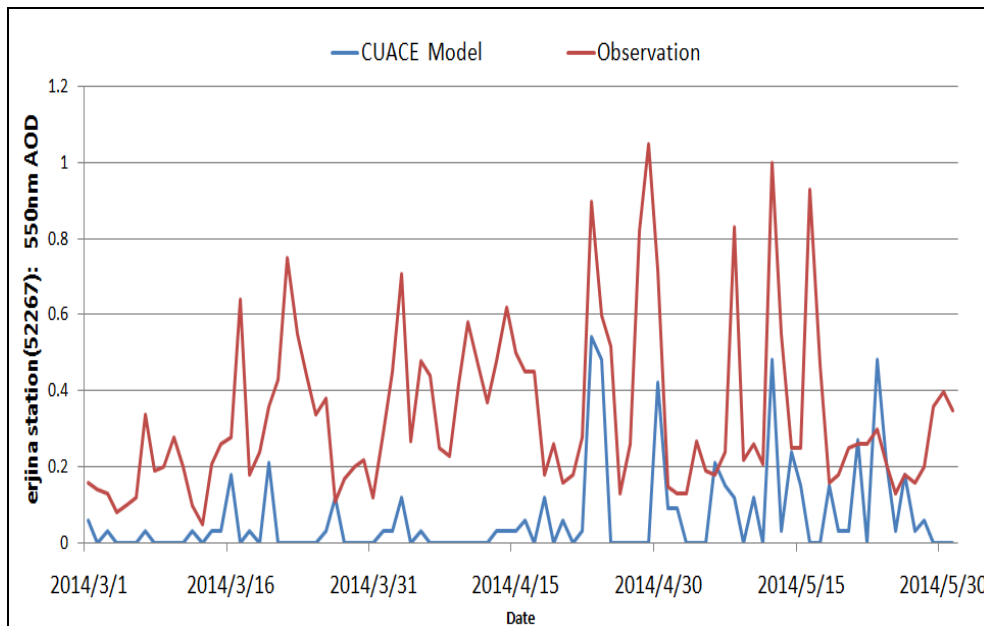
### 3.4.4    Severe Dust Storm Events Validations

The weather processes of severe dust storms affecting Asia since 2002 were selected to synoptically assess CMA CUACE/Dust in terms of forecasting performance, which shows a great strength that this Model boasts in this connection. Detailed information is given in the annex.

### 3.4.5    MASINGAR and ADAM Models Validation

**MASINGAR Model Validation**    A grid to grid threat score validation method is also used in JMA for MASINGAR model validation. (1) Extract all the stations that observed (or surely does not observe) dust events, from every 3-hour SYNOP data. (2) Convert the SYNOP information to $1.25^{\circ} \times 1.25^{\circ}$ grid resolution. (3) Model or forecast results of surface dust concentration at the same time are converted to the $1.25^{\circ} \times 1.25^{\circ}$ grid resolution in the same way as the SYNOP conversion, using an arbitrary threshold of 90 μg m$^{-3}$. (4) Compare the results of (2) and (3), calculating threat scores. MASINGAR model was improved in 2014  and the TS results were calculated for 2010-2013 with old and new models (Table3-6). The results indicated that the Threat Scores are improved mainly for the first half of the forecast period. Figure 3-19 shows an example of the 48 hours and 120 hours forecast results. Even 120 hour forecast shows a reasonable result.

Table3-6 Threat score of MASINGAR against surface observation in Japan.

| Forecast Period | 00-24h | 24-48h | 48-72h | 72-96h |
|---|---|---|---|---|
| 2010-2013 (Old model) | 0.334 | 0.317 | 0.300 | 0.237 |
| 2010-2013 (New model) | 0.365 | 0.343 | 0.329 | 0.219 |

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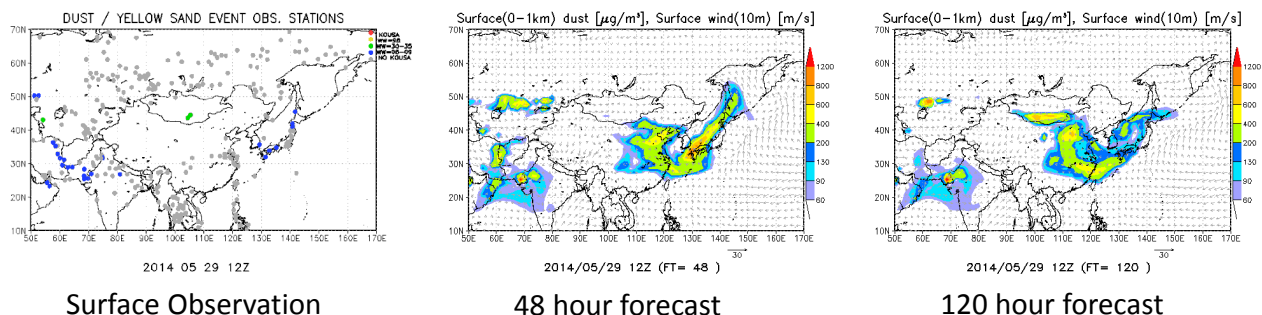| Surface Observation | 48 hour forecast | 120 hour forecast |

Fig.3-19 An example of 48 and 120 hours KOSA forecast by MASINGAR (1 April 2007).

**ADAM Model Validation**   A performance test of the ADAM2 model was conducted with observed PM10 concentrations at some monitoring sites in the source region and the downstream region of Korea for the whole months of May and December in 2007 (Park, Choe et al., 2010a). It was found that the ADAM2 model was able to simulate quite well most of Asian dust-storm occurrences in the source region and dust events observed in Korea. The model simulates quite well the starting and ending times of the dust storms in the source region within 10 % margin of error with the observed surface PM10 concentration. In the downstream region of Korea, the starting and ending times of dust events were well-simulated; however, the surface PM10 concentration was slightly overestimated for some dust events. Nevertheless, there is a great potential for the ADAM2 model to be used as an operational Asian dust forecast model for Asia (Fig. 3-20).
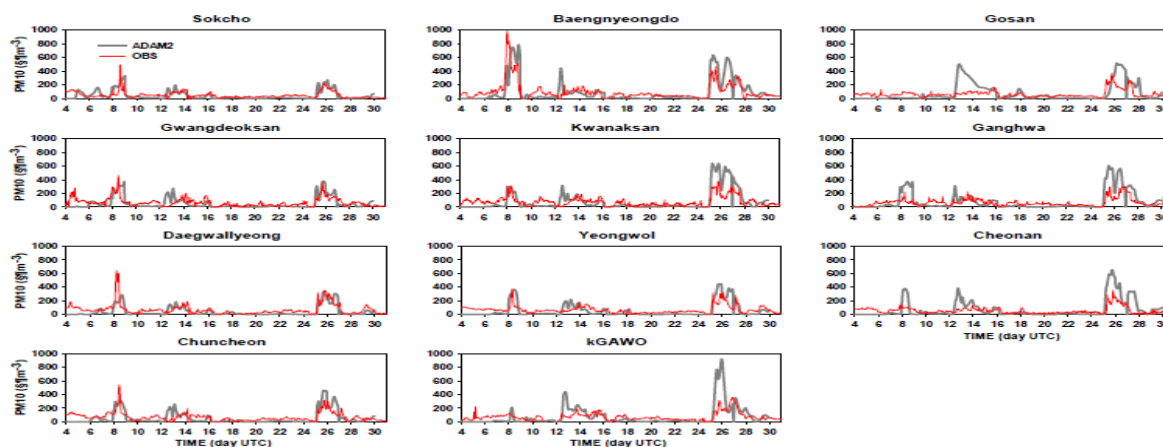


Fig.3-20 Time series of observed (red line) and modeled (ADAM2 (grey line)) surface PM10 concentration ($\mu g\ m^{-3}$) at the downstream sites in Korea in May 2007.

## 4    Web Portal of Asian-RC

At the fourteenth session of the Commission for Basic Systems (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. It agreed that there  was a need to incorporate the mandatory functions and criteria for the designation of RSMC with activity specialization in 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.

（At the fifteenth session of WMO Regional Association II, December 2012, The Association noted that as a result of collaboration between CAS and CBS, CBS-15 recommended incorporating the mandatory functions and criteria for the designation of a RSMC with activity specialization in Atmospheric Sand and Dust storm Forecasts (RSMC-ASDF) in the current version of the Manual on the GDPFS (WMO-No. 485) and approved of the formal designation of the Barcelona Supercomputing Centre acting as an RSMC-ASDF for Northern Africa (north of Equator), Middle East and Europe and strongly encouraged China to implement its plans related to sand and dust storm-related services and recommended a demonstration of operational forecasting capabilities in the upcoming season, to serve Members of the eastern part of RA II in dust monitoring and forecasting and supported the formal nomination of a center to act as a RSMC-ASDF, for CBS consideration.

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, SDS-WAS Asian-RC (potential RSMC-ASDF candidate) has carried out the following functions:

1) Prepare regional forecast fields by using CUACE/Dust continuously throughout the year on a daily basis. The model consists of a numerical weather prediction model incorporating online parameterizations of all the major phases of the atmospheric dust cycle;

2) Generate forecasts, with an appropriate uncertainty information statement, of the following minimum set of variables:
   a) Dust load ($kg \cdot m^{-2}$)
   b) Dust concentration at the surface ($\mu g \cdot m^{-3}$)
   c) Dust optical depth at 550 nm (-)
   d) 3-hour accumulated dry and wet deposition ($kg \cdot m^{-2}$)

All the forecasts cover the period from the starting time (00 and/or 12 UTC) up to a valid time of 72 hours, with an output frequency of 3 hours. They cover the whole designated area with a horizontal resolution of about 0.5x0.5 degrees. All the forecasts will be disseminated through GTS/WIS and presented on its web portal no later than 12 hours after the forecast starting time when RSMC-ASDF Beijing has been approved.

The SDS-WAS Asian-RC Web Portal (http://eng.weather.gov.cn/dust/) has been designed to allow users access to forecast products as well as sources of basic information (Fig.4-1). An explanatory note will be issued on the web portal when it is in operational run.
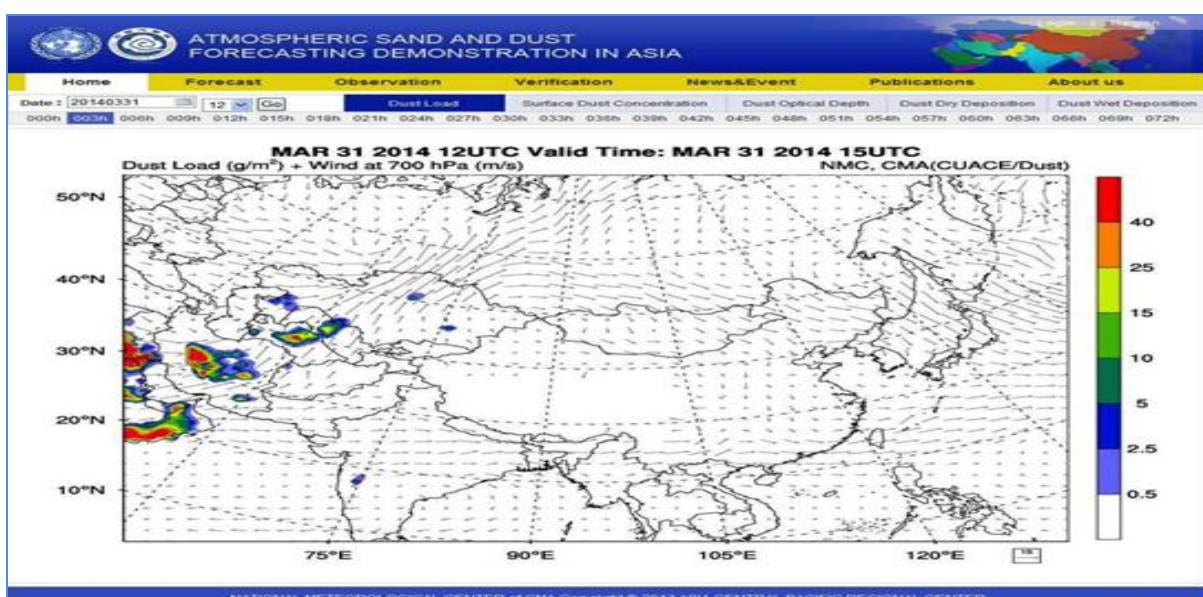


Fig.4-1 The homepage of SDS-WAS Asian Regional Centre
(Candidate RSMC-ASDF Beijing) Web Portal

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The Non-real-time functions of RSMC-ASDF Beijing have been fulfilled since 2014 as well. The CUACE/Dust forecasting system has been put into operational run in Asian region node centre. It shows the forecasting results on the web portal of the centre and provides a link with forecasting results from two other systems of JMA and KMA, respectively.

## 5    Model Inter-Comparison

### 5.1   CUACE/Dust in CMA

CUACE is now being developed as a system for dust and air quality forecasts in China. Since it is envisioned as a unified system, it can be implemented into any meteorological models such as regional air quality and climate models. CUACE/Dust is an application of CUACE to dust aerosol forecasts and  an integrated system that combines a size segregated multi-component aerosol module (Gong et al., 2003a) with a 3D-Var data assimilation system implemented into two operational weather forecasting models. The dust module (Gong et al., 2003b, 2006b) has been used for Asian dust aerosol studies during ACE-Asia and reasonable agreements have been achieved between various surface measurements (Zhang et al., 2003a) and air-borne observations. CUACE/Dust was implemented on-line in two meteorological frameworks: MM5 (Zhou et al., 2008) and GRAPES (Global/Regional Assimilation and PrEdiction System) which is the newest generation of Chinese weather forecast model (Xue, 2004). Running at 54 km and 54 km horizontal resolutions, respectively, MM5 and GRAPES with CUACE/Dust deliver 24 h, 48 h and 72 h forecasts of dust storms twice a day for the Asian area. Full details of the CUACE/Dust developments and evaluations for MM5 are given by Zhou et al. (2008). The results with GRAPES will be published elsewhere.

In CUACE/Dust, all the atmospheric processes are included except for the coagulation and nucleation which are of little importance for mesoscale SDS simulation and forecasting. Particle size distribution plays a great role in aerosol microphysics and large scale transportation processes. Studies (Zhang, Gong et al. 2003) show that the dominant mass of the mineral aerosols in Northeast Asia is of a diameter from 2 to 20 µm which accounts for about 53%-68% of the total mineral dust loading. It may shift slightly to a coarse mode in heavy dust storms near the source regions and to a fine mode in regions downwind. Based on the Zhang's studies, the mineral aerosol size spectra in CUACE/Dust are divided into 12 size bins with a radius range of 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, 10.24-15.36, 15.36-17.36, 17.36-20.72, 20.72-30 µm.

There are two dust emission schemes built in CUACE/Dust: (1) by Marticorena and Bergametti (1995), Alfaro et al. (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 distribution, 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, Gong et al. 2006). In current CUACE/Dust, the MBA scheme is used. A detailed desert distribution and soil texture data base for China was given in (Gong, Zhang et al. 2003). The snow cover was retrieved from a China meteorological satellite FY-2C with a resolution of 0.02º×0.02º.

Data assimilation is a key component in the CUACE/Dust system, which needs near real-time measurements of dust aerosols (concentrations and visibility) at ground stations, vertical profiles from lidar and spatial coverage from satellites. In a paper by Hu et al. (2008), the detailed methodology to retrieve the dust intensity from the Chinese geostationary FY-2C satellite is given with validations from the ground network observation data. Niu et al. (2007) developed the dust assimilation module in CUACE/Dust by combining the satellite and surface network data to form a coherent data set with a method proposed to treat the dust data under clouds where a satellite is unable to detect SDS.
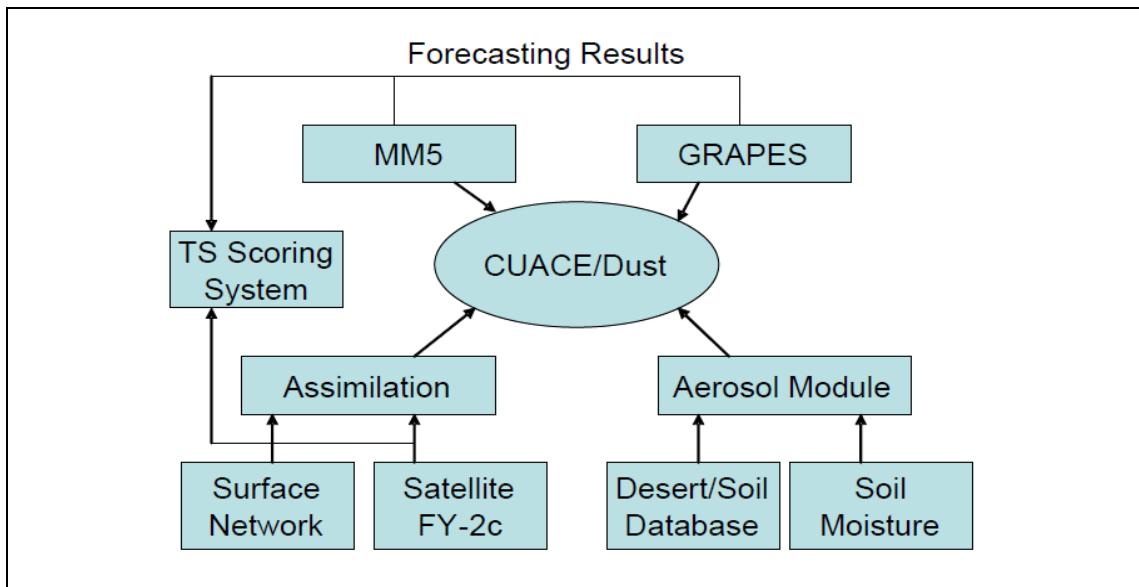
Fig.5-1The structure of CUACE/Dust in two weather forecasting models:MM5 and GRAPES

Finally, a threat scoring (TS) system was established in a GIS framework to evaluate the forecasting results with all observational data sets (Wang et al., 2008). This system uses the same principles for evaluating the routine precipitation forecasts to compute the threat score (TS), miss ratio (MR), false alarm ratio (FAR), bias score (BS) and accuracy (AC) for the whole model domain or part of the domain.

## 5.2 MASINGAR in JMA

JMA started to operate an aeolian dust information service through its website (http://www.jma.go.jp/en/kosafcst/index.html) in January 2004. Both prediction and observation are presented in a map of East Asian region. The observation information is based on the present weather code and visibility obtained from SYNOP reports in the region of East Asia from 20ºN to 50ºN and from 110ºE to 150ºE.

The operational dust prediction is calculated by a global aerosol model called MASINGAR (Model of Aerosol Species IN the Global AtmospheRe) mk-2, which replaced the previous version of the model (Tanaka, Orito et al. 2003; Tanaka and Chiba 2005) in November 2014. The atmospheric part of the model is called the MRI-AGCM3 atmospheric general circulation model (Mizuta et al. 2006; Yukimoto et al. 2012), which is a spectral AGCM developed by the Meteorological Research Institute (MRI) and JMA. The aerosol model includes five major aerosol species: nss-sulfate and its precursors, black carbon, organic matter, mineral dust, and sea-salt aerosols.

The mineral dust module in MASINGAR uses a size-bin method to transport discrete, non-interacting dust size classes ranging from 0.2 to 20 μm in diameter and logarithmically divided into 10 size classes. It is composed of four different physical processes of Aeolian dust, (1) wind erosion scheme, (2) boundary layer module, (3) long-range transport model, and (4) wet and dry deposition scheme.

A dust emission scheme developed by Shao et al. (1996) is adopted to calculate dust emission flux online. In the dust emission scheme, dust emission generated by wind erosion is initiated when the friction velocity over an erodible surface determined by several ground-surface conditions exceeds a threshold value proposed by Shao and Lu (2000) (Shao and Lu 2000). Effect of vegetation cover on reducing the friction velocity on the bare ground around and beneath the vegetation cover has also been considered. For simplicity, the areal fraction of the bare ground, in which the dust emission is suppressed by the vegetation, is assumed to be proportional to the leaf area index (LAI). The dust-emission flux is assumed to be linearly reduced with the areal fraction of snow and ice cover.

The 1°×1° resolution land-use database from DeFries and Townshend (1994) (DeFries and Townshend 1994) is used to locate the potential erodible land-use types. The land-use types of broadleaf evergreen forest and coniferous evergreen forest are removed from the potential erodible surface. The vegetation map of the Gobi Desert, northeastern China and Inner Mongol has been updated based on MODIS 2000-2001 data and JMA's analysis of Aeolian dust observations in 2006.

## 5.3 ADAM2 in KMA

The operational dust forecasting model in Korea is called Asian Dust Aerosol Model (ADAMx. x is the version number) (Park and In 2003; Park, Choe et al. 2010b; Park, Choe et al. 2012). It is an Eulerian dust-transport model that includes specifications of dust source regions, delineated by a statistical analysis of WMO dust-reporting data and statistically derived dust emission conditions in sand, gobi, loess and mixed soil surfaces in the domain. It is an offline dust forecasting model. The meteorological model is the Global Unified Model (UM) with a horizontal resolution of 25 km and 47 vertical layers up to the 100 hPa level. The aerosol model in ADAMx includes physical processes such as three dimensional advection, diffusion, dry and wet depositions in the σ coordinate system. This aerosol model uses the meteorological output of UM. The mineral aerosol particles of 0.2– 74 mm in diameter are divided into 11 size bins with the same logarithm intervals: 0.2~0.50, 0.50 ~ 0.82, 0.82~1.35, 1.35~2.23, 2.23~3.67, 3.67~6.06, 6.06~10.00, 10.00~16.50, 16.50~27.25, 27.25~45.00, 45.00~74.00 μm in diameter.It also uses time-dependent dust emission reduction factors due to vegetation parameterized with the use of the Normalized Difference Vegetation Index (NDVI) values for 9 years (1998–2006) obtained from the spot/vegetation product of the maximum value composite syntheses for a 10-day period in a spatial resolution of 1×1 km2 (http://free.vgt.vito.be) in the Asian dust source region. The dust emission flux in the ADAM2 model is assumed to be proportional to the fourth power of the friction velocity when the wind speed exceeds the threshold wind speed and modified by the time-dependent dust emission reduction factors due to vegetation parameterized by NDVI. The model uses the suspended particle-size distribution parameterized by the several log-normal distributions of the soil particle-size distribution in the source regions, based on the concept of the minimally and fully dispersed particle-size distribution (Table5-1).

Table5-1 Configurations of the SDS-WAS Models

| Items | CUACE/Dust (CMA) | MASINGAR mk-2 ( JMA) | ADAM2  (KMA) |
|---|---|---|---|
| Forecast area | Asia | Global | Asia |
| Horizontal Resolution | 54km | 1.1 degree, Global | 25 km, Asia |
| Vertical Resolution | 23 layers (surface to 100 hpa) | 40 Layers (Surface – 0.4hPa) | 47 layers (surface to 100hpa) |
| Forecast Period | 3 days | 4 days | 3 days |
| Transport Process | MPDATA | 3D Semi-Lagrange | |
| Dust Emission | MBA | Based on Shao et al. (1996) | $\propto U_*^4$ |
| Vertical Transport | Turbulent diffusion, | Cumulus, Turbulent | eddy diffusivity |
| Dust Deposition | Dry and Wet deposition | Dry and Wet deposition | Dry  and Wet deposition |
| Forcing (Meteorology) | Global analysis and forecast | Global analysis and forecast | Global  analysis and forecast |
| Forcing (Land surface) | Land use and land cover, soil texture, Soil moisture and snow cover analysis | (none) | Land use and land cover, soil texture |
| Sectional bins | 12bins | 10bins | 11 bins |

**5.4  Future model comparison within potential RSMC-ASDF**

To improve the SDS forecast ability and to evaluate SDS forecast models representation in Asian-RC, one of the three activities is model inter-comparison planned at WMO SDS-WAS Regional Steering Group. At present there are three operational forecast models CUACE/Dust, MASINGAR and ADAM2 in CMA, JMA and KMA respectively in Asian node (Table 1). All of them will join the regional SDS forecast model inter-comparison, We welcome more research models in the model inter-comparison.

**Experiment Time**   Only one or two dust events are not enough for forecast model representation which should show stable and relative high forecast accuracy in operational run, as long time period simulation is not easy to accomplish for regional model inter-comparison.

For example, there were 31 SDS events in spring   of which 11 occurred in April in 2006 in North East Asia. In the 11 events, 5 were severe SDS with 4 influencing Mongolia, China, Korea Peninsula and Japan (Table 5-2). April in 2006 can be a very good time   for the model inter-comparison in dust aerosol emission, transportation and deposition. So the experience experiment? time can be set in April (from April 1 to April 30) .

Table5-2 SDS Events in April 2006

| No. of SDS Events | Lasting Time | Strength Class | Influenced areas |
|---|---|---|---|
| 1 | 4.1-4.3 | SDS | Mongolia |
| 2 | 4.5-4.9 | Severe SDS | Central  and Southern Mongolia, NW, N and NE China, Korea Peninsula and Japan |
| 3 | 4.8-4.9 | SDS | W and SE of Mongolia, Centre of Inner Mongolia |
| 4 | 4.9-4.11 | Severe SDS | West of Mongolia, NW, N and NE of China |
| 5 | 4.9-4.20 | Severe SDS | Xinjiang of China |
| 6 | 4.12-4.13 | SDS | Mongolia, Centre of Inner Mongolia |
| 7 | 4.14-4.15 | Blowing dust | SW of Mongolia, NW and N of China |
| 8 | 4.15-4.19 | Severe SDS | Mongolia, NW, N NE of China, Korea Peninsula and Japan |
| 9 | 4.20-4.25 | Severe SDS | Mongolia, NW, N NE of China, Korea Peninsula and Japan |
| 10 | 4.24-4.25 | SDS | West of Mongolia, NW and West of Inner Mongolia of China |
| 11 | 4.28-5.1 | SDS | Mongolia, NW, N NE of China, Korea Peninsula and Japan |

**Model Outputs**    With different emission schemes, dry/wet deposition and transport schemes and different driving models (online for CUACE/Dust, MASINGAR, offline for ADAM), and different horizontal and vertical resolutions, the diversity of models makes the inter-comparison difficult. A unified model outputs should be set for better comparison with obs. and inter-comparison. In Table 9, there is information about key areas, resolution, output variables and file format.

Table5-3 Outputs from Models

| Items | Elements |
|---|---|
| area | control :(70°E-150°E, 20°N-55°N);optional: (30°E-90°E,   10°N-55°N) |
| stations | TBD: depends on the surface obs. |
| horizontal resolution | 1 degree*1degree |
| vertical | surface , 850hpa,700hpa ,500hpa,etc. |
| temporal resolution | 3 hrs |
| 3D elements | dust aerosol concentration, wind speed, humidity, temperature |
| 2D elements | dust emission, deposition, ,column amount, optical thickness ,precipitation ,friction velocity |
| surface | surface wind speed, , temperature and humidity, soil moisture, snow cover, vegetation, etc |

**Observation** CMA can provide the following data for regional model inter-comparisons:
1)  PM10 (some stations_PM2.5, PM1)

2) 24-h Dust concentrations (derived from Fe)_14 Chinese stations
3) SDS synoptic data
4) Satellite retrieval SDS data (FY-2C/2D)
5) AOD_From CARSNET

KMA can provide the following data for regional model inter-comparisons:

PM10(5 stations; Gwanaksan, Baengnyeongdo, Ulleungdo, Gwangju, Gudeoksan)

AOD(2 stations; Baengnyeongdo, Seoul)

## 6 Acknowledgements

## 7 Reference

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