

WMO AIRBORNE DUST BULLETIN

Sand and Dust Storm
Warning Advisory and Assessment System

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For countries in and downwind of arid regions, airborne sand and dust presents serious risks to the environment, property and human health. Impacts on health include respiratory and cardio-vascular problems, eye infections and, in some regions, diseases such as meningitis and valley fever. Dust can carry irritating spores, bacteria, viruses and persistent organic pollutants. It can also transport nutrients to the oceans and affect marine biomass production. Other impacts include negative effects on ground transport, aviation, agriculture and the generation of solar energy. The **Intergovernmental Panel on Climate Change (IPCC)** recognizes dust as a major component of atmospheric aerosols, which are an “essential climate variable.” Dust particles are increasingly considered by atmospheric researchers as having important effects on weather through their influence on atmospheric dynamics, clouds and precipitation.

Recognizing the need for international coordination of the diverse community that deals with the societal impacts of sand and dust storms, in 2007 the World Meteorological Organization took the lead and worked with international partners to develop and implement a **Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)**. The mission of SDS-WAS is to enhance the ability of countries to deliver timely and high-quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities (Nickovic et al., 2014, Terradellas et al., 2015).



Figure 1: Sand and dust storms are common meteorological hazards in arid and semi-arid regions.

GAW / WMO

SDS-WAS operates as an international hub of researchers, operational centres and end-users and is organized through regional nodes. Three nodes are currently in operation:

- **Regional Node for Asia**, coordinated by a Regional Center in Beijing, China, hosted by the China Meteorological Administration.
- **Regional Node for Northern Africa, Middle East and Europe**, coordinated by a Regional Center in Barcelona, Spain, hosted by the State Meteorological Agency of Spain (AEMET) and the Barcelona Supercomputing Center (BSC).
- **Regional Node for Pan-America**, coordinated by a Regional Center in Bridgetown, Barbados, hosted by the Caribbean Institute for Meteorology and Hydrology.

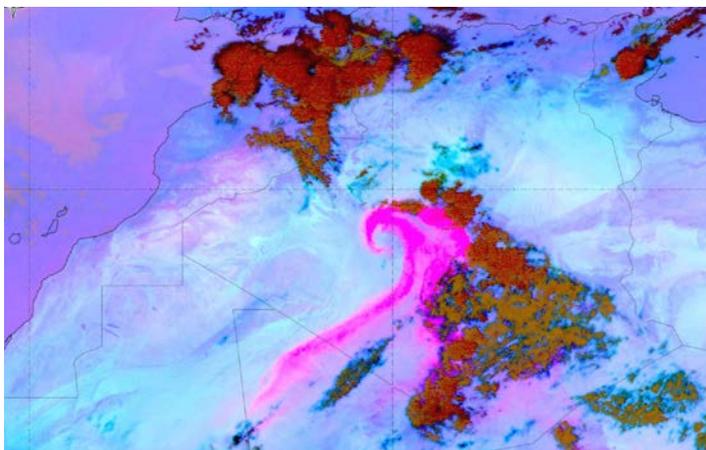


Figure 2: The METEOSAT RGB-Dust product shows a dust storm (pink area) over Algeria on 26-28 June 2016

Overview of atmospheric dust content in 2016

This first **Airborne Dust Bulletin** reports on the atmospheric burden of mineral dust through 2016, its geographical distribution and its inter-annual variation. A key challenge is that the availability of suitable dust observations is limited. Extracting specific dust signals from satellite observations is complicated by the presence of other kinds of aerosols and substances in the atmosphere. In addition, observations from sensors with visible channels are not available over bright surfaces such as deserts (Benedetti et al., 2014).

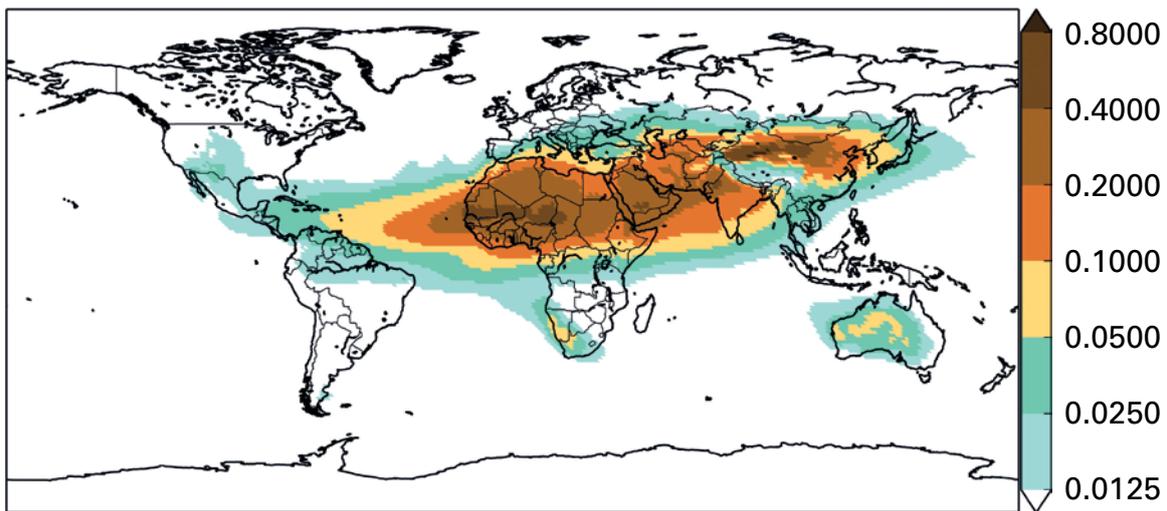


Figure 3: Annual mean distribution of dust Aerosol Optical Depth (AOD) in 2016.

For these reasons, this report relies on model simulations. Numerical models incorporate observations through data assimilation techniques, but uncertainties still persist. The estimates of dust content in 2016 presented here are derived from daily forecasts that are provided by the **Copernicus Atmosphere Monitoring Service** (CAMS, <https://atmosphere.copernicus.eu/>) based on the Integrated Forecasting System for Composition of the **European Center for Medium-range Weather Forecast**. Reference values are computed from the CAMS Interim Reanalysis of Carbon Monoxide, Ozone and Aerosol for 2003–2015 (Flemming et al., 2016), which is based on the same modelling system.

The geographic distribution of the average airborne dust content in 2016 (Figure 3) follows a pattern similar to that of the climatic values found in the literature (i.e. Ginoux et al., 2001) and also to that of the reference values considered here. The units of the Y-axis refer to aerosol optical depth (AOD), a measure of how aerosols block sunlight by absorbing or by scattering light. Most of the dust is concentrated around its main sources: the belt of tropical and subtropical deserts of the northern hemisphere, stretching from the Sahara through the Arabian and Syrian deserts to the Thar desert between

India and Pakistan, as well as the mid-latitude deserts of Central Asia (Karakum and Kyzylkum) and China-Mongolia (Taklamakan and Gobi).

From these sources, dust is transported to the surrounding regions, such as the Mediterranean and Equatorial Africa, and northern India or the eastern coast of China. Above all, it is worth noting the transport of Saharan dust over the Atlantic that can reach Central America and the Caribbean Sea. Dust content can also be observed over much of Australia, around the Kalahari Desert in southern Africa, and in the central and southern US. Other regions, such as Argentinian Patagonia, have lower, but non-negligible, values.

Figure 3 shows that the average dust aerosol optical depth is about 10 times higher in the northern hemisphere than in the southern. Much of the southern hemisphere dust is found over Equatorial Africa. It is transported there from the Sahara and the Sahel during the northern winter, when the inter-tropical convergence zone – the belt of low pressure circling the Earth near the Equator, where the trade winds of the northern and southern hemispheres come together – is in the southernmost position of its annual cycle.

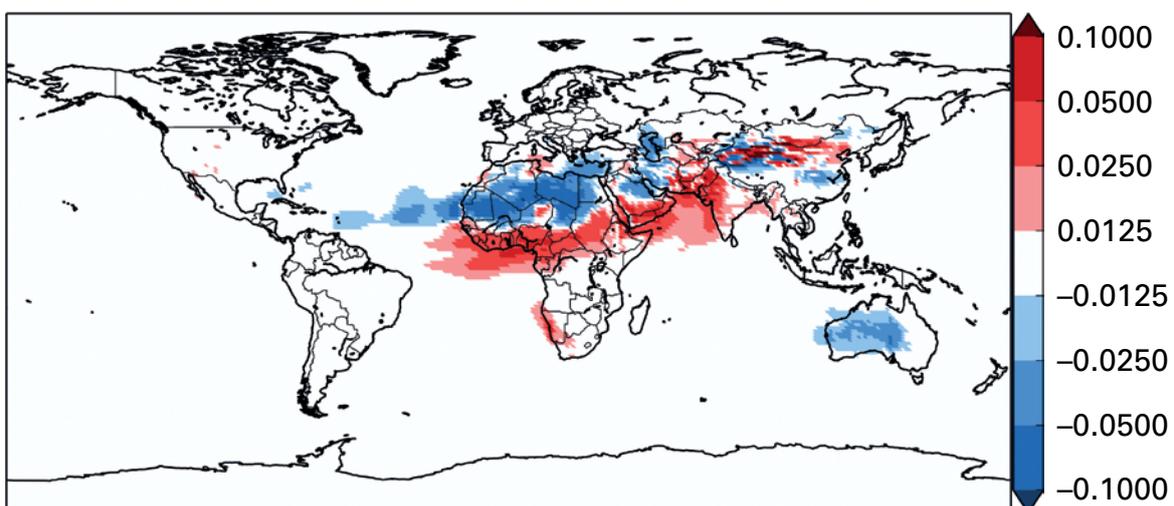


Figure 4: Anomaly of dust AOD in 2016 compared to reference values 2003-2015

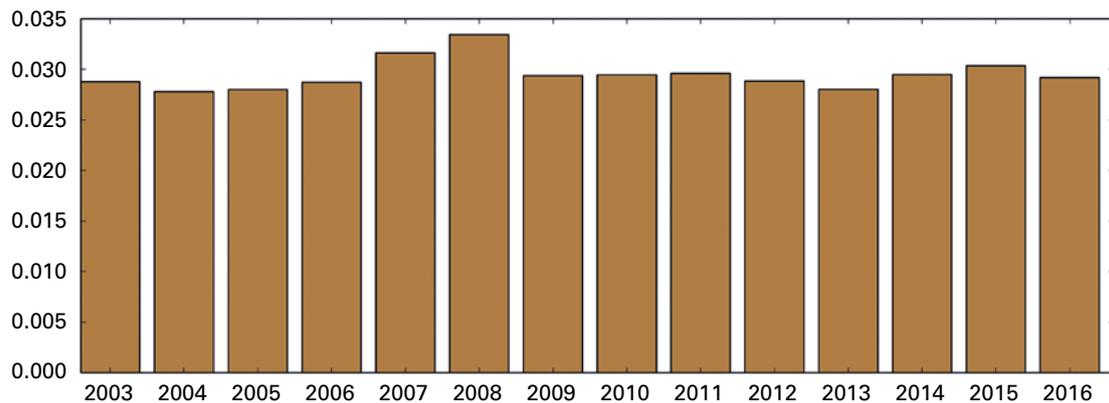


Figure 5: Annual global average of dust AOD at 550 nm

Comparing 2016 to the 2003–2015 reference levels (Figure 4) shows that less dust was observed over much of the Sahara last year, and less dust was transported over the Atlantic. Conversely, dust transport to the Gulf of Guinea and to the rest of Equatorial Africa has been higher than usual. While relatively low amounts of dust were emitted from the Sahara in the summer, a remarkable amount of dust activity occurred in the southern Sahara and the Sahel during the first weeks of the year. This is when the northerlies are dominant, which explains the positive anomaly – the increase in dust – that occurred to the south, close to the Equator.

In the Middle East, the distribution of anomalies has been uneven. In the northern part, dust levels were slightly below the 2003–2015 average, whereas in the south of the Arabian Peninsula, frequent dust episodes in the spring result in higher-than-average annual levels. Above-average levels of dust were also seen in the Pakistan-India region, where the strong spring activity led to high dust concentrations in the Indo-Gangetic basin and even in South-East Asia.

The distribution of anomalies is confusing and does not present a clear signal in China and Mongolia. Elsewhere, the dust concentration has been clearly lower than usual in Australia and higher in southern Africa.

As described in the previous paragraphs, then, at the regional scale, significant differences have been found between the estimated dust load in 2016 and the average value of previous years. However, once all of the values are integrated over the globe, the average AOD for 2016 turns out to be very similar to those of previous years (Figure 5). The differences are probably much lower than the uncertainty inherent in the estimation method, especially considering that the values for 2016 have been calculated with a model configuration that was different from the one used in previous years.

A well-defined trend from 2003 through 2016 cannot be observed, either because the model is not capable of reproducing it, or because the length of the series is too short. Different studies projecting changes in dust emissions for future conditions have so far led to widely differing results (Tegen, 2016).

Two severe episodes that occurred during 2016 are described below.

July: Severe dust event in Iran

A severe dust event occurred in July 2016 in Sistan-Baluchestan, an Iranian province located in the south-east of the country, along the border with Afghanistan and Pakistan. A progressive desiccation of the wetlands that has been attributed to climate change, a prolonged drought and overuse of water resources on both sides of the border has turned this province into one of the dustiest places on the planet (Alizadeh-Choozari et al., 2014). In particular, the disappearance in the early 2000s of the nearby Hamoun Lake has exacerbated the situation in the city of Zabol (Figure 6) to an unprecedented extent.

The Sistan endorheic basin (a closed drainage basin that retains water and allows no outflow) is the most active dust source in the interior of Iran, with an average of 167 dusty days per year. Dust storms within the basin may occur at any time throughout the year, but they are more frequent from mid-May to mid-September, when there is little or no



Figure 6: According to WHO, Iran's south-eastern Zabol city ranks first among the most polluted cities in the world.

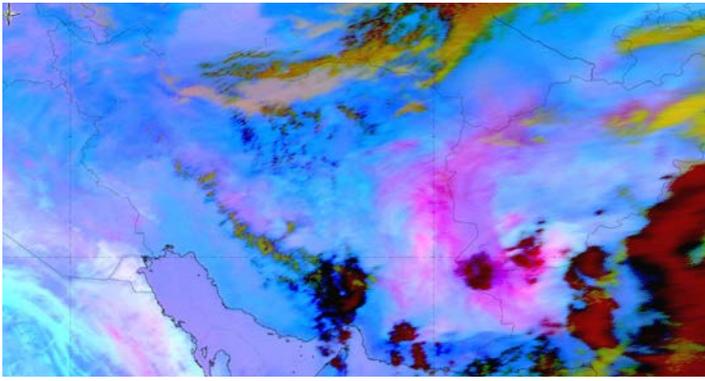


Figure 7: METEOSAT RGB-Dust product of 13 July 2016 at 12 UTC

precipitation and the strong northerly “wind of 120 days” (locally known as *levar*) is the dominant flow. This wind is the result of a meridional pressure gradient between a persistent cold high-pressure system over the high mountains of the Hindu-Kush and a summertime thermal low over the desert lands of eastern Iran and western Afghanistan. When the synoptic situation (occurring on a horizontal scale of 1 000 km or more) reinforces the wind speed, the pick-up or entrainment of dust particles from bare soils where large amounts of erodible sediment are available, particularly from dried wetlands, is accelerated.

Between 13 and 14 July 2016, a strong anticyclone over the Caspian Sea and a well-developed thermal low over western Afghanistan and southern Iran produced a significant increase in the meridional pressure gradient. This reinforced the surface wind speed and intensified dust release. The dust plume spread over the entire south-eastern part of Iran, as observed from satellite in the METEOSAT RGB-dust product of 13 July at 12:00 UTC, where dust is highlighted in pink colour (Figure 7). The daily-averaged level of small particulate matter PM₁₀ reached 10,000 µg/m³ in Zabol and visibility was reduced to less than 100 m (Figure 8). News agencies reported that thousands of people received emergency aid and dust masks from the Iranian Red Crescent as dust storms blew through the province of Sistan-Baluchestan, affecting major towns, such as Zabol, along with small towns and villages.

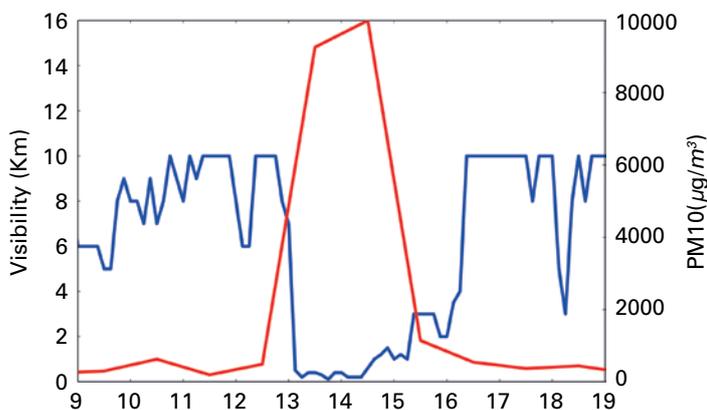


Figure 8: Daily-averaged PM₁₀ (red line) and visibility (blue line) recorded in Zabol in July 2016

The high frequency of similar episodes makes the situation unsustainable. Iran has mainly suffered due to poor water management, the depletion of underground water, and development policies that failed to consider the impact on the environment and ecosystems.. Fortunately, steps have already been taken to reverse the situation, both nationally and internationally. The UN Environment Programme (UNEP) has worked with Iran and Afghanistan to try to rehabilitate the Hamouns (seasonal or ephemeral lakes), and the UN Educational, Scientific and Cultural Organization (UNESCO) has designated them as a biosphere reservoir. At a national level, authorities are revising irrigation methods and the agricultural use of about 46 000 hectares of land in Sistan-Baluchestan to make farming more sustainable.

May: dust storm in Northern China and Mongolia

The arid and semi-arid regions of Northern China and Mongolia, stretching from the Taklamakan to the Gobi Desert, are major sources of dust. Over this vast area, dust events are frequent and sometimes severe, especially in spring. The most intense cases are usually generated by cold-air outbreaks associated with low-pressure systems. The large amounts of dust released into the atmosphere are then transported downwind by the north-westerly wind (Shao and Wang, 2003).

A severe event occurred on 10 and 11 May 2016 when a cold front with low pressure swept the region from west to east. On 9 May at 00:00 UTC, the cold front stretched from mid-Mongolia to the Chinese province of Xinjiang, moving eastwards and causing strong surface winds that raised significant amounts of dust. On 10 May at 03:00 UTC, the well-developed dust storm affected eastern and southern Mongolia, and dusty weather was reported in northern Xinjiang.

On 11 May at 03:00 UTC, the system crossed the Tian Shan mountain range, resulting in a dramatic strengthening of the wind and a dust storm in southern Xinjiang. At 06:00 UTC, the cold front moved eastwards to the Gansu province, the wind gradually weakened and the dust storm thinned. However, blowing dust persisted over Gansu, Qinghai and the western part of Inner Mongolia.

This severe dust event was successfully predicted by the models contributing to the SDS-WAS Asian node, as shown in Figure 9, where a 33-hour forecast released by the China Meteorological Administration is compared with observations.

The high frequency of dust events in the region, with peak values in the 1970s, is not only related to climatic conditions. It is also linked to the expansion of the desert due to the massive deforestation China had pursued over the years to make room for more farming and mining. In an effort to combat the loss of its grassland to the Gobi Desert, the Chinese Government started several ecological restoration projects, especially the Three-North Shelterbelt Project, also known as the Great Green Wall (GGW) in 1978. The GGW is a project to re-forest the northern provinces of China, a territory covering 4,480 km from east to west and 400 to 1,700 km from north to south (Figure 10) with 100 billion trees. So far, over 500 000 km² have been planted. The project is expected to conclude by 2050.

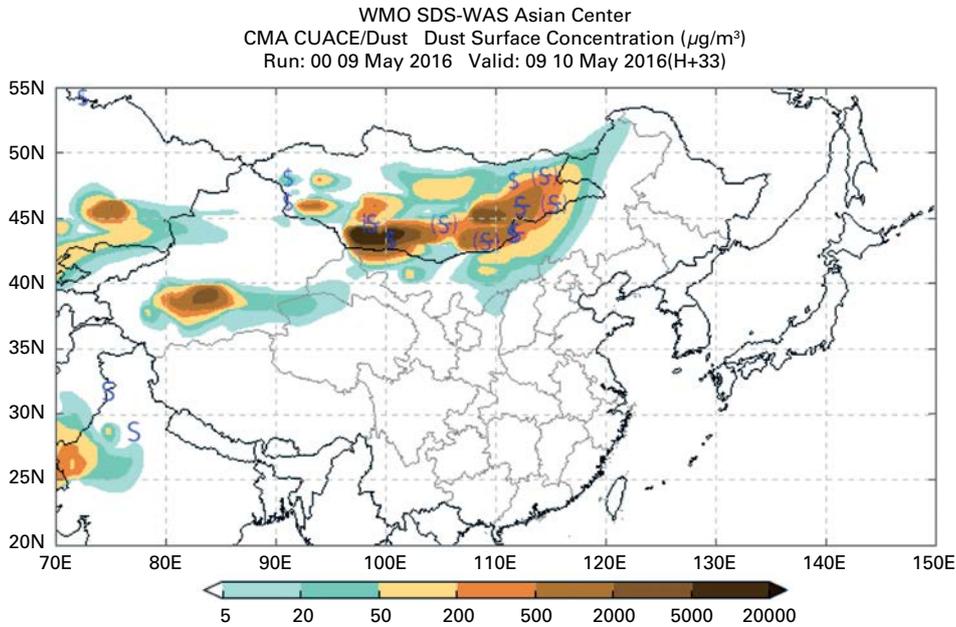


Figure 9: Dust surface concentration forecast by the CMA CUACE/Dust model valid for 10 May 2016 at 09 UTC. Dust observations are represented in blue

There is great controversy regarding the impact of these policies. Some authors consider the GGW project to have been successful, pointing to the fact that the forest cover rate has increased considerably and that vegetation conditions have improved. Both of these factors control desertification and may decrease dust storm frequency. Conversely, other studies conclude that the programme's effectiveness at controlling dust storms should be questioned, because decreases in dust storm frequency are caused mainly by climatic factors, such as a weakening of the winter monsoon (Tan and Li, 2015).

A similar initiative is planned for the Sahel, with the objective of tackling the detrimental social, economic and environmental impacts of land degradation and desertification in the region. This African Union programme is bringing together more than 20 countries from the Sahelo-Saharan region with support from many regional and international organizations.



Figure 10: Area affected by the Great Green Wall Project.

News and events

GLOBAL ASSESSMENT OF SAND AND DUST STORMS

At a request of the 70th session of the **UN General Assembly**, the United Nations Environment Programme (UNEP) has published the **Global Assessment of Sand and Dust Storms** (UNEP, WMO, UNCCD, 2016), jointly written by UNEP, WMO and United Nations Convention to Combat Desertification (UNCCD).

As stressed in the foreword by the UN Secretary-General **Ban Ki-Moon**, the report synthesizes the latest scientific information on the causes of sand and dust storms and their consequences for human and environmental well-being, and summarizes the latest knowledge on how predicting them and reducing their impact. The Global Assessment of Sand and Dust Storms proposes a consolidated and coordinated global policy for responding to sand and dust storms, integrated and synergistic actions across sectors, and strengthened cooperation among global institutions.

SDS-WAS TECHNICAL REPORT: INTERANNUAL VARIABILITY AND DECADEAL TRENDS IN MINERAL DUST AEROSOL

SDS-WAS has published the Technical Report **Inter-annual Variability and Decadal Trends in Mineral Dust Aerosol** (Tegen, 2016).

ABSTRACT: Atmospheric mineral dust concentrations may vary greatly on daily, seasonal and inter-annual time scales, as well as in different climates. Dust emissions depend on meteorological conditions and on surface properties, which may change at different time scales. While seasonal changes in the atmospheric dust load are well characterized, given that they follow the seasonal changes in meteorology and vegetation patterns, inter-annual changes and decadal trends

in dust emission and atmospheric loads can be of similar magnitude, but are less easy to explain. Dust loads may change in response to different meteorological conditions in individual years, which may in turn be related to climate modes. Other reasons for multi-year trends in emission and atmospheric loads of dust particles can be changes in vegetation cover in source regions. Modifications in vegetation cover can result from climatic changes and from modifications of surface properties in dust-emitting regions. Model studies projecting changes in dust emissions for future conditions have so far led to widely differing results. Early estimates using global dust models that consider projected climate changes as well as vegetation changes in a warming climate that change the extent of dust sources have led to a wide range of results – estimates have ranged from about 50% decrease to 50% increase in global dust emissions in the next century.



INTERNATIONAL WORKSHOP ON SAND AND DUST STORMS

The **International Workshop on Sand and Dust Storms** was held in Istanbul, Turkey, on 4-7 October 2016. It was hosted by the Turkish Ministry of Forestry and Water Affairs, the General Directorate of Combating Desertification and Erosion and the Turkish Meteorological Service with technical support from WMO, UNEP and UNCCD. The event was attended by 89 participants from international organizations and 16 countries were represented (Algeria, Chad, China, Egypt, Iran, Iraq, Italy, Kuwait, Pakistan, Qatar, Saudi Arabia, Somalia, Spain, Sudan, Turkey and Turkmenistan).

The workshop appreciated the joint efforts of UNCCD, UNEP and WMO in their coordination of activities on sand and dust storm (SDS) issues, in particular in writing the Global Assessment of SDS and a further initiative for elaboration of a Technical Guide for SDS. However, better coordination



and harmonization between UN bodies and national agencies was requested to address the implementation of a West Asia regional research plan and the establishment of regional SDS-WAS centre(s) in the region.

Other issues discussed during the workshop were the way to improve data availability, the need to assess the economic impact of SDS and the definition of mitigation measures.

SDS-WAS MODEL INTERCOMPARISON AND FORECAST EVALUATION



Since 2011, the **SDS-WAS Regional Center for Northern Africa, Middle East and Europe** conducts dust model intercomparisons and forecast evaluations. In 2016, there were 12 models contributing to the initiative.

Forecasts of dust surface concentration and dust optical depth for lead times up to 72 hours are daily plotted side by side with the same geographical framework and colour palette.

Then, multi-model products are generated from the different predictions. In particular, two products describing centrality (multi-model median and mean) and two products describing spread (standard deviation and range of variation) are computed.

Finally, AOD retrievals from remote-sensing measurements are used for a common evaluation system. Data provided by the Aerosol Robotic Network (AERONET) and the MODIS spectrometer travelling on board Terra and Aqua NASA's satellites are used for this purpose.

IZAÑA: 100 YEARS OF ATMOSPHERIC OBSERVATION

The Izaña Observatory (Tenerife, Spain) celebrated its 100th anniversary in 2016. This observatory, strategically located in the Saharan dust outflow corridor to the sub-tropical North Atlantic, has one of the longest high-quality mountain meteorological data series in the world.

Prof. Christian E. Junge, considered the founder of modern atmospheric chemistry, was the first researcher that analyzed (in the 1950s) the long-range transport of Saharan dust to the Americas. In 1968, during a field campaign at the observatory, he realized the great atmospheric environment of Izaña. Prof. Joseph M. Prospero continued Junge's studies and, in the 1970s, he conducted a series of projects for the characterization of atmospheric aerosols, and specifically of mineral dust, at the observatory. He was indeed the pioneer in the investigation of atmospheric aerosols in Izaña.

At present, the Izaña Observatory has one of the longest data series of aerosols and dust chemical composition in the world (1986-2016). It is an absolute calibration center of AERONET master photometers and runs a comprehensive aerosol programme including in situ and remote measurements, in



which the characterization of Saharan mineral dust is one of the main objectives.

The Izaña Atmospheric Research Center (AEMET), which manages the observatory, has been a key element in the implementation of the SDS-WAS Regional Center for Northern Africa, Middle East and Europe.

SECOND MEETING OF THE WMO SDS-WAS STEERING COMMITTEE

The second meeting of the **Steering Committee of SDS-WAS** was held on 20 September 2016 in Jeju, Korea, hosted by the Korea Meteorological Administration. On the occasion of this event, an **International Asian Dust and Aerosol Workshop** and a meeting of the **SDS-WAS Regional Steering Group for Asia** were organized in the same venue. The Steering Committee emphasized the interdisciplinary nature of the dust problem, thus requiring close collaboration between WMO and other United Nations agencies. For this reason, WHO, UNEP and UNCCD representatives had been invited to the meeting.

The Committee discussed extensively on the difficulty of finding suitable products for dust monitoring, data assimilation and forecast evaluation, and investigation of long-term trends. It was decided to create a task team with the mission to write a white paper describing the state-of-the-art, existing gaps and recommendations for future actions.

It reported on the creation in Barbados of an **SDS-WAS Regional Centre for the Americas**, hosted by the Caribbean Institute for Meteorology and Hydrology. Also, on the steps made for the designation of China Meteorological Administration to host a Center for operational sand and dust forecast in Asia.

INTERNATIONAL ASIAN DUST AND AEROSOL WORKSHOP

The 2016 **International Asian Dust and Aerosol Workshop** was organized by the **National Institute of Meteorological Sciences** of Korea.

The workshop commenced with keynote speeches from Alexander Baklanov (WMO), who outlined the status and

future plans of SDS-WAS, and Xiaoye Zhang (CMA), who described the impact of high concentrations of mineral dust in Asia. Then, a series of talks on observation and analysis, modelling and prediction, and other aspects of dust and aerosol science depicted the current state of knowledge and highlighted different initiatives aimed to improve the capacity to monitor and forecast atmospheric aerosol and airborne dust in particular.



MEETING OF THE SDS-WAS REGIONAL STEERING GROUP FOR ASIA

The meeting of the **SDS-WAS Regional Steering Group** for Asia was attended by representatives of the National Meteorological and Hydrological Services (NMHSs) of Korea, Japan, China, Mongolia and Kazakhstan, in addition to WMO and the Chairperson of the SDS-WAS Steering Committee.

Firstly, progress was reported in the exchange of observational data among the partners. Data included measurements from stations jointly operated by different countries.

Progress has also been made in the exchange of numerical predictions. Currently, the Regional Center collects and distributes through its website daily predictions from ECMWF and NOAA, in addition to those provided by the NMHSs of China, Korea and Japan. It highlighted the work done by several partners in data assimilation and it was agreed to create a working group to share the experience gained.

Finally, the CMA confirmed its application to host an operational dust forecast centre and reported the steps taken to achieve this goal.

CHINA WILL HOST A WMO REGIONAL METEOROLOGICAL CENTER SPECIALIZED ON ATMOSPHERIC SAND AND DUST FORECAST

The Sixteenth Session of the WMO Commission of Basic Systems held in Guangzhou, China, on 23-29 November 2016 acknowledged that **China Meteorological Administration**, in the framework of the SDS-WAS, has demonstrated its capabilities to comply with the mandatory functions entrusted to operational dust prediction centres. Accordingly, it recommended the establishment in Beijing of a **Regional Specialized Meteorological Center with activity specialization on**

Atmospheric Sand and Dust Forecast (RSMC-ASDF). The formal designation is expected to be done in 2017 by the WMO Executive Council. In this way, CMA will operationally provide daily dust predictions for Asia. Currently, the Barcelona Dust Forecast Center is the only RSMC-ASDF. It distributes dust forecasts for Northern Africa, Middle East and Europe since 2014.



KOREA-USA AEROSOL MEASUREMENTS IN THE YELLOW SEA

The Korean government and NASA teamed up for the KORUS-AQ campaign, conducted from 1 May to 12 June

2016 on the Korean Peninsula and surrounding seas. The campaign included ground-based, vessel, aircraft and satellite measurements. Its main scientific goals are to increase fundamental understanding of the chemical processes that influence air quality and ultimately the health of millions of people, to advance the ability to monitor atmospheric aerosol and other air pollutants from space, and to improve the modelling of air quality, affected both by local sources and by long-range transport.

Although the KORUS-AQ campaign was finished in 2016, the vessel measurements of aerosol over the Yellow Sea will be continued by the National Institute of Meteorological Sciences for further understanding of physical and chemical characteristics of aerosol and its impact on climate.



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