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SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

Science and Implementation Plan: 2021-2025

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

World Meteorological Organization

Global Atmosphere Watch (GAW)

SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

SCIENCE AND IMPLEMENTATION PLAN: 2021–2025

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1. MISSION

The WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) addresses two aspects of SDS: the complex science issues; and the technical aspects needed to coordinate, cooperate and fill in the gaps regionally and globally − those that are too difficult to be tackled by a single nation, agency or scientific discipline alone. Through international science coordination and successful partnerships, SDS-WAS leads the way in understanding the fundamentals of the SDS and its interactions with human activities, weather, and climate change and provides the warning advisory and assessment of SDS. Overall, the SDS-WAS intends:

- To facilitate international coordinated research, through the Earth system approach, in order to advance SDS forecasting and to improve its integration with general air quality and chemical weather forecasting, in response to user requirements for more tailored services;
- To provide research components which are sufficiently developed for operational implementation;
- To promote the use of dust products through the organization of training activities;
- To build capacity to enhance collaboration and to enlarge the SDS monitoring and modelling capabilities.

SDS-WAS also contributes the SDS science that underpins the United Nations Coalition for Combating Sand and Dust Storms. This coalition comprises more than fifteen Member organizations of the United Nations (UN), including: WMO, the United Nations Convention to Combat Desertification (UNCCD), the United Nations Environment Programme (UNEP), the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the Economic and Social Commission for Asia and the Pacific (ESCAP). It promotes and coordinates a collaborative United Nations system response to SDS issues, on local, regional and global scales. In this United Nations Coalition, WMO is leading the Working Group that focuses on SDS forecasting products and early warnings. Annex 3 includes detailed information on the SDS-WAS contribution to United Nations Cooperation including the United Nations Coalition.

2. SAND AND DUST STORM SCIENTIFIC CHALLENGES

Atmospheric dust consists of tiny mineral particles originating from soils in the arid and semi-arid parts of the Earth. When lifted by the wind, dust can be transported over thousands of kilometres to be finally deposited on the land, vegetation and glaciers, or into the ocean. The Intergovernmental Panel on Climate Change (IPCC) recognizes dust as a major component of atmospheric aerosols, one of the essential climate variables that characterize the Earth's climate. Atmospheric researchers increasingly consider that dust particles significantly affect weather as they are involved in feedback processes related to atmospheric dynamics, clouds and precipitation formation. Dust is gaining visibility because of its direct impact on society and the economy; airborne dust can carry irritating spores, bacteria, viruses and persistent organic pollutants and in, or downwind of, arid regions, sand and dust storms present severe risks to human health, the environment and infrastructure. Impacts on health include respiratory and cardiovascular problems, eye infections, and increased risk of infectious diseases in some regions, such as meningitis in Sahel and valley fever in Arizona. Dust can also transport nutrients to other parts of the world, like the oceans, where it can affect marine biomass production. Other impacts include adverse effects on ground transport, aviation, agriculture and solar energy generation.

2.1. Dust interactions with weather and climate processes

Not only meteorological conditions can affect the global aerosol budget (including dust), but the increased aerosol loading can also modify meteorological conditions. The climate modelling community first addressed the role of aerosols in Earth's radiation balance in the early 1990s

(Crutzen and Andreae 1990; Charlson et al. 1991; 1992). Aerosols can also modify the radiative forcing of climate change through their interaction with clouds as cloud condensation nuclei (CCN) (Albrecht, 1989; Haywood and Boucher, 2000; Lohmann and Feichter, 2005).

Given the influence of atmospheric aerosols on weather forecasting, an in-depth understanding of aerosol-radiation interaction, aerosol-cloud interaction and the resulting thermal and dynamic changes of the atmosphere is an increasingly important area of research; in particular, the aerosol impact on the Planetary Boundary Layer (PBL) structure, and the feedback effect of PBL changes (Vogel and Baklanov, 2013-2018; Benedetti et al., 2018). Understanding of aerosol-weather interactions not only enhances the accuracy of SDS forecasts but will also improve numerical weather forecasts for temperature and precipitation during high pollution seasons. It can even affect the long-term prediction precision of dust on the subseasonal-to-seasonal (S2S) scale.

Benedetti and Vitart (2018) explored whether aerosol variability could offer some predictability in S2S forecasts. Their work shows that predictability is afforded by the aerosol variability connected to the different phases of the Madden-Julian oscillation, notably, the variability of dust and carbonaceous aerosols. The degree of improvement depends crucially on aerosol initialization, which underlines the importance of having accurate aerosol analysis, well constrained by observations. In addition, the research demonstrated the possibility of having skilful dust forecasts at the monthly scale, as illustrated in Figure 1. The fact that the calculation of dust emissions is based on model parameters (i.e. surface winds) allows for the provision of the emissions throughout the forecast range. The forecasts initialized from the Copernicus Atmosphere Monitoring Service (CAMS) Interim Reanalysis (Flemming et al., 2017; Inness et al., 2019) are more skilful than persistence. More research and effort will be needed to move from these initial attempts to a service-like provision of dust forecasts at the S2S scale in the coming years.

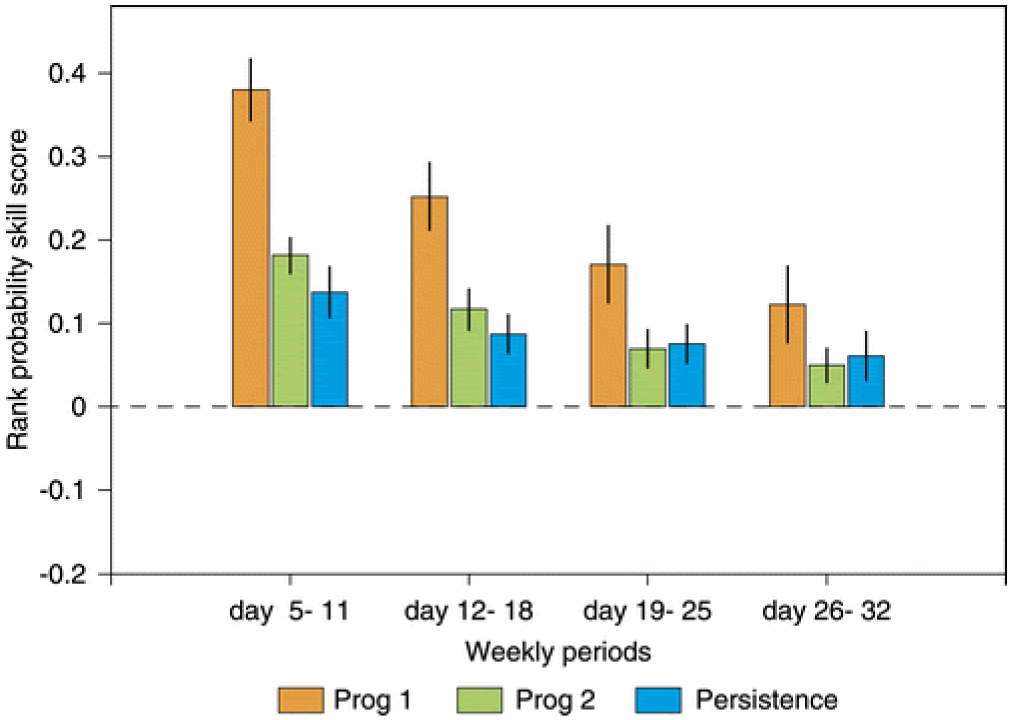

Figure 1. Skill of the dust forecast over a month measured by the ranked probability skill score (RPSS) for experiments PROG1 (orange) in which the aerosols were initialized using the CAMS Interim Reanalysis and PROG2 (green) in which the aerosols were initialized with an aerosol climatology with respect to a persistence forecast (blue) of dust optical depth for the tropics. Figure 12 from Benedetti and Vitart (2018).

Otherwise, soil dust aerosols are mixtures of different minerals whose relative abundances, particle size distribution (PSD), shape, surface topography and mixing state influence their effect on climate. At present, Earth system models poorly represent the local/regional variations in dust mineral composition due to two main challenges: (1) Our knowledge of the global soil-surface mineralogical composition is limited due to a lack of observations. (2) There is an incomplete understanding of the emitted dust PSD in terms of its constituent minerals (which result from the fragmentation of soil aggregates during wind erosion). The first challenge, the determination of the mineral composition of natural sources that produce dust aerosols around the world, is being tackled by the Earth Surface Mineral Dust Source Investigation (EMIT), which will use a hyperspectral sensor developed by NASA and mounted to the exterior of the International Space Station (ISS), as well as the German Environmental Mapping and Analysis Program (EnMAP). The second challenge, around the understanding of the emitted dust PSD, is one of the main goals of the **Fr**ontiers in Dust Miner**a**lo**g**ical Co**m**position and its **E**ffects upo**n** Clima**t**e (FRAGMENT) project. FRAGMENT seeks to understand and assess the global mineralogical composition of dust along with its effects upon climate.

2.2. Local-scale SDS

Local-scale phenomena such as convective downdrafts over arid regions lead to the formation of density currents and the generation of the severe "haboob" dust storms (e.g. Solomos et al., 2017). In addition, when the traveling dust layers arrive over mountainous ridges downwind of their sources, local flows (e.g. Foehn winds) can result in increased surface concentrations, especially on the leeward side of the mountains (Solomos et al., 2018). One of the principal limitations for the assessment of these local-scale SDS is the lack of information on surface dust/aerosols in the areas near the dust sources.

Ground-level dust aerosol concentration plays a critical role in air quality and human health particularly in areas near dust sources, however, it cannot be detected by satellite remote sensing. Furthermore, PM_{10} measurements are necessary to evaluate and correct the surface dust concentration information provided by models that have a much higher associated uncertainty than that of Aerosol Optical Depth (AOD). There is a broad range of low-cost $PM_{2.5}$ / PM_{10} analysers on the market, but first these must be carefully evaluated against reference instruments. Some tests and studies have already been carried out (Peletier et al., 2021). The use of low-cost instruments should be encouraged, but with due caution and the necessary quality assurance, to fill large observation gaps on aerosols, and specifically dust, in remote regions close to dust sources, mainly in Northern Africa, Middle East and Asia, where there are very few ground-based instruments.

For the classic parameters, AOD and Ångström exponent (AE), new, robust zenith-vision radiometers could be used. These instruments have no moving parts, low power consumption, and a lower cost and could be an alternative to the more sophisticated classic photometers (for example, the CIMEL photometers in the global NASA AERONET network). They can be used in remote sites where technical maintenance staff and instrument replacement possibilities are minimal. These new instruments, and their corresponding measurement methodologies, have already been sufficiently tested (Almansa et al., 2017; 2020). In parallel, the possibility of equipping airport meteorological observatories and hundreds of small airfields in these remote areas with hand-held photometers could be explored. These modest and easy-to-use instruments have proven effective in quantifying dust-AOD for AOD> 0.05 (Guirado et al., 2014) in desert areas. A large amount of information on dust-AOD and AE, of enormous importance for data assimilation, would be obtained if this information were reported together with the surface synoptic observations (SYNOP) and/or Meteorological Aerodrome Reports (METAR) portions (via WMO Information System – Global Telecommunication System, WMO WIS-GTS). These observations are necessary to evaluate satellite measurements in highly reflective soils and to evaluate dust prediction models.

Furthermore, mesoscale convective systems (associated with the generation of "haboobs") are not well reproduced by models; consequently, neither are the associated SDS. Mesoscale systems and their downbursts and wind gusts are thought to be responsible for one third of the winds capable of uplifting sand and generating an SDS during the convective season (Vukovic et al., 2021). The location and timing of these systems have proved difficult to predict, even for the new generation non-hydrostatic high-resolution models. One method to deal with dust emission of mesoscale convective systems is to implement a specific parametrization for them in the models (see Pantillon et al., 2015). Other types of local-scale SDS are linked with the effects of anthropogenic land disturbance on dust emission and the desiccation of playas (Gill 1996), as well as mining and related operations (e.g. tailing dumps, ore enrichment activities) that can create dust sources. For such sources, future dust models need to consider the interactions with surface characteristics and geometry with local-scale CFD-type models (e.g. Amosov et al. 2014).

2.3. Heterogeneous reactions on dust interface

Studies have explored heterogeneous and/or multiphase chemical reactions between dust aerosols and trace gases in the atmosphere and how they may generate secondary aerosol particles on the dust surface and subsequently change their physicochemical properties, including hygroscopicity, chemical composition, size and morphological characteristics (Tang et al., 2017; Crowley et al., 2010; Usher et al., 2003; Dentener et al., 1996). Heterogeneous reactions can enable dust aerosols coated with particles with high hygroscopicity to activate more efficiently to CCN and ice nuclei (IN), altering the radiation budget and climate (Tang et al., 2016; Kelly et al., 2007). This may have a significant impact on the prediction of dust aerosol concentration and its related SDS forecast in regions with high dust aerosol concentration and high emission of anthropogenic aerosols. It may also have a significant impact on air quality forecasts and related fog-haze prediction.

Heterogeneous reactivity is highly dependent on dust mineralogy, relative humidity, temperature, co-presence of trace gases, and mutual influences between these factors, giving rise to high uncertainty in heterogeneous reactions (Tang et al., 2017). How to identify sensible and necessary heterogeneous chemical reaction mechanisms on the basis of inadequate observation and experiments and reliably apply them to the SDS forecasting system is one crucial aspect. How to logically sort heterogeneous chemical reaction processes of different grades of complexity and to enable them to be implemented in operational forecasting is another critical issue. This is also essential for dust aerosol and other anthropogenic aerosols forecasts with respect to the impact on the chemical reaction pathway on nitrate, sulfate, and organic carbon aerosol at dust surface through aqueous and other heterogeneous chemical reactions.

There is a need to explore the benefits of the nest schemes of heterogeneous reactions for the SDS numerical forecast system; they may play an important role in improving SDS prediction in the future. The benefits may also extend to future cloud simulation and forecasting in high pollution areas and to future chemical weather numerical forecasting systems. Progress in this area will also promote the study of the impact of natural source dust aerosols on climate change and weather.

2.4. SDS reconstruction

There is an urgent need to develop hazard maps and other disaster countermeasures in arid areas and their vicinity, where SDS have caused significant damage to human life and livestock. Moreover, in terms of transportation and industry, SDS have a substantial impact on traffic disruptions and the production of renewable energy (solar power projection). To accurately assess and predict these impacts, it is essential to have a precise picture of the dust storm conditions in the past. One of the challenges in providing SDS forecasts and services is the paucity of direct in-situ measurements, particularly in the areas most affected by SDS (Di Tomaso et al., 2022). Satellites typically provide column-integrated aerosol measurements, but observationally constrained continuous 3D dust fields are needed to support SDS services for a variety of socioeconomic sectors.

The observational methodologies currently employed for dust from ground and space are limited in terms of the necessary information and content they provide. Currently, there is no complete solution for the remote sensing of dust from the ground or space which can take in the range of dust sizes, shapes, chemical composition, refractive indices and the possible orientation of dust particles (Ulanowski et al., 2007). For example, for monitoring the larger particles, near-infrared and infrared measurements are needed. Additionally, the code used for remote-sensing retrievals for calculating the optical properties of dust has limited applicability due to the oversimplified treatment of the shape and size of the particles. Specifically, the irregular shape of dust is usually modelled using spheroids which does not always reproduce the optical properties of dust (see for example Wiegner et al., 2009). The scattering databases that are constructed with respect to realistic shapes are limited in size range (e.g. Gasteiger et al., 2018; 2011) due to the extensive computing resources required for larger sizes. To further extend this activity, there is a need for faster solutions provided by new, speedier scattering codes, and for greater access to high-performance computing systems. Advancements in dust observations are expected from future satellite sensors employing polarization measurements, as well as from new ground-based lidar systems, specifically designed to monitor dust (e.g. Tsekeri et al., 2020).

The development, collection and archiving of multiscale observations of SDS by robust and straightforward methods and instruments or satellite-retrieval-based observation are the foundational activity of global SDS research and operational forecasts. In the coming years, we encourage the SDS community to establish a satellite retrieval-based global or regional SDS observation virtual network supported by the existing SDS global observation system. Machine learning approaches are needed to build this virtual gridded network. Compared to traditional algorithms, machine learning methods have shown strong application potential in the retrieval and prediction of key pollution indicators (such as $PM_{2.5}$ or PM_{10}) (Gui et al., 2020). In the model training and evaluation stage, the ground-based global observation data will be used for training and cross-verification. These machine learning approaches are expected to achieve complete spatial-temporal coverage estimation of key SDS-related parameters such as near-ground PM_{10}. The virtual PM_{10} grid observation networks are also essential for numerical assimilation in the coming years. This will permit the reanalysis of a historical (10–15 years) surface PM_{10} concentration data set over different timescales. The former can be applied to the near real-time monitoring of varying spatial scale requirements of SDS while the latter can be used as the primary data set for scientific research.

Numerical models have the advantage of being able to produce spatially and temporally uniform data but are always subject to uncertainties. A reanalysis product using a data assimilation method that organically integrates observational data and models is undoubtedly the best tool for understanding past SDS. The aerosol reanalyses, based on the assimilation of satellite AOD data, have been made available by CAMS, (https://atmosphere.copernicus.eu/) for several years. The latest version of the CAMS reanalysis covers from 2003 to the present-day and is described in Inness et al (2019). It is publicly available at https://www.ecmwf.int/en/research/climate-reanalysis/cams-reanalysis. These reanalyses have been used in several assessments such as those published in the bulletin State of the Climate - American Meteorological Society (ametsoc.org). Other aerosol reanalyses include the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) (Randles et al 2017) which goes back to 1980 and the US Naval Research Laboratory (NRL) 11-year aerosol reanalysis (Lynch et al 2016). More recently, Di Tomaso et al. (2022) presented an advance high-resolution dust regional reanalysis. All these reanalyses have laid a foundation for the SDS community to carry out a further reanalysis of SDS. SDS-WAS will encourage the sharing of models and observation data among its partners and collaborators in order to: further develop standard validation methods; foster intercomparison of dust reanalysis to meet user needs; endorse sharing reanalysis data with United Nations SDS coalition partners; to extend impact-based prediction and warning services; improve regional innovation and strengthen regional development. We will investigate the simulation of dust-weather interactions in the two-way coupled SDS modelling system with data assimilation capabilities for both meteorology and chemistry.

3. OVERARCHING SAND AND DUST STORM CHALLENGES

3.1. SDS-WAS within WMO

Given societal needs for monitoring and forecasting SDS, and for assessing its impacts, in 2005, WMO launched a Sand and Dust Storm Research Development Project and created an ad-hoc Steering Committee (SC). More than forty Member countries expressed interest in participating in activities to improve capacities for more reliable SDS monitoring, forecasting and assessment. In 2006, the SC of the Sand and Dust Storm Research Development Project proposed the implementation of a Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS). In 2007, the fourteenth WMO Congress endorsed launching SDS-WAS with its mission to enhance the ability of WMO Members to deliver timely and quality SDS forecasts, observations, information and knowledge to users through an international partnership of research and operational communities.

SDS-WAS is considered a **WMO research activity**. Initially, SDS-WAS was jointly coordinated by the WMO World Weather Research Programme (WWRP– 2016-4) and Global Atmosphere Watch (GAW); both programmes are under the WMO Science and Innovation department (the research branch of WMO). Since 2022, SDS-WAS has been coordinated by the WMO GAW programme and has collaborated with WWRP and other WMO and United Nations agency programmes.

SDS-WAS follows the priority action areas as set out in the WWRP Implementation Plan 2016–2023 (WWRP– 2016-4) and has selected four main focus areas: "Address Limitations"; "Advanced Methods"; "New Observations"; and "Applications". SDS-WAS also heeds the GAW Implementation Plan 2016–2023 (GAW Report No. 228); in particular, the section 2.1 recommendations for "Forecasting Atmospheric Composition Change and their Induced Environmental Phenomena, including support for operations such as sand and dust storm warning, haze-fog prediction and chemical weather forecasts"

SDS-WAS is cooperating and coordinating with GAW, and its contributing networks, to use GAW observation system data for model evaluation and data assimilation and to obtain: non-traditional meteorological observations and chemical and physical processes of aerosol (including dust) for as many models as necessary; output, such as aerosol number concentration, new particle formation processes, chemical compositions, hygroscopic growth of aerosol, CCN activation and optical-radiation features; and more accurate aerosol distribution beyond climatological significance.

SDS-WAS is also working with the GAW Urban Research for Meteorology and Environment (GURME) and Modelling Applications Scientific Advisory Groups in the application of near real-time non-traditional meteorological data on haze-fog operational forecasts. The dust observation networks are expected to be further developed in close cooperation with the GAW Scientific Advisory Group on Aerosols.

SDS-WAS efforts have also been made to study the impact of the fully prognostic and interactive aerosols (including dust) on relevant numerical weather prediction variables, with international coordination in the domain of Earth system science with the Working Group on Numerical Experimentation. It is of great importance to represent the dust lifecycle accurately in Earth system models (e.g. Scanza et al., 2015, Li et al., 2021) for the assessment of mineral dust in response to climate change. In particular, there are distinct differences in simulated dust properties in the same climate model under different aerosol model configurations (e.g. Wu et al., 2020). In the context of this plan SDS-WAS will be more closely linked to climate research under the World Climate Research Programme (WCRP).

SDS-WAS will continue contributing to the current WMO global studies and formulation of priorities for further research in coupled chemistry-meteorology modelling (CCMM) within the Earth system prediction science (WMO-No. 1156, WMO-No. 1172, Baklanov et al, 2017) according to the Research Board (RB)'s Concept Note and Plans for "Earth system

Prediction" (RB.WMO, 2021a). Some nodes of SDS-WAS work with the S2S Working Group to carry out seasonal forecasting of Asian SDS associated with genetic algorithms and deep learning techniques; to demonstrate the possibility of making skilful dust forecasts at monthly scales. The studies performed by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Benedetti and Vitard, 2018) explore the impact of interactive aerosols, particularly dust, on subseasonal model predictability. In the previous phase SDS-WAS has had a very fruitful collaboration with the WMO Space programme (e.g. SCOPE-Nowcasting) and expect to continue this cooperation. SDS-WAS will coordinate with the Data Assimilation and Observation System Working Group (DAOS WG) in WWRP to take advantage of research activities and to reduce any possible gap between the meteorological community and the "air quality/aerosols" community in terms of data assimilation. Accordingly, SDS-WAS will support and promote research projects that aim to develop a new scheme for "haboobs" that can be taken into consideration in operational forecasting.

As one of the major components of aerosol particles, dust aerosol continues to have an impact on air quality worldwide. In regions with higher population density, the impact of anthropogenic activity on dust and air quality is an ever-increasing issue. In the context of WMO's encouragement of science for services and the shift from traditional meteorology to Earth system science, GAW provides air quality research and supports air quality initiatives such as the Prediction and Forecasting Improvement for Africa (PREFIA) for the Pan Africa continent (https://public.wmo.int/en/resources/meteoworld/advances-made-towards-increased-air quality-prediction-and-forecasting-capacity) and the Global Air Quality Forecasting and Information System (GAFIS). GAFIS is focused on reducing the current health burden of pollution on society, saving environmental resources and supporting socioeconomic development.

Strengthening the connection of SDS-WAS with GAW related projects (atmospheric composition observation, air quality analysis, forecasting of atmospheric components and its induced environmental phenomena, such as SDS, haze-fog, forest fires etc.) and Earth system modelling is expected and encouraged. SDS-WAS is considered a starting platform and one of the prototypes for GAFIS for the realization of the chain from research to operational systems and services. Successful SDS-WAS experience and organizational systems will be provided as examples of good practice for the realization of global, regional and national projects combining research, operations and services to address specific problems in the context of the WMO focus on science for services.

SDS-WAS experience can be used to address the problems of establishing a project that has clear operational objectives and maintains continuity of scientific research communities given the variation in the availability of resources, in the skill levels of scientific research teams and in mandates and user constraints across countries.

In the next five years from 2021 to 2025, SDS-WAS will continue its existing cooperation with other projects (e.g. WWRP and WCRP) under the guidance of the framework of GAW current and future IPs; and it will open up new cooperation and expand its visibility to make contributions to the regional and global coordinated scientific research carried out by WMO.

3.2. SDS-WAS scientific and technical challenges

There is growing demand from Members, particularly those in, around and downwind of arid and semi-arid regions, for products that help reduce the adverse impacts of SDS and assess the impacts of SDS on society and the environment.

The first version of the *Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Science and Implementation Plan* (SIP) was for 2011–2015 (WMO, 2012); the second version, for 2015–2020 (WWRP- 2015-5), was approved by the Seventeenth World Meteorological Congress. In 2020, the SDS-WAS Steering Committee revised the future science priorities in the third version of the SIP for the years 2021–2025. The Eighteenth World Meteorological Congress in 2019 adopted Resolution 19 (Cg-18) – Enhancing cooperation for monitoring and forecasting sand and dust storms, which calls for: the promotion of international cooperation to combat sand and dust storms through the exchange of knowledge, experiences, best practices and by launching training courses; enhancement of capacity building and technical assistance for monitoring and forecasting sand and dust storms and support for the implementation of national, regional, and global action plans of affected countries.

The main achievements of SDS-WAS and the current status of SDS-WAS research and development are described in: the recently published scientific progress reports of SDS-WAS, GAW Report No.254/WWRP- 2020-4; Cuevas et al., 2021; the Global Assessment of Sand and Dust Storms (UNEP, 2016); the SDS Compendium (UNCCD 2022) and the WMO Airborne Dust Bulletins (nos.1, 2, 3, 4, 5, 6). They are also reflected in the reports of the Secretary-General to the General Assembly (United Nations Secretary-General, 2018, 2019, 2020).

In the coming years, SDS-WAS will, for all participating groups, support and promote research projects that aim to explore the impact of the prognostic and interactive aerosols on relevant numerical weather prediction variables. It will also add the dust-IN or related parameterization scheme into the fully coupled models and study and advance the treatment of turbulence decrease and intermittent turbulence in the PBL by aerosol (including dust) during heavy aerosol or dust storm episodes. It is necessary to transfer the knowledge and results gained in the SDS-WAS project to other communities and to co-design joint-research activities to optimize the usefulness of outcomes and to ensure that efforts are not being duplicated through the exchange and cooperation mechanism between different groups and projects in GAW.

SDS-WAS has been integral in promoting and enabling SDS services for air quality and human health, agriculture, marine productivity, ground transportation, infrastructure and industry (e.g. tourism, solar energy). Society's needs have been evolving, and SDS science is called upon to support the knowledge required for prudent disaster prevention, mitigation and adaptation choices in a constantly changing world. Society's expectations of SDS science are higher, with scientists being asked to deliver improved forecasts and predictions and long-term reanalysis data sets at finer spatial resolutions and for a broader range of timescales. Some of these needs can be met with seamless forecasting (WMO-No. 1156). and the Global Data-processing and Forecasting Systems (GDPFS) (WMO-No. 485). These new requirements call for the advancement of fundamental knowledge of the formation and development of SDS, now-casting, forecasting, predicting of SDS at the S2S scale, and a better understanding of the impact of anthropogenic activities and climate change. These service needs are also emerging opportunities to bring SDS-WAS to the next phase.

The next five years (2021–2025) will require further worldwide efforts, a trained scientific workforce, and better coordinated global partnerships to advance the scientific and operational aspects of SDS. There will be opportunities to develop new partnerships for research and operation, to facilitate improved SDS observations and operational forecasts, to better utilize emerging technologies, impact-based warning and to create scientific capacities in different regions across the globe. The IP describes how these challenges and opportunities will be exploited over this time period, to improve the delivery of the SDS operational forecasts and scientific information necessary to achieve better services. Specifically, SDS-WAS will address the following challenges:

1. Continuing the refinement of meteorological factors in the formation and variability of SDS and the long-term variations of these factors and their linkage with climate change and anthropogenic activities;
2. Advancing technology for retrieving dust mineralogy from space-borne measurements;
3. Developing new techniques and methodologies of observations of atmospheric aerosols optimized for mineral dust, and utilizing satellite and ground based SDS observation to build on virtual networks on the basis of the existing SDS global observation system to enhance the ability of SDS verification and data assimilation and dust reanalysis;

4. Improving our understanding of the most uncertain issues in the interaction between dust aerosols and the regional atmospheric boundary layer, and ice clouds; clarify the two-way feedback mechanisms of SDS and meteorological processes in different regions to foster better SDS forecast and the chemical weather forecast; refine sensible and necessary heterogeneous chemical reaction schemes from observations and experiments to apply to SDS forecasting systems;
5. Working towards establishing the Integrated SDS Forecast System, contributing to seamless numerical SDS prediction from a few days up to whole seasons;
6. Achieving better coordination and harmonizing the process of transferring dust observations and forecasts to users;
7. Developing community consensus on dust emission, surface concentration, atmospheric loading and deposition based on multimodel ensemble reanalysis for long-term changes of SDS in different regions to underpin the establishment of an impact-based warning system of SDS with other UN Agencies in the United Nations Coalition;
8. Improving the usability of SDS-WAS science and services in more vulnerable areas to support the risk management and disaster response in various countries and for urban areas, building on existing collaborations to advance scientific knowledge in this domain;
9. Support the implementation of dust operational services providing a baseline of operational capabilities based on the state-of-the-art dust modelling systems.

SDS-WAS holds great promise for delivering meaningful guidance and support in a range of SDS warning and advisory services and advancing the accuracy of SDS numerical forecasts during the severe SDS season in various countries, underpinning macrolevel decision-making for combating and mitigation of SDS.

3.3. SDS-WAS organization

SDS-WAS operates as an international hub of researchers, operational centres and end users, and is organized into regional activity nodes. All the activities, initiatives and events within each regional node are coordinated by a Regional Steering Group (RSG) and implemented by the associated Regional Centre. RSGs are self-organizing structures with a high level of autonomy. The Global Steering Committee (GSC) coordinates SDS-WAS activities globally and facilitates information exchange among RSGs. Figure 2 presents the SDS-WAS structure.

Members of GSC and RSGs and chairs of RSGs will be nominated for a four-year period, with a possibility to extend for another four years. In general, GSC and RSG membership will reflect diverse scientific expertise and secure gender balance.

3.3.1 Global coordination

SDS-WAS activities at the global scale are coordinated by the SDS-WAS GSC as described in Resolution 13 (EC-66) – Sand and Dust Storm Warning Advisory and Assessment System (see Annex 1). The GSC’s role is to:

- Coordinate SDS-WAS activities globally and between regional nodes (see 3.3.2 below);
- Define the research priorities of SDS-WAS and regularly update it;
- Integrate regionally based research;
- Guide the standardization of activities at the regional level;
- Identify research gaps in SDS-WAS activities at the global scale and recommend solutions;
- Monitor and provide periodic reviews on the fulfilment of the research objectives as

specified in the plan for the SDS-WAS implementation;

- Encourage global activities in research and assessment and promote their implementation;
- Encourage contributions to a WMO trust fund for SDS-WAS;
- Report to the GAW/Environmental Pollution and Atmospheric Chemistry Science Steering Committee (EPAC SSC).

In addition to the above-mentioned functions, the SDS-WAS GSC will coordinate activities of Working Group 2 (WG2): Forecasting and Early warning of the United Nations Coalition for Combating Sand and Dust Storms within the mandate provided by the Coalition and agreed by WMO as its Member.

The GSC Chair and members of the GSC will be nominated as described in Resolution 13 (EC-66) – Sand and Dust Storm Warning Advisory and Assessment System, (see Annex 1), current regulations of the RB and approved by the EPAC SSC.

3.3.2. Regional coordination

At the regional level, SDS-WAS is structured as a federation of regional partners. The collaboration is realized through regional activity nodes (see Figure 2), which are self-organized structures with a high level of autonomy. The organization of regional nodes allows flexibility, growth and evolution, while preserving the autonomy of individual institutions. It involves a variety of participants (universities, research organizations, meteorological services, health, agriculture, transport organizations, etc.) gathered to cooperate and benefit without requiring changes to their internal structures and existing arrangements. The partners of a regional node will agree on minimum regional activities to cooperate. Regional nodes will be open to new members to join. SDS-WAS will involve regional research and operational communities in a clear way to ensure the transfer of knowledge especially for developing countries. Selection of chairs and members of an RSG will be made through an agreed decision of partners of a particular region.

Any new regional node needs formal approval from the GSC which will evaluate a scientific or technical application submitted by an organization representing and coordinating formation of a new regional node. Activities of SDS-WAS in regions will be realized in close cooperation with the WMO Regional Associations and the Secretariat's Regional Offices according to the Research Board's Concept Note and Plans for "Innovation in the Regions" (RB.WMO, 2021b). SDS-WAS regional nodes and associated Regional Centres (RC) will be collaborating with the corresponding WMO Regional Associations and Regional Offices, arranging together relevant regional events, workshops and trainings, as well as providing resource mobilizations.

SDS-WAS encourages all regional nodes to contribute to regional cooperation and innovation through delivering experimental forecasting and early warning advisory services, providing reanalysis data and scientific research. Working with the regional associations the feasibility of the extension of the system will be established for different regions and interested countries.

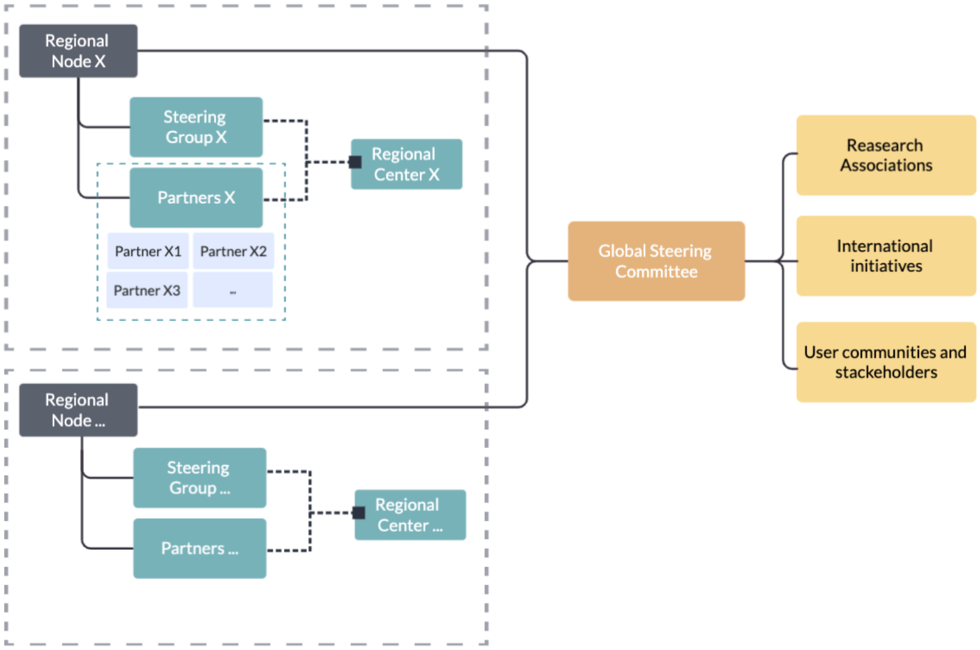

Figure 2. The WMO SDS-WAS structure. In the scheme is presented global and regional coordination and their interactions.

The RCs manage and coordinate the research activities and operations of WMO related to SDS, i.e. coordinating and implementing SDS-WAS RSG activities, and can also host a WMO Regional Specialized Meteorological Centre (RMSC) – see Section 4. The activities of an RC focus on facilitating access to the available dust information. The regional partners network around a RC promotes scientific collaborations that aim to deepen our understanding of the dust cycle and its variability, along with its impacts on key socioeconomic sectors. The RC is acting as a main focal point to allow and facilitate cooperation among the institutions and meteorological agencies in their regions. Furthermore, the RC's web portals include in-situ and remote-sensing dust-relevant observations, dust forecasts from several organizations, information and training material from several past workshops, and news for the SDS-WAS community.

A result of this cooperation is a suite of multimodel products developed thanks to the numerical models of the research and operational institutions in the RC domains. As well as monitoring platforms (either ground-based or satellite), multimodel intercomparisons and probabilistic and deterministic modelling approaches configure the best framework to help institutions, economic sectors and decision-makers in the delivery of weather and related services, which in turn support sound decision-making on public safety and cost-efficiency in all social and economic activities affected by mineral dust intrusion and SDS. An example of these products would be the SDS warning advisory system for Burkina Faso and the probabilistic products (GAW Report No.254/WWRP- 2020-4).

Additionally, one of the core activities of a RC is to build the capacity of end users to promote the use of dust products to address the risks associated with airborne dust. It is important that all available monitoring and modelling outputs are fully understood by the users to avoid misleading conclusions. A further step is the development of tailored products aimed at specific end users. Differences and particularities of the specific sectors affected by SDS (aviation, solar energy, agriculture, air quality and health, etc.) require a variety of actionable products and there is a need to fund projects so that they can become a reality. To support the development activities of these services, workshops covering these products and forecasting guidelines must be included in the capacity building activities of the RC. Overall, given the complexity and uncertainties of weather forecasting, these products make a significant contribution to the better assessment of

SDS and complement deterministic outputs of the operational models.

In 2008, the sixtieth Executive Council of WMO (EC-LX, 2008) welcomed initiatives towards the development of SDS-WAS in Asia and Northern Africa-the Middle East-Europe regions, as well as the establishment of two SDS-WAS RCs in China and Spain in support of the corresponding SDS-WAS nodes. In 2011, the Pan American regional node started its activities covering the entire American continent. Following substantial interest from countries in Western Asia and the Middle East, the WMO and UNEP collaboration explored the needs of these regions (see Cuevas, 2013) with a view to the possible creation of new regional nodes.

As of 2021, there are three SDS-WAS regional nodes:

- The RSG for Northern Africa, the Middle East and Europe was created in 2007. The corresponding Regional Centre is in Barcelona, Spain, and is jointly managed by the Spanish State Meteorological Agency (AEMET) and the Barcelona Supercomputing Center (BSC). Its web portal is at https://dust.aemet.es.
- The RSG for Asia was created in 2008 and the associated Regional Centre has been hosted by the China Meteorological Administration (CMA) in Beijing, China. Its web portal is at http://www.asdf-bj.net.
- In 2012, the RSG for Pan America was created in Orange County, California, USA, hosted by Chapman University. Currently, the Pan-American Regional Center is coordinated by a Regional Centre in Bridgetown, Barbados, hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH). Its web portal is at http://sds-was.cimh.edu.bb.

Annex 4 includes a detailed description of the activities conducted in each of these active SDS-WAS RCs. Also, in 2021 at the time of writing, two groups of interested countries have proposed the establishment of new SDS-WAS regional nodes in West Asia: Iran/Turkey and the Gulf Cooperation Council (GCC) initiatives.

4. THE NEXT STEP: TRANSITION FROM RESEARCH TO SERVICES

Most of the research into the direct and indirect hazardous impacts of desert dust on society is focused on individual sectors, including health, agriculture, road and air transport, solar power production, water quality and sources (Painter et al., 2018; Nemuc et al., 2021). While SDS rarely cause the same level of destruction as cyclones, their persistence and the lasting impact of dust deposition means they can disrupt production throughout a large part of the year in places downwind of major dust sources. Tailored information meets the ambition to bridge the gap between providers and users of dust information. The co-design of dust forecasting services, understood as the process through which the service is defined and developed together with the end users, (and other relevant stakeholders), is perceived as an essential step for delivering successful services that adequately respond to the users' needs and requirements. One essential component of the co-design approach is effective engagement and communication between providers and users.

SDS-WAS, its regional nodes and experts provide regular training workshops for users in different affected regions (check the SDS-WAS RC activities in Annex 4) and have contributed with SDS case studies to the recently published WMO Training Materials and Best Practices for Chemical Weather/Air Quality Forecasting (Volume III)

For air quality, real-time dust forecasts/observations, as well as long-term trend data, could provide timely updates of the efficacy of air quality legislation and support the decision-makers in designing and implementing mitigation policies. Other socioeconomic sectors, such as energy and transport, can enhance their capabilities with better information for managing solar production or air traffic. Otherwise, there are few systematic analyses of the total costs of SDS across countries. One of the main problems is the lack of long-term and harmonized information. To better coordinate, harmonize and facilitate the process of transferring dust observations and predictions to end users and socioeconomic sectors affected by dust, SDS--WAS will continue to collaborate and participate in projects which aim to achieve this goal. Lessons learned from a few pilot projects, including inDust (International Network to Encourage the Use of Monitoring and Forecasting Dust Products, Nemuc et al., 2021) and DustClim (SDSs Assessment for the development of user-oriented climate services in Northern Africa, the Middle East and Europe, Votsis et al., 2020) focused on the production of climate services for target user sectors (i.e. aviation, health and solar energy).

SDS-WAS partners also cooperated with other UN initiatives. One of the highlighted projects is a result of a collaboration with the WMO Climate Risk and Early Warning Systems (CREWS) initiative that has been the development of the Burkina Faso Warning Advisory System launched in October 2018. This WAS is a tailored product designed at the request of the Agence National de la Météorologie – Burkina Faso (ANAM). It is currently in the evaluation and improvement phase and we plan to expand this project to other Northern African countries during the next few years. Another example of our collaboration with international institutions is the participation in the first SDS Science Project Technical Scoping Meeting organized by the UNEP Science Division and the WMO Research Department in Geneva in April 2019. The main goals of the meeting were to learn about the work currently taking place across the UN Agencies and partners and to outline the relative roles of WMO and other agencies related to SDS. Other participant institutions were: UNCCD, ESCAP, Instituto Agronómico Mediterráneo Bari (IAMB), Agency of Spain (AEMET), Barcelona Supercomputing Center (BSC), the UNEP – International Ecosystem Management Partnership (UNEP-IEMP) and Asian Disaster Reduction Center (ADRC).

Otherwise, SDS-WAS has been built upon the successful research-to-operations experience by the RCs to promote research to operations transition among its regional nodes. Given the demand of many national meteorological services and the good results obtained by SDS-WAS, WMO included in the Global Data -Processing and Forecasting System (GDPFS) a new "Regional Specialized Meteorological Centre" type with activity specialization on "Atmospheric Sand and Dust Forecast". The mandatory functions of Regional Specialized Meteorological Centres on Atmospheric Sand and Dust Forecast (RSMC-ASDF) are described in the Manual on the Global Data-Processing and Forecasting System (WMO-No. 485)

Those institutions hosting an SDS forecasting system that have reached an elevated level of maturity in dust forecasting and are interested and committed to initiating operational dust predictions in the context of the WMO GDPFS structures, should follow the procedure, prepared by the WMO Technical Commissions. The previous procedure, put forward by the WMO Commission for Basic Systems (CBS) on 13 January 2015 and reviewed by relevant CBS experts and GDPFS secretariats, was enclosed as Annex 2 of the SDS-WAS Science and Implementation Plan for 2015–2020 (WWRP- 2015-5). The current procedure is based on this previous one but has been adjusted for the new WMO structure and is enclosed as Annex 2 of this document. This RSMC-ASDF designation process, elaborated on with CBS, needs to be updated and adjusted to meet the new structure of the WMO constituent bodies; it also needs to detail the operational capabilities that any candidate to host a RSMC-ASDF must meet. The WMO Secretariat is currently in a period of transition to a new structure that reflects the Governance Reform and WMO Strategic Plan 2020–2023, both approved by the Eighteenth World Meteorological Congress in June 2019. This new structure includes a WMO RB for weather, climate, water and the environment (also covering SDS-WAS) and two WMO Technical Commissions for Infrastructure (INFCOM) and Services (SERCOM). INFCOM's role is the development and implementation of a coordinate global network for acquiring, processing, transmitting and disseminating Earth system observations (as GDPFS). Meanwhile, SERCOM contributes to the development and implementation of harmonized Earth system services and applications to support informed decision-making for the socioeconomic benefit of individuals and society as a whole.

In 2021, there are two designated RSMC-ASDF:

- The Barcelona RSMC-ASDF was created in Barcelona (Spain) and started operations in 2014. It generates and distributes operational dust predictions for Northern Africa, the Middle East and Europe.
- The Beijing RSMC-ASDF was created in Beijing (China) and began operations in 2017. It generates and distributes operational dust predictions for Asia.

It is important to emphasize that RSMC-ASDFs are considered as operational services while SDS-WAS is considered as a research activity. Those institutions hosting at the same time an SDS-WAS RC and a RSMC-ASDC, are carrying on parallel activities on research and operations.

SDS-WAS will continue to maintain and further develop these high levels of collaboration among SDS-WAS and WMO Infrastructure and Services departments, as well as other UN groups, to improve the available products and services and to minimize the gap that exists between research and operational institutions and end users. SDS-WAS will also nurture future projects by leveraging these pilot projects through the networks in its regional nodes.

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ANNEX 1

Resolution 13 (EC-66)

SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM

THE EXECUTIVE COUNCIL,

Noting:

(1) The three Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Nodes for Asia, Pan America and for Northern Africa, Middle East and Europe,

(2) The additional potential Regional Node in West Asia in collaboration with the United Nations Environment Programme,

(3) The development of the SDS-WAS Science and Implementation Plan,

Considering the need for a global coordination mechanism to facilitate information exchange among these SDS-WAS Regional Nodes,

Recommends:

(1) That the SDS-WAS Steering Committee be established, with two nominations from each Regional Node;

(2) That once established, the Steering Committee will select a chairperson, on a rotational basis from its members, for a two-year period;

(3) That the Steering Committee will meet regularly to review research progress and priorities, and that the Chairperson of the Committee will report the SDS-WAS-related activities to annual meetings of the World Weather Research Programme Scientific Steering Committee;

(4) That the Steering Committee be funded by the SDS-WAS Trust Fund from contributing Members;

Requests the Secretary-General to support the establishment of the Steering Committee and the Trust Fund for the Sand and Dust Storm Warning Advisory and Assessment System.

ANNEX 2

DESIGNATION PROCESS OF RSMC-ASDF

Transition to operational activities: Standard designation procedure as Regional Specialized Meteorological Centre with activity specialization in Atmospheric Sand and Dust Forecasting (RSMC-ASDF)

An institution can be designated as Regional Specialized Meteorological Centre with activity specialization in Atmospheric Sand and Dust Forecasting (RSMC-ASDF) if this institution candidate is taking part of an existing SDS-WAS Regional Node and it has reached a high level of maturity in dust forecasting and it is also capable of producing operational dust predictions in real time 24 hours a day, 7 days a week and 365 days a year. The mandatory functions of RSMC-ASDF are described in the *Manual on the Global Data -Processing and Forecasting System* (GDPFS) (WMO-No. 485). If a group of institutions share the RSMC functions, they can be designated as RSMC Network with activity specialization in ASDF.

Such institution(s) concerned shall go through the following designation procedures:

Step 1. The institution concerned should express its intent to be designated as RSMC-ASDF shall prepare a technical report to outline the institution's operational capabilities as well as to demonstrate the quality of dust forecasts for operational use in the region following criteria and recommendations documented in the Manual on GDPFS. Model evaluation and intercomparison studies conducted within one of the SDS-WAS Regional Nodes must be described in detail. The proposal, including the technical report that must proof the quality of the products in the context of the current operational existing systems, requires the approval of the SDS-WAS RSG in which the institution is taking part.

Step 2. The institution concerned should express its intent to be designated as RSMC-ASDF to the President of the Regional Association (P/RA) through, and with the endorsement of, Permanent Representative (PR) of the country in which it is situated to ensure commitment to provide the information as described in the Manual on GDPFS and shall obtain the approval of P/RA on this designation proposal.

Step 3. The Chair of the SDS-WAS RSG should convey the intent of the institution concerned to SDS-WAS Global Steering Committee (GSC) with the technical report. The SDS-WAS SC shall review the proposal, including the technical report. The proposal requires the approval by the SDS--WAS GSC.

Step 4. The Chair of the SDS-WAS GSC should submit the technical report and propose the nomination of the institution concerned to the Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC SSC) of the Global Atmosphere Watch (GAW) Programme. The proposal requires the approval by EPAC SSC.

Step 5. The Chair of EPAC SSC should submit the technical report and propose the nomination of the institution concerned to the Chair of the Research Board (C/RB). When C/RB approves the proposal, C/RB shall recommend the proposal, including the technical report, to the President of the Commission for Observation, Infrastructure and Information Systems (INFCOM) (P/INFCOM) by sending the official letter/email with supporting documents to demonstrate the capabilities of the institution concerned to WMO copying dpfsmail@wmo.int.

Step 6. P/INFCOM shall request the Expert Team on Emergency Response Activities (ET-ERA) through the Chair of the Standing Committee on Data Processing for Applied Earth System Modelling and Prediction (SC-ESMP) to review the proposal and the technical report. The proposal, including the technical report, requires the approval by ET-ERA.

Step 7. When the proposal of the institution concerned is approved by the abovementioned WMO bodies, the P/INFCOM will table the designation of the institution as a recommendation to WMO Congress or to WMO Executive Council (EC) or to an INFCOM session. The presentation of the proposal shall be complemented by the respective demonstration of capabilities, through documentation as well as oral presentation. WMO Secretariat will assist in the development of the proposed amendment to the Manual on the GDPFS.

Step 8. With the approval of INFCOM, the amendment to the Manual will be put up to EC or Congress for approval.

Step 9. With this final WMO approval, the Manual on the GDPFS will be revised and the institution concerned will be formally designated as RSMC-ASDF.

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ANNEX 3

SDS-WAS CONTRIBUTION TO UN COOPERATION

The United Nations General Assembly (UNGA) considered and accepted several UNGA Resolutions on Sand and Dust Storm issues (A/RES/70/195 in 2015, A/RES/71/219 in 2016, A/RES/72/225 in 2017, A/RES/73/237 in 2018, and UN SG report 73/306 in 2019).

In response to UNGA Resolution A/RES/70/195, the United Nations Environment Programme (UNEP), the World Meteorological Organization and the United Nations Convention to Combat Desertification (UNCCD) conducted together a "Global Assessment of Sand and Dust Storms" (UNEP-WMO-UNCCD, 2016). The assessment report, which was recognized in UN General Assembly Resolution A/RES/71/219, sets out proposals for consolidated and coordinated technical and policy options for responding to sand and dust storms. These recommendations include an integrated policy framework to guide further action to mitigate sand and dust storms. The priority in the short to medium-term is to reinforce protective strategies to reduce the negative impacts of sand and dust storms on human health, infrastructure and operations. Monitoring, prediction, and early warning are critical for mobilizing emergency responses and further efforts are recommended towards extending the WMO SDS-WAS and involving other UN Agencies. In the longer term, emphasis should be on preventing new dust sources through integrated strategies that promote sustainable land and water management, including cropland, rangelands, deserts, and urban areas.

In response to the two UNGA resolutions (A/RES/71/219 in 2015 and A/RES/70/195 in 2016), the International Conference on Combating Sand and Dust Storms was co-organized by the Islamic Republic of Iran and the WMO, United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), United Nations Department of Economic and Social Affairs (UNDESA) of the United Nations Secretariat, as well as other relevant UN entities. The objective of the Conference was to share knowledge of the key challenges posed by sand and dust storms, identify practical solutions and concrete actions to increase resilience, and promote regional and international partnerships to combat the growing problem of sand and dust storms in West Asia. The Conference in its Tehran Ministerial Declaration requested the UN General Assembly to consider this declaration for appropriate actions and invited the Environment Management Group (EMG) of the UN to consider initiating an inter-agency process involving relevant UN systems; warranting to prepare a global response to Sand and Dust Storms including situation analysis, strategy and an action plan. This will result in developing an UN-wide approach in addressing Sand and Dust Storms which can be used as an inter-agency framework for mid- or long-term cooperation and division of labour.

For the realization of the next UNGA Resolution (A/RES/72/225, Dec 2017) WMO participated in the UN high-level interactive dialogue on Sand and Dust Storms in New York, USA, 16 July 2018 and contributed to the UN SG report on Combating sand and dust storms. For further realization of the UNGA Resolutions (A/RES/70/195, A/RES/71/219, A/RES/72/225, A/RES/73/237, and UN SG report 73/306) it is important to harmonize and coordinate the efforts of various UN bodies in order to have one voice and to realize the most effective way to combat SDS. UN Agencies (WMO, UNEP, UNCCD, WHO, etc.) have different responsibilities in the SDS problem and can perfectly complement each other if the arrangement is well-coordinated and harmonious. As the first step in this direction representatives of UNEP, UNCCD, WHO, FAO and ESCAP are already involved in the SDS-WAS Steering Committee. From the Policy Framework for Mitigation of Sand and Dust Storms, elaborated in the Global Assessment of SDS (UNEP, WMO, UNCCD, 2016), WMO SDS-WAS is coordinating Task 3 - Monitoring, prediction and warning systems for sand and dust storms, and Task 6 - Research to reduce critical uncertainties, and is involved in other tasks, in particular, Task 4- Preparedness and emergency response procedures.

In 2018, the United Nations Environment Programme suggested that the EMG consider their proposal to build a UN Coalition on Combating Sand and Dust Storms. The EMG Senior Officials (including WMO) approved this in 2019 and it is included in the UN SG report on SDS 73/306. The Memorandum of Understanding of the UN SDS Coalition, discussed and approved at the Coalition meetings in October 2020. The following Working Groups and leads/co-leads have been identified and approved by the Coalition:

- WG1 Adaptation and Mitigation: UNDP and FAO
- WG2 Forecasting and Early Warning: WMO
- WG3 Health and Safety: WHO
- WG4 Policy and Governance: UNCCD
- WG5 Mediation and Regional Collaboration: ESCAP and ESCWA.

The Working Groups will be responsible for agreeing on when and how they meet, but these meetings can be coordinated and facilitated by the EMG. Since 2020, the coordination of the Coalition has moved from UNEP to FAO.

WMO SDS-WAS has been leading the SDS forecasting and early warning studies for several years. It is natural for WMO to continue to do so by leading Working Group 2 (WG2): Forecasting and Early Warning of the SDS Coalition. The existing SDS-WAS Global Steering Committee plans to be a coordinating body for WG2. Representatives of UNEP, UNCCD, WHO, FAO and ESCAP are already involved in the SDS-WAS Steering Committee. All interested are welcome to join the SC in this effort. The first initial meeting of WG2 was organized in November 2019 within the SDS-WAS SC meeting and workshop in Hangzhou, China, and the second WG2 meeting was arranged online on 21 October 2020. WMO is well prepared to lead WG2 - Forecasting and Early Warning, and to be involved as a member in other WGs, e.g. WG1 - Adaptation & Mitigation; WG3 - Health & Safety; and SDS-WAS Regional Nodes/Centres in WG5 - Mediation & Regional Collaboration.

The SDS-WAS suggests increasing the role and the contribution of SDS-WAS in the UN SDS coalition and collaboration to test different approaches, to promote SDS impact-based warning, source management and assessment, etc. The ESCAP Asian and Pacific Centre for the Development of Disaster Information Management (APDIM), UNCCD, and UNEP in the UN SDS coalition expressed willingness to strengthen cooperation with SDS-WAS. We will share the data with ESCAP APDIM in the 10-15 years long-term reanalysis of SDS in the Asian region initially. Future SDS reanalysis data will be shared with our partners as finer-resolution, longer-term products are made available.

In cooperation with other UN agencies, we will work with member countries to conduct impact-based assessments and SDS early warning, including their strength, duration, impact area and other parameters through regional cooperation and innovation. We will calculate the exposure and vulnerability of people and property to dust weather in different regions and develop an impact-based warning system of dust weather.

SDS-WAS also expressed willingness to share the data of a 1-km global map on SDS sources by UNCCD as another concrete action to strengthen cooperation within the UN SDS coalition, especially to provide an improved forecast of a SDS event at the small spatial scale, such as a haboob or technogenic dust storms.

ANNEX 4

REGIONAL CENTER'S OVERVIEW

A. Barcelona Dust Regional Center

The **Barcelona Dust Regional Center** is jointly managed by the Spanish State Agency (AEMET) and the Barcelona Supercomputer Center (BSC). This Regional Center is hosting the research activities and products associated to the SDS-WAS Regional Center for Northern Africa, the Middle East and Europe; as well as; the operational SDS forecasting products of the RSMC-ASDF of Barcelona. All activities and products are accessible through the web portal at https://dust.aemet.es/.The reference model of the RSMC-ASDF is the chemical-aerosol-weather MONARCH model, which is developed and maintained by the BSC. The overview of the activities of this Dust Regional Center can be found its web portal as well its annual activity reports. The activities of this Regional Center include:

- Regular updates of the reference operational forecasting system based on the MONARCH model.
- Develop and implement multi-model ensemble and probabilistic forecasting products.
- Enhanced the available dust-derived observational datasets for monitoring and evaluating dust forecasting products.
- Promote and develop high-quality and long-term dust products, as the development of dust regional reanalysis.
- Develop tailored product (as Warning Advisory System, WAS) and services platforms.
- Develop and maintain data repository infrastructure for the exchange of monitoring and forecasting products.
- Coordinate and promote training activities and capacity building. Here, it is worthy to emphasize the alliance of the Barcelona Dust Regional Center with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Copernicus and meteorological services in the region on different actions aimed at strengthening the capacity of countries to use the observational and forecast products distributed in the framework of the WMO SDS-WAS programme.

B. Beijing Dust Regional Center

The **Beijing Dust Regional Center** is managing by CMA and is hosting the research activities and products associated to the SDS-WAS Regional Center for Asia; as well as; the operational SDS forecasting products of the RSMC-ASDF of Beijing. All activities and products are accessible through the web portal at http://www.asdf-bj.net/.The reference model of the RSMC-ASDF is the chemical-aerosol-weather CUACE/DUST which is developed and maintained by the Chinese Meteorological Agency (CMA). The overview of the activities of this Dust Regional Center can be found its web portal as well its annual activity reports. The activities of this Regional Center include:

- Regular updates of the reference operational forecasting system based on the CUACE/DUST model.
- Develop and implement multi-model ensemble and probabilistic forecasting products. Here it is worthy the efforts of this Regional Center on the development of artificial intelligence and machine learning methods to further improve the forecast accuracy of the multimodel ensemble dust forecast system.

- Enhanced the available dust-derived observational datasets for monitoring and evaluating dust forecasting products.

- Promote and develop high-quality and long-term dust products, as the development of dust regional reanalysis.

- Development of sub-seasonal-to-seasonal dust forecasts based on statistical methods and dynamic downscaling models to build up the dust storm seamless forecast system in the future.

- Develop tailored product and services platforms (as Apps for different devices).

- Develop and maintain data repository infrastructure for the exchange of monitoring and forecasting products.

- Coordinate and promote training activities and capacity building.

C. Barbados Dust Regional Center

The **Barbados Dust Regional Center** is managed by CIMH and is hosting the research activities and products associated to the SDS-WAS Regional Center for Pan-America. All activities and products are accessible through the web portal at http://sds-was.cimh.edu.bb/. This Regional Center is not a RSMC-ASDF but is keeping forecasting activities based on Weather Research and Forecasting (WRF) model coupled with Chemistry (WRF-Chem). The overview of the activities of this Dust Regional Center can be found its web portal as well its annual activity reports. The activities of this Regional Center include:

- Regular updates of the reference operational forecasting system based on the WRF-Chem model. These WRF-Chem outputs have been made available publicly on the CIMH Dust and Air Quality Forecasting Centre (DAFC) website at http://dafc.cimh.edu.bb/.

- Enhanced the available dust-derived observational datasets for monitoring and evaluating dust forecasting products. To strengthen the surface observation network for particulate matter and dust in the Caribbean considers the procurement of $PM_{2.5}$ and PM_{10} systems on Barbados at the Ragged Point site so that the relevant personnel has the opportunity to get hands-on experience in maintaining and operating these systems.

- Develop and maintain data repository infrastructure for the exchange of monitoring and forecasting products.

- Develop tailored product and services platforms. Since July 2020 daily WRF-Chem runs were integrated on the DEWETRA platform in order to allow users to obtain numerical values over particular regions of interest to them. DEWETRA is a fully operational platform used by the Italian Civil Protection Department and designed by CIMA Research Foundation to support operational activities at the national or international scale. The system is a web-GIS platform aimed at multirisk mapping, forecasting and monitoring. This feature was successfully tested and utilized during the Caribbean Air quality Alert and Management Assistance System-Public Health (CALIMA-PH) Summer Intensive Field Campaign where the CIMH aerosols and dust team provided daily weather and dust briefings from 1 June to 7 August 2020.

- Coordinate and promote training activities and capacity building. Training with aerosols, air quality and related atmospheric chemistry concepts for WMO Basic Instructional Package for Meteorologists and Meteorological Technicians (BIP-M and BIP-MT) courses and other short courses to interested stakeholders will be promoted through the WMO Regional Training Centre (RTC) hosted by CIMH.

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