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Establishing a WMO Sand and Dust Storm Warning Advisory and Assessment System Regional Node for West Asia: Current Capabilities and Needs

Executive Summary

UNEP

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Executive Summary

The report, *Establishing a WMO Sand and Dust Storm Warning Advisory and Assessment System Regional Node for West Asia: Current Capabilities and Needs*, has been elaborated under the overall supervision of the World Meteorological Organization (WMO) Atmospheric Research and Environment Branch, with the support of the United Nations Environment Programme (UNEP) Regional Office for West Asia.

Its aim is to assess the observation and prediction capabilities of sand and dust storms in West Asia and provide guidance in establishing a WMO Sand and Dust Storm (SDS) Warning Advisory and Assessment System (WAS) Regional Node for West Asia, by presenting the essential actions and activities to be implemented.

The specific objectives of this report are to:

- Review published information on dust storm incidence in West Asia, including the Islamic Republic of Iran and Turkey;
- Compile existing information on dust sources, frequency/intensity of dust storms and socio-economic and environmental impacts of dust;
- Recommend a strategy for dust-model validation;
- Establish regional and national institutional mapping;
- Propose regional institutional collaboration mechanisms for the monitoring, prediction and delivery of dust-related products and services:
- Propose types and density of measurements in the region, based on existing observation capacity;
- Propose a multiscale/downscaling dust-forecasting strategy for the region, based on identified existing numerical modelling facilities;
- Propose a regional data-exchange policy;
- Advise on regional training and capacity-building programmes.

The WMO SDS-WAS mission is to enhance the ability of countries to deliver timely and high-quality SDS forecasts, observations, information and knowledge to users through an international partnership of the research and operational communities. It is proposed that the WMO SDS-WAS Regional Node for West Asia be established in collaboration with the UNEP Regional Programme to Combat Sand and Dust Storms. Through collaborative partnership with UNEP, the WMO SDS-WAS Regional Node for West Asia will provide SDS phenomena assessment and secure an SDS monitoring and early warning system for the region.

Dust climatology and trend analysis in West Asia

Sandstorms and dust storms are two completely different phenomena that require different treatments and approaches. While sandstorms are very local and confined to the first few metres above ground, dust storms occur at an altitude of a few kilometres (1–6 km) with horizontal extensions of thousands of kilometres. Dust storms cannot be stopped by natural or artificial physical barriers. Action is required at their source – degraded lands, which are often hundreds or thousands of kilometres from the points of impact. Basically, WMO SDS-WAS refers to dust storm assessment, monitoring and forecasting.

SDS are a major problem in West Asia but their main characteristics (intensity, extent and frequency) are not well known or, at least, have not yet been addressed in a scientific and systematic way. The absence of a basic climatology of dust sources and pathways in a regional context has hindered the compilation of a regional SDS picture.

Given the absence of a regional climatology of dust storms – and although not initially foreseen in this report – a basic climatology of dust storms from the Aerosol Robotic Network (AERONET, http://aeronet.gsfc.nasa.gov) data, satellite information and reanalysis outputs of global and regional dust models has been performed. Different climatologies obtained from dust-model simulations and satellite observations show some differences but common patterns can be distinguished in all of them.

West Asia is part of the well-known "dust belt" stretching from the western Sahara (with long dust intrusions to the west over the Atlantic Ocean) to central and eastern Asia (with long dust intrusions to the east over the Pacific Ocean). The climatology shows the existence, from March to September, of active dust sources and pathways. It is worth noting the pronounced dust corridor from eastern Syrian Arab Republic to Oman, with significant dusty areas over Iraq impacting the Gulf under a northern airflow. A second prominent dust source is observed over the Empty Quarter and central Saudi Arabia. South-western Islamic Republic of Iran and areas on the Iranian Gulf coast are also active dust sources. Dust sources in the Iranian-Afghan-Pakistan border region contribute to high dust levels observed over the northern Arabian Sea. In summer, the Tokar Gap in north-eastern Sudan, near the Red Sea, impacts the Arabian Peninsula and the Arabian Sea. Under different synoptic and mesoscale weather conditions, most of the region – apart from Turkey – is a potential dust source.

Of particular interest is the presence in the air in many areas – mainly in Gulf countries – of a mixture of mineral dust from desert and industrial aerosols. Unfortunately, the ground-based observation networks are not sufficiently comprehensive nor the network topologies the most suitable to perform a detailed spatial-temporal analysis of this characteristic aerosol distribution.

Concerning trend analysis, West Asia – especially the Arabian Peninsula and Mesopotamia – is the only region in the world where a positive trend of aerosol optical depth (AOD) is found. AOD, a parameter that indicates the total content of aerosol in the atmospheric column, is basically constituted by dust in this region. The positive trend found over Iraq might be linked to the increase in the number of dust sources in the last decade identified in eastern Syrian Arab Republic and Iraq. On the other hand, a negative trend of the enhanced vegetation index (EVI) has been found for the period 2002–2013 across Mesopotamia. EVI is a measurement of the "greenness" of the Earth's land surface, with increasing greenness indicating increased ground covered by growing vegetation. The positive trend in AOD values over this region might therefore be a result of land degradation, probably due to reduced water availability and changes in land use.

On the other hand, global warming has the potential to cause major changes in dust emissions. IPCC (2007) suggests that, under most scenarios, many dryland areas will suffer from lower rainfall regimes and drier terrains because of higher rates of evapotranspiration. Lower rainfall will favour the formation of shallow or extremely shallow soils that are often characterized by a high content of airborne particles and small fractions of rock-erosion elements. Under this scenario, dust storm activity could increase, though this conclusion depends on how winds may change – a matter of great uncertainty.

According to the averaged projection of 21 climate models for West Asia, the percentage changes in average annual temperature by 2100 from the 1960–1990 climate baseline, are up to 4°C over most of the region. The agreement between the models is good. Similarly, it is expected that a broad swathe of West Asia between 19°N and 41°N will experience mainly decreases in precipitation of up to 20% or more, while increases of up to 20% or more are projected for the far south-eastern Arabian Peninsula.

Projected higher temperatures and reduced rainfall could favour desertification processes and thus the strength of dust mobilization in West Asia. The WAS-SDS will most probably play a more important role in this domain over the next few decades.

Impacts of dust storms in West Asia

The Middle East is the second largest source of global dust after the Sahara desert, but, unlike North Africa, where large population centres are concentrated along the coasts of the Mediterranean and the Atlantic Ocean, relatively far away from dust sources, much of the population in West Asia lives inside, or in the vicinity of, dust sources. The impact on ecosystems and on many economic and social activities is therefore of utmost importance.

There is some evidence to indicate enormous impacts on many aspects of human health and on road and air transport, the latter owing to the severe reductions in visibility caused by dust storms. These studies are scarce in the region and, in most cases, consist of simple notes and internal reports, not rigorous scientific studies which have been carried out and validated. In the health sector, based on a systematic review of the literature using the Web of Knowledge database, very few publications in West Asia report the impacts of atmospheric dust on the population.

The impacts of SDS on terrestrial and marine ecosystems are huge. To those on land must be added the movement of dunes invading farmlands. In marine ecosystems – and considering the importance of fisheries in the region – attention is drawn to the absence of studies regarding the effect of dust deposition on the ocean, which contributes to marine primary production. Moreover, deposition of dust over the ocean can also produce harmful algal blooms, popularly known as red ties. Photosynthetic activity in the Gulf and the Arabian Sea due to fertilization by dust nutrients may well be important in mitigating the increase in anthropogenic CO_2 in the atmosphere.

In relation to the rapid diversification of energy sources that is being experienced in West Asia, particularly in relation to solar power, few studies have analysed the role of atmospheric dust in the extinction of solar radiation, as in decreased solar-plant performance arising from the deposition of dust on collecting surfaces and reflectors. Even fewer studies have been carried out on the use of applications, such as dust observations and predictions, to improve the operation of solar plants and to better manage the distribution of energy in national grids.

Atmospheric dust affects weather, atmospheric composition and climate through a wide range of interactions and both positive and negative feedbacks. For example, dust has a significant effect on sea-surface temperature (SST) retrievals from satellites. Although cloud-screening algorithms will often detect thick layers of aerosol, biases up to 3°C will remain, depending on the SST retrieval algorithm and brightness-temperature impacts of the dust, affecting NWP models. Mineral dust may also affect air temperature through the absorption and scattering of radiation. Mineral dust is one of the major contributors to Earth's radiative balance, since its radiation backscattering is remarkable. Depending on the size distribution, chemical composition and shape of the dust particles and the vertical position/extent of the dust layer and the local surface albedo, mineral dust particles may have a positive (heating of the climate system) or negative (cooling) radiative forcing. IPCC (2007) reported that the dust radiative effect due to mineral aerosols lies in the range of -0.56 to +0.1 W/m^2, and we know that dust also affects the hydrological cycle. Firstly, when dust cools, the surface inhibits both evaporation and precipitation. Secondly, dust modifies the size distribution and the phase of cloud particles by acting as cloud condensation and ice nuclei, modifying the development of precipitation. Mineral dust must, therefore, affect regional the weather and climate of West Asia decisively. These terms are used because there are no studies that evaluate and quantify these impacts in the region.

The assessment and quantification of the different impacts that atmospheric dust exerts on ecosystems and on numerous socio-economic activities in the region have yet to be performed. There are several reasons for this wide gap in our knowledge of dust impacts but the most important is probably the significant lack of a comprehensive and long-term dust-observation system. The lack of dust databases means that studies crossing information with databases of an entirely different nature in the fields of health, agriculture, industry, oceans, etc., cannot be carried out. Epidemiological studies on the role of dust in respiratory diseases are impossible, for example, without a relatively long series of particulate matter with diameter of 10 µ or less (PM10) in which the contribution of mineral dust is known.

All the countries of the region should start – and as soon as possible – to build an organized body of knowledge that provides scientifically backed information about the importance and impacts of SDS, so that policymakers can take concrete actions aimed at obtaining, and supported by the use of, such information.

The problem of the weak observation system in the region is addressed in the next section.

Dust monitoring in West Asia

The SDS observation system currently available in the region is far below what is actually needed for dust storm monitoring, prediction and characterization. Minimum efforts focused on improving, expanding and adapting existing dust-observation networks will result in significant improvements.

The most basic network with conventional meteorological observations are provided in SYNOP and METAR reports, in which horizontal visibility is a first indication of the presence of dust, is, in general, well distributed and with a relatively good density of stations. Some gaps exist, such as the Empty Quarter in Saudi Arabia, adjacent regions of Oman and Yemen and also certain lowland areas of the Islamic Republic of Iran. Most of the countries have operational automatic devices for visibility ranges such as MOR and RVR and all of them are important in airports, since one of the activities most affected by dust is air traffic. Visibility reduced by atmospheric dust from SYNOP observations would be an interesting product, at least for dust nowcasting. Some value-added activity should be implemented in near-real-time (NRT), such as filters for including relative humidity and present-weather data, in order to avoid including reduced visibility due to fog or heavy rain. Long-term climatologies might already be obtained, for example, by computing the monthly mean number of days in which visibility is below a threshold value. Climatology from visibility data on the regional scale would constitute a simple but unique picture of the spatial-temporal distribution of dust storms and an interesting first approach to indirectly determine dust trends.

The second dust-observation network type, based on dust-deposition gauges, is highly recommended. Although this method does not provide data on dust concentrations or enable determination of dust levels from a particular event, it does enable determination of the relative "dustiness" of sampling locations and so might provide a temporal and spatial climatology of breathable dust at surface level. A regional network of dust-deposition gauges should be installed in each country, using standardized sampling and evaluation methodologies and a network topology that meets objective criteria, taking into account dust sources and pathways, and filling observation gaps.

Stations measuring particulate matter constitute the third level of in situ observations. These useful atmospheric parameters are normally monitored within air-quality programmes. The number of PM10/PM2.5 (particulate matter having a diameter of 2.5 µor less) stations in the countries reporting this information is reasonable and proportional to their population and geographical extension; some countries even have an excellent density of stations.

PM10/PM2.5 networks for dust characterization and for understanding impacts of dust on the population are of great importance and in situ PM10 measurements are crucial to validate surface-dust concentration from models. In situ PM measurements provide information about aerosols/dust inhaled by people and, therefore, how dust storms directly affect people and ecosystems. Most of the information provided by satellites corresponds to the total content of aerosol/dust in the atmospheric column and this does not necessarily have a direct correspondence with surface-dust concentrations. Furthermore, the chemical composition of surface aerosol/dust is another critical aspect in health impacts and other applications and cannot be provided by remote techniques, only by in situ PM sampling. From the point of view of SDS monitoring, the major deficiencies identified are the following:

- Too few stations are located in rural background conditions to monitor mineral dust only (mainly PM10), which would allow us to know its impact on air quality in the cities. PM10 and PM2.5 measurements in urban air-quality networks represent a mix of anthropogenic pollution (vehicles, gas-flares, industries, ships) and natural contributions. It is difficult to separate the contribution of each source if there are no background stations unaffected by anthropogenic contributions monitoring natural PM10.

- There are no standards of air quality common to all countries of the region, especially for PM10.

- A regional centre managing a common and homogenized quality-assurance system is lacking.

For these reasons, efforts should be made in the design and strategy of at least part of the PM measurement programme, in order to obtain optimal performance in the characterization of aerosol/dust background. Some PM10 stations should be set up in rural sites, far away from the direct impacts of anthropogenic sources located in cities and industrial centres in order to obtain aerosol background measurements which should be affected, basically, by mineral dust from local resuspension or transported from other regions.

Because of the complexity and vastness of West Asia, it is not possible to make recommendations on specific geographic locations for rural background stations. At national level, all dust storm pathways should be explored. As a rough estimate, about 10% of PM10 stations in each country should be located in rural background conditions. The rural background PM10 station network would provide useful information regarding the spatial and temporal variability of surface mineral-dust concentration and, at the same time, help to distinguish and understand the different sources of PM pollution measured by the air-quality networks in each country.

Since soil deterioration, together with wind, is one the primary causes of dust sources and consequently of SDS, improvement of in situ observation networks at dust hotspots is crucial for effective monitoring and forecasting. Mesopotamia should be properly monitored in collaboration with neighbouring countries that suffer most from the impacts of land degradation.

A fourth level of dust monitoring is found in ground-based, remote-sensing techniques, mainly sunphotometers and lidars or ceilometers.

Concerning sunphotometers, we have to highlight the role of AERONET (http://aeronet.gsfc.nasa.gov), a federation of regional networks based on photometric instruments located at ground stations (currently more than 400 worldwide) for monitoring atmospheric aerosols, including atmospheric mineral dust. It requires the standardization and calibration of instruments, data processing and distribution. AERONET seeks to provide continuous and easily accessible time series of aerosol measurements, such as microphysical and radiative properties in the atmospheric column. It is dedicated mainly to the characterization of aerosols and the validation of satellite data and aerosol models, as well as synergies with other databases.

The two most important dust sources in the world (North Africa and West Asia) have few AERONET stations. In West Asia, network coverage is sparse – only six stations are operational and these are unevenly distributed. AERONET does not cover dust hotspots or large cities affected by SDS.

As AERONET is the largest and most important network in the world for aerosol monitoring and the validation of both satellite and aerosol models, we propose the following actions aimed at improving AERONET in the region:

- Re-start operations at the following former AERONET sites:
  - Kuwait University, Khalidiyah campus
  - Bahrain (re-start operations in the most convenient free-horizon site)
  - Dhadnah (United Arab Emirates (UAE))

- Set up new AERONET sites chosen for the geographical location of dust storm pathways and topology of the regional network:
  - Arar (northern Saudi Arabia)
  - Najran (south-western Saudi Arabia)
  - Somewhere in the Empty Quarter (Saudi Arabia)
  - Dayr az Zawr (eastern Syrian Arab Republic)
  - Mosul (northern Iraq)
  - Baghdad (central Iraq)
  - As Smawah (southern Iraq)
  - Faud, Dhahirah (Oman)
  - Bani Bu Hassan (Oman)
  - Ahvaz, Khuzestan (south-western Iran)
  - Zabol (preferable) or Zahedan (Sistan basin, eastern/south-eastern Islamic Republic of Iran)
  - Tehran (Islamic Republic of Iran)

Annual maintenance and calibration of AERONET sunphotometers, following standardized protocols, are absolutely mandatory. The possibility of creating a regional AERONET centre should be seriously considered.

The situation concerning lidars and ceilometers, there are still substantial data-sparse areas in West Asia compared to North Africa and the Sahara. There is one lidar station at Zanjan (Islamic Republic of Iran) and more than 20 new-generation ceilometers in Turkey with potential use for SDS activities but, at present, they are operated only for aeronautic meteorology purposes. Lidars, however, permit the analysis of desert dust that has intruded into the planetary boundary layer (PBL) and the mixing processes of dust with other aerosol types, as well as the transport of dust at upper levels, which might be interesting for aviation in the region. Lidar measurements in combination with other techniques, such as sunphotometry, are ideal for investigating certain aspects of atmospheric composition, transport, deposition of dust and dust-cloud interaction, including cloud-formation processes. Nevertheless, lidars are advanced, expensive (>US$ 100 000) instruments that require specialists specifically trained for their operation, as well as dedicated personnel to retrieve vertical profiles with data-inversion algorithms. Maintenance costs are also high. Compared to sunphotometers, the lidar technique is more expensive and requires much more experienced specialists to work in both operations and data processing.

A lidar network similar to that proposed for AERONET sunphotometers would be the ideal scenario. Nonetheless, given the enormous complexity of the lidar technique, its high cost, and the level of development of this technology in the region, caution must be exercised when proposing lidar sites. For this reason, a first recommendation is to strengthen what has already been achieved. Support to the Institute for Advanced Studies in Basic Sciences group that has designed, developed and operated two lidars in Zanjan (Islamic Republic of Iran) is therefore highly recommended.

A second recommendation for a lidar site would be Kuwait, strategically located in the dust outflow from Iraq and in the pathway of west-east-west dust clouds. Kuwait would be a key station of great interest for both operational and research activities. This lidar programme might be a collaborative effort between a university/research institute group and the Kuwait Meteorological Centre. A potential site could be at Kuwait University, where an AERONET station was in operation until August 2012.

The third recommendation concerning concerns Saudi Arabia, where two interesting sites with AERONET stations are in operation: the King Abdullah University of Science and Technology (KAUST) campus and the Solar Village at the Energy Research Institute of King Abdulaziz City for Science and Technology. The KAUST campus station could monitor intercontinental dust transport, especially dust plumes over the Red Sea, while Solar Village would be an interesting site to monitor and characterize vertical dust distribution in the central Arabian Peninsula at or near dust sources.

In a second phase, and co-located at existing AERONET stations, two additional lidar stations could be set up in the dust corridor (beginning in northern Iraq) in the UAE and Oman, respectively. These stations could monitor dust transport along the Gulf to the Arabian Sea and between the Arabian Peninsula and the Islamic Republic of Iran.

Initiatives from other groups of countries in the region would of course be welcome and should be considered in a medium-term dust-monitoring plan. A lidar programme requires a commitment and a significant involvement of research groups, without which it would not be possible to implement the technique.

Besides research-oriented lidar networks, a large number of ceilometers are distributed worldwide. Ceilometers (often called low-power lidars) are robust systems for continuous operation that can provide useful information about the aerosol layers, which can be used for operational dust monitoring and forecasting. Ceilometers are single-wavelength backscatter instruments that are relatively inexpensive (~US$ 20 000) and are used at most airports for cloud-base monitoring. Many National Meteorological or Hydrometeorological Services (NMSs), as well airports, operate ceilometer networks, providing atmospheric measurements fully automatically and continuously of, for example, cloud-base and PBL height, but also profiles of atmospheric aerosol backscattering. The involvement of NMSs in gradually extending the use of ceilometers into SDS activities is obvious, relatively easy and inexpensive.

Satellite observations are crucial for monitoring SDS events and providing SDS climatologies in the region, filling the huge gaps identified by in situ observations but they have marked limitations. Satellite observations require validation with accurate ground observations and satellite products are still limited both in time (usually once a day for quantitative dust observations) and variety of useful products for many applications. For example, satellites do not provide information about dust-surface concentrations affecting people and ecosystems and they cannot address chemical composition or aerosol size distribution.

Most of the countries in West Asia use the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board Meteosat Second Generation (MSG) (European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)) satellites for dust storm monitoring. In some countries, the Moderate Resolution Imaging Spectroradiometer (MODIS (Aqua/Terra), both images and quantitative AOD) and the Multi-angle Imaging Spectroradiometer (MISR) are used, but to a lesser extent and mainly for case analysis or for short short-term studies of a few years. US National Oceanic and Atmospheric Administration satellite dust information is used mainly for meteorological analysis. The degree of utilization of aerosols/dust data from satellites is low in West Asia and, in most cases, quite basic, focused on immediate use for weather forecasting. Satellite pictures of dust storms are used for illustrating analysed events in some scientific articles.

The best sensor for continuous monitoring of dust storms is, without doubt, SEVIRI-MSG. Its high spatial resolution is complemented with a unique and powerful capacity: a high temporal resolution (15 minutes now and 10 minutes in the near future). While SEVIRI-MSG is currently the ideal satellite sensor for dust nowcasting, it does not provide reliable, quantitative AOD.

Aerosol products from MISR are excellent in generating climatologies for dust-source and pathway regions, while MODIS and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) are excellent for quantitative AOD over the oceans. The Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP) and PARASOL (polarization and anisotropy of reflectances for atmospheric science coupled with observations from a lidar) on board the Cloud-Aerosol Lidar and Infra-red Pathfinder Satellite Observations (CALIPSO) platform provide aerosol backscatter and extinction-coefficient profiles. Data from these space-based sensors are available in the corresponding databases and can be used in case analysis and for establishing climatologies for West Asia.

Long-term reanalysis of satellite-based observations at dust hotspots, specific stations (e.g. AERONET or SYNOP stations), as well as sensitive dust-impacted areas (cities, industrial facilities, airports) will quickly improve knowledge of the spatial-temporal variability of dust storms. Use of the Goddard Earth Sciences Data and Information Services Center (GES DISC) interactive online visualization and analysis infrastructure (Giovanni) application is highly recommended for this type of analysis. Giovanni is a web-based application that provides a simple and intuitive way to access, visualize and analyse vast amounts of Earth-science remote-sensing data without having to download them.

The Centre of Excellence (CoE) for Training in Satellite Meteorology in Muscat (Oman), that forms part of the WMO-Coordination Group for Meteorological Satellites Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) and is sponsored by EUMETSAT, could play a special role in satellite observations in West Asia.

Regarding observations, a particularly important requirement in West Asia is an accurate inventory (1 km resolution if possible) of dust sources, soil texture and land use. This inventory would greatly help the development of better dust models, since the sources are used as model inputs.

SDS monitoring will help facilitate timely and accurate dust storm forecasting and nowcasting but, in the long term, and in collaboration with UNEP national institutions, it will also support monitoring of the evolution of dust sources and dust pathways and the assessment and verification of measures implemented to reduce the impact of SDS after action has been taken in land-degraded, dust-source regions.

Dust modelling and forecasting in West Asia

Only two countries, the Islamic Republic of Iran and Turkey, run appropriate regional dust models. DREAM8 Eta has been run at the Islamic Republic of Iran Meteorological Organization since 2012 as a result of cooperation with the South East European Virtual Climate Change Centre (SEEVCCC). BSC-DREAM8b has been run at the Turkish State Meteorological Service since July 2010, thanks to cooperation with the Barcelona Supercomputing Centre, Spain. In the case of the Atmospheric Science and Meteorological Research Centre (Islamic Republic of Iran), the use of WRF-CHEM as a dust model for operational purposes does not seem to be an appropriate solution. The CHEM module associated with WRF was not conceived and developed for dust, but for chemical processes in air-quality issues, as is also the case in the UAE with the COSMO_ART aerosol model.

Capabilities in the area of modelling are rather poor. A marked improvement can be quickly achieved through collaboration with model-provider institutions. Recently, the SDS-WAS Northern Africa, Middle East and Europe (NAMEE) Regional Centre made available a set of dust-model outputs to West Asia countries, so there are real and immediate ways to improve notably the modelling and prediction of dust storms.

The modelling structure proposed for West Asia consists of a three-level nesting scheme. At the first level, daily global dust-model data could be provided by organizations/initiatives such as the International Cooperative on Aerosol Prediction (ICAP). Either an ICAP median of such model outputs or data from a particular global model group should be secured by the future West Asia Regional Centre through a special agreement with data providers. Nowadays, global models have a spatial resolution of ~50 km, which will be increased to ~25–30 km in the near future.

In the next nesting step, global model data should be used for the initial and boundary conditions in a large regional dust-model area to feed regional models. Ideally, these models should have a resolution of ~10–15 km. Over the last 20 years, a modelling community focused on dust models has developed dust-source specifications, parameterizations of dust emissions, radiation-dust and dust-cloud interactions, parameterizations, etc., building up a robust dust-forecasting system. Fortunately, many of these regional models running over the West Asia geographical domain are currently available through the SDS-WAS NAMEE Regional Centre. In particular, this Centre offers dust-forecast outputs generated by different regional numerical models, both graphically and numerically, at:
http://sds-was.aemet.es/forecast-products/dust-forecasts.

The availability of this set of specialized dust-prediction models constitutes an unprecedented breakthrough for the international community and especially for the countries of West Asia, which will have six digital models outputs and an ensemble available to add to the current dust-forecasting capabilities of each country. The geographical domain of these models should be expanded eastward in order to include dust sources and pathways in Afghanistan and Pakistan.

Dust storms associated with small-scale convective processes in space and time, such as haboobs and cold-air downburst storms, can be captured neither by global models nor by regional models, given the small size of these meteorological processes, and because most of these models have not carried out adequate parameterizations of mesoscale convective cloud-resolving processes, low-level jets, etc. The third nesting level therefore consists of mesoscale/local dust models fed by data from (a) regional scale model(s). Such mesoscale modelling systems, which include non-hydrostatic atmospheric processes, should be downscaled to resolutions of ~1–3 km in order to resolve both atmospheric driving conditions and dust soil sources and will complement global and regional models. The spatial resolution of mesoscale/local dust models will depend largely on the region to be covered and available computational resources. Two regional models that might easily be upgraded to mesoscale high-resolution models are SEEVCCC NMM-DREAM8 and NMMB/BSC-Dust.

Dust-model verification is an important activity targeting knowledge of model performance and model reliability quantification. A great effort should be made to secure proper NRT and offline validation of dust models. The example of the SDS-WAS NAMEE Regional Centre could be followed. Model validation, in a first stage, requires a significant strengthening of AERONET in the region.

Dust-model reanalysis (model simulation) is essential for understanding basic aspects of the spatio-temporal distribution of dust storms.

Some specific recommendations concerning dust modelling and forecasting are the following:

- Establish a web-based virtual centre with both graphical and numerical prediction products from outputs of global, regional and mesoscale dust models. The SDS-WAS NAMEE web portal concept would be a good starting point.

- Create a working group formed by weather forecasters of all countries and supported by researchers in each country to evaluate the quality of each model by comparison with dust storm events (mostly from satellite information).

- Provide model-comparison exercises during selected dust episodes, as well as continuous model validation against ground-based or satellite-borne observations.
- Reach agreements with the institutions currently running the dust-forecast models available through the SDS-WAS NAMEE Regional Centre, so that the geographical domains of the models are extended to the eastern West Asia region.

- Develop and implement high-resolution models in order to predict dust storms associated with mesoscale convective systems by bilateral cooperation agreements or contracts with groups specialized in high-resolution dust modelling.

- Replicate for West Asia the evaluation/validation system developed at the SDS-WAS NAMEE Regional Centre, incorporating the dust models currently run in West Asia.

- Evaluate models for a few selected dust storm events caused by both small-scale meteorological processes (such as convective-based haboobs, low-level jet dust storms) and large scale processes (shamal, meteorological fronts).

- Use dust-model reanalysis to obtain dust climatologies at the regional scale and long-term trend analysis.

- Promote, in close collaboration with UNEP and national environmental agencies, multidisciplinary studies leading to the establishment of high-resolution maps of dust sources and their characteristics and PM-type observations, in order to improve modelling, using UNEP communication links with national environmental authorities. Local/national data on land use, soil texture and land cover are ingredients in the model emission parameterization. Land/soil information should be at the highest possible resolution, preferably finer than 1 km.

Modelling is a complex issue requiring well-trained, qualified personnel. A thorough training plan for modellers of the region, in collaboration with recognized international dust-modelling institutions and providers is therefore necessary.

User-oriented products and services

There are no specific user-oriented products and services on sand and dust storms in West Asia.

NMSs, environment protection agencies, health institutions, aviation authorities, energy departments, marine resources and fishery agencies, wildlife, forestry and agriculture agencies, disaster risk and civil protection agencies, research institutions and universities should participate in the SDS-WAS Regional Node for West Asia, as contributors and/or as specialized users.

One of the most important products that NMSs could provide to the general public and specific users and professionals in different sectors would be accurate SDS early warnings, anticipating their impacts and reducing societal and economic losses. Environment, health, transport and civil defence authorities need to be notified of observed or predicted SDS events in a timely fashion. A challenging, and probably profitable, orientation of SDS products would be the support to emerging activities for which SDS can be critical: solar-power plants (production efficiency and maintenance), the electronics industry, airport operations and aviation maintenance, high-speed rail operations and farm and livestock management. SDS-WAS will be an essential tool to help environmental authorities in formulating future air-quality regulations. The WMO SDS-WAS Regional Node for West Asia will provide unique complementary information to climate services concerning drought and desertification monitoring.

End-products should be agreed with potential users and SDS products must be “translated” into language that is understandable to the end-user. Thus, a working group (WG) specialized in user-oriented SDS products and services should also be created within the SDS-WAS Regional Centre for West Asia. This WG would ask potential users to state their needs, at the same time explaining the capacities and limitations to delivering different SDS products and services.

Training and capacity-building

Most countries in the region have an interest in both general and specific SDS capacity-building. The Islamic Republic of Iran and Turkey have notable experience in organizing general SDS training courses and workshops. Oman, with the CoE for Training in Satellite Meteorology, has valuable experience in organizing international courses on satellite observations and applications to SDS monitoring and forecasting. There is, however, a clear gap in capacity-building in the areas of in situ observation, ground-based remote-sensing and modelling techniques and methodologies. The importance of training in standardized methods and techniques on a regional scale is to be emphasized.

Regional cooperation in capacity-building and training, within the SDS-WAS Regional Node, will lower costs and allow all countries to work with common rules and standardized procedures, facilitating data exchange and information sharing. Capacity-building within the WMO SDS-WAS involves technology transfer with self-sustaining capability and long-term partnership in mind. It will be coordinated through various mechanisms, including those well established in WMO through its Development and Regional Activities Department.

Depending on available resources, capacity-building and training activities should include:

- Regular scientific exchange through workshops or seminars to discuss recent developments in general SDS issues, such as observation, modelling, forecasting and users.

- Specialized capacity-building, including training in specific technical issues such as, for example, satellite-data access and analysis, dust storm forecast and simulation model-output analysis, targeting user needs through new information products, measuring and monitoring air quality through remote-sensing (sunphotometers or lidar) and in situ air-sampling instruments, etc.

- Medium-term (several months) stays at specialized centres to learn techniques or methodologies regarding observations, modelling and elaboration of user-oriented products.

Collaboration mechanisms for the SDS-WAS Regional Node for West Asia

Unfortunately, there are currently no mechanisms for collaboration in SDS activities in West Asia. Each country deals with the issue in an isolated manner and within each country there is little or virtually no collaboration between different actors who can contribute to SDS activities such as those of NMSs, air-quality authorities, research centres and universities.

Countries have minimal preparation for monitoring and forecasting activities and managing background information on SDS.

Like other meteorological parameters and variables, dust has no international borders. Countries cannot address dust monitoring and forecasting individually. Most of them are dust sources and at the same time are impacted by dust transported from neighbouring countries. A smooth and rapid exchange of information between countries is therefore essential for an effective and useful SDS-WAS. This can only be achieved by implementing an SDS-WAS Regional Node for West Asia as proposed by WMO.

SDS-WAS was established in 2007 as a WMO programme in response to the intention of 40 WMO Member States to improve capabilities for more reliable SDS forecasts. The SDS-WAS mission is to achieve comprehensive, coordinated and sustained observations and modelling capabilities in order to improve monitoring and so increase the understanding of dust processes and enhance dust prediction. SDS-WAS integrates the research and user communities.

The WMO SDS-WAS Science and Implementation Plan offers an operational structure for dealing with a diverse community underpinned by well-established WMO systems of research, observations, numerical weather and climate prediction and service delivery. The diverse requirements of SDS research and user communities for observations, forecasts and analyses require the development of interfaces through careful assessments. A comprehensive, coordinated observing network for the monitoring of SDS and improved modelling capabilities will increase the understanding of dust processes and enhance their prediction. The WMO SDS-WAS Science and Implementation Plan thus proposes an architecture and information exchange that will secure efficient and balanced cooperation and participation of the major components: research, prediction, observations and service delivery. It is an activity that cuts across WMO programmes, as well as involving a substantive partnership outside the NMSs, particularly in research. In the framework of this concept, SDS-WAS is an international network of research, national operational centres and users organized through regional nodes, assisted by the SDS-WAS regional centres. It is coordinated by the SDS-WAS Steering Committee, supported by the WMO Secretariat, and reports to the Commission for Atmospheric Sciences through WWRP and GAW programmes.

At the regional level of nodes, SDS-WAS is structured as a federation of partners. What the term federation implies is an organized structure following minimum global standards and rules of practice. A federated approach allows flexibility, growth and evolution, while preserving the autonomy of individual institutions. It allows a variety of participants, such as NMSs, air-quality agencies/authorities, universities and research centres and user institutions serving as hosts or/and partners, to cooperate and benefit without changes to their own internal structures and existing arrangements. The structure is scalable and allows for adaptability to changing research and operational environments.

A regional node is also organized according to federal principles. Activities within each node are harmonized by an SDS-WAS Regional Steering Group (RSG), assisted by the WMO Secretariat. Each node has to implement the following tasks agreed by a corresponding RSG:

- Provide a web-based portal agreed between regional partners for user access to regional research and forecast activities and services;
- Support efficient observation data-sharing, providing neutral ground for SDS-WAS data exchange;
- Assist partners in implementing agreed research and forecast activities at regional level;
- Cooperate with existing operational service delivery mechanisms, recognizing that warnings related to SDS-WAS are generally the responsibility of the NMSs and that SDS-WAS products provide input to them.
- Report on implementation progress to the WWRP Joint Scientific Committee and to the SDS-WAS RSG;

- Support research among partners of the SDS-WAS regional node and help implement operational SDS-WAS forecasts at the NMSs;

- Guide the RSG on implementing agreed research and forecast activities at a regional level;

- Organize training workshops in the use of SDS-WAS products;

- Convene symposia, conferences, workshops and other meetings, as necessary, to advance research SDS activities;

- Assist, when necessary, in resource mobilization through trust-fund contributions.

Partners can contribute to SDS-WAS regional node activities, according to their capabilities. Considering that the most important areas of collaboration within the SDS-WAS are observation, modelling and prediction, capacity-building and user support, and that these areas can be subdivided, in turn, into other more specific topics, partners may propose to take the responsibility of leading the coordination of a topic and implement a dedicated website with all the information agreed on that topic. Each topical website would be part of the SDS-WAS web portal of the regional node. This, in turn, could be mirrored in servers of countries with adequate computational resources. A web portal will be established in the regional node as a result of node activities and partners' coordination. Thus, the regional node will not depend on a single institution, and if any member fails, another partner could assume its corresponding function. In this way, a robust, participatory regional system can be established, which is transparent to all partners. Any member of the region may join the regional node at any time.

To achieve this configuration, it is necessary to create several WGs addressing different subjects, which should be integrated by corresponding specialists and experts of the region. They will identify activities, and specific partners of the regional node should assume responsibilities and obligations. These WGs should emerge from a first meeting of the SDS-WAS RSG.

The WMO SDS-WAS Regional Node for West Asia: a collaborative partner of the UNEP Regional Programme to Combat Sand and Dust Storms

The proposed WMO SDS-WAS Regional Node for West Asia is self-sufficient and builds on a model that has already been successfully implemented in other regions. The WMO SDS-WAS Regional Node for West Asia will be a fundamental tool for dust storm monitoring and early warning, as well as for long-term monitoring of the evolution of dust hotspots at different spatial and temporal scales.

SDS originates in dry and desert regions. Many of these areas have been extremely dry for hundreds or thousands of years, owing to natural causes. They currently emit atmospheric dust and are expected to continue to do so in the future with no remedy in the medium term. These dust emissions require monitoring and early warning systems. In other regions, soils have been degraded over a few decades, directly by human activities such as mismanagement of water resources and land misuse, and indirectly by climate change. This results in new dust sources and increasing dust emissions to the atmosphere, which have been intensifying rapidly in recent decades, adding to emissions from natural dust sources. In this sense, an SDS-WAS Regional Node for West Asia is essential for understanding, monitoring and combating desertification in collaboration with the UNEP Regional Programme to Combat Sand and Dust Storms, with the participation of the affected countries and support from other UN organizations and agencies and other partners.

The UNEP SDS Programme has the following four objectives:

1. To strengthen cooperation among countries of the Region (and within countries) to address the SDS problem through collaborative and innovative solutions, institutions and adequate resources.
2. To enhance scientific and societal knowledge about the causes, sources, impacts and dynamics of, and coping with, SDS.
3. To reduce occurrence and impacts of SDS through the design and implementation of innovative and scalable solutions that will at the same time promote investment in the green economy, benefiting local communities and livelihoods.
4. To establish systems of coordinated and state-of-the art monitoring and early warning, including the development of specialized regional centres.

The WMO SDS-WAS Regional Node for West Asia will help to achieve all the objectives, but will play a key role in Objectives 1, 2 and 4.

The UNEP SDS Programme will be built and developed in a logical, four-step approach:

1. Understand and diagnose the problem
2. Propose and reach consensus on the solutions
3. Implement the agreed actions
4. Monitor, learn and scale up

The WMO SDS-WAS Regional Node for West Asia will help to understand and diagnose the problem, using proven scientific techniques and methodologies in the first step of the UNEP SDS Programme and will contribute to the fourth step, measuring success of implemented actions, and providing knowledge to define and implement carefully tailored strategies for the scaling-up of these actions.

The well-defined collaboration mechanisms of the WMO SDS-WAS regional nodes ensure collaboration between groups within a country, collaboration between countries in a region and exchange of information and collaboration at the interregional level under the WMO umbrella. The fact that the WMO SDS-WAS Regional Node for West Asia is a collaborative partner of the UNEP SDS Programme ensures the interconnection and coordination of United Nations Programmes.

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