WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION | GLOBAL ATMOSPHERE WATCH | WWRP WORLD WEATHER RESEARCH PROGRAMME

WMO AIRBORNE DUST BULLETIN

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WMO Sand and Dust Storm – Warning Advisory and Assessment System (SDS-WAS)

The WMO Global Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) is intended to provide continuous and improved SDS operational forecasts as well as to facilitate international coordinated SDS research in the earth-system science domain, fostering the seamless forecast of SDSs, air quality and chemical weather. It is also expected to sustainably realize the value of SDS scientific research in the chain of research, operational forecasts and services (WMO, 2020).

SDS-WAS is the only initiative in the world that has been providing the longest-running SDS research and operational forecasts. After fifteen years of successful development, SDS-WAS looks at new scientific and operational challenges in the next five years (2021-2025) to support disaster prevention, mitigation and adaptation choices in a constantly changing world. The new challenges will be reflected in the initiative implementation plan that is being finalized this month.

As this is the annual issue of the WMO Airborne Dust Bulletin, an analysis of the global distribution of mineral aerosols in 2020, as well as some major SDS events, are provided. The final sections reflect on advances in research and operational forecasting of SDS-WAS.

Overview of atmospheric dust content in 2020

The spatial distribution of the global surface concentration of mineral dust in 2020 (Figure 1) and its anomaly relative to climatologically mean values (1981–2010) (Figure 2) were derived based on the dust products from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) (Gelaro et al., 2017), the latest atmospheric reanalysis version for the modern satellite era produced by NASA's Global Modelling and Assimilation Office (GMAO). MERRA-2 includes an online implementation of the Goddard Chemistry, Aerosol, Radiation, and Transport model (GOCART) integrated into the Goddard Earth Observing System Model, Version 5 (GEOS-5) and is capable of simulating five types of aerosols. The results shown here are based on the dust surface concentration parameter which is different from the dust aerosol optical depth (DAOD) parameter and more relevant to ground air quality.

Generally, the spatial distribution of the global surface concentration of mineral dust in 2020 was similar to that present in 2019 (Zhang et al., 2020), although some slight differences were found. The estimated peak annual mean dust surface concentration (~900–1200 μg/m^3) in 2020 was found in some areas of Chad in north-central Africa. Enhanced dust concentrations were also observed in some regions in the Arabian Peninsula, Central Asia, the Iranian

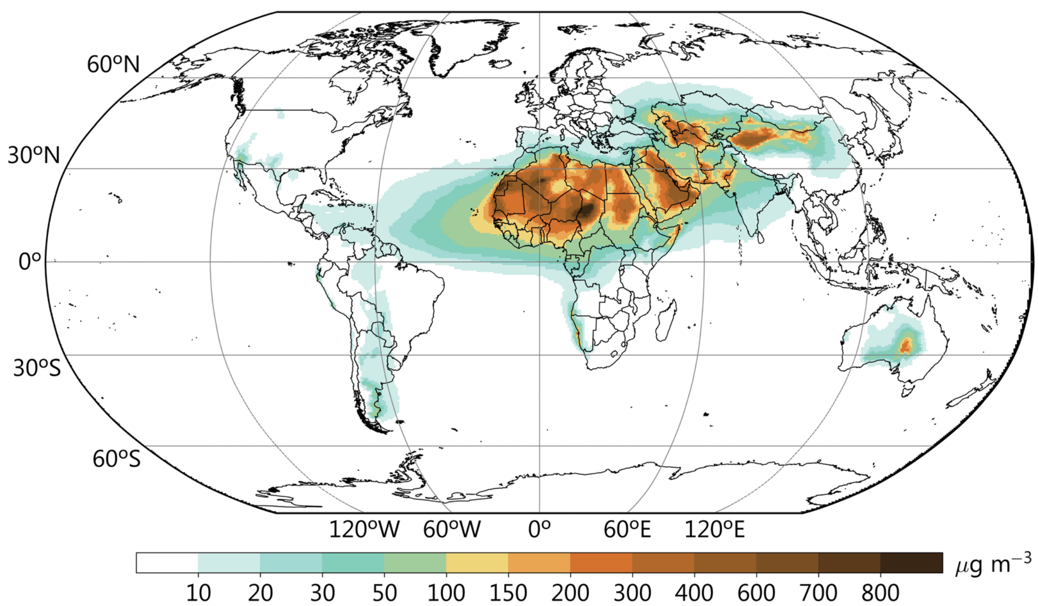

Figure 1. Annual mean surface concentration of mineral dust in 2020

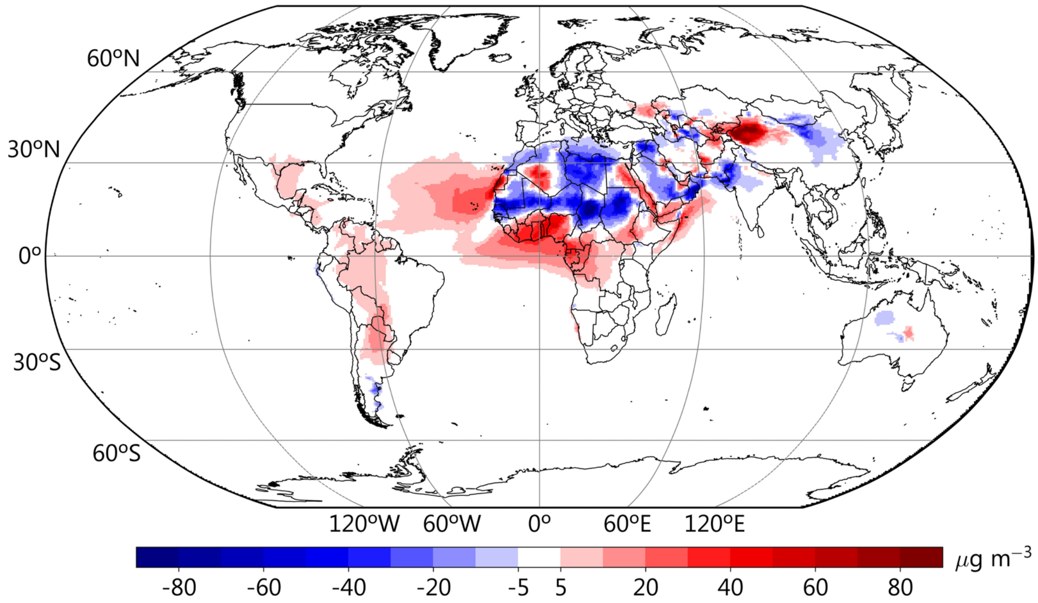

Figure 2. Anomaly of the annual mean surface dust concentration in 2020 relative to 1981–2010 mean

Plateau, and north-western China (mass concentrations of ~300–600 μg/m^3). In the southern hemisphere, dust concentrations reached their highest level (~100–300 μg/m^3) in parts of Central Australia and the west coast of South Africa. From these locations, wind-driven dust was transported to the surrounding regions, including the northern tropical Atlantic Ocean between West Africa and the Caribbean, South America, the Mediterranean Sea, the Arabian Sea, the Bay of Bengal, central-eastern China, the Korean Peninsula and Japan, demonstrating the significant impact of SDSs on many regions of the world. In terms of impact geographic area, SDSs from dust sources in West Africa had a slightly expanded impact area across Central and South America compared to 2019, while the impact area of SDSs originating from dust sources in East Asia was slightly reduced.

In most dust plume-affected areas, the surface dust concentration in 2020 was lower than the climatological mean; exceptions to this were the regions of Central Africa, including Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon, Gabon and Congo; Southwestern Algeria; the northern tropical Atlantic Ocean; Central and South America; the Red Sea; and north-western China (Figure 2). Hot spots with significantly lower dust concentrations included most of North Africa, the Arabian Peninsula, Turkmenistan, the Iranian Plateau, central-northern China, and central-northern Australia.

The three-dimensional (3D) distribution of the dust extinction coefficient (DEC) in the spring of 2020 (Figure 3) was derived based on the Level-3 tropospheric aerosol profile product (CAL_LID_L3_Tropospheric_APro-Standard-V4-20) from CALIPSO lidar (Tackett et al., 2018). The results presented here are the average values for daytime and night-time under the all-sky condition. Satellite observations in the spring of 2020 successfully captured dust activity in the near-dust source regions in the Northern Hemisphere, and its spatial extent of influence was portrayed. As observed, a dust belt, extending from the west coast of North Africa, spanning the entire Arabian Peninsula and central and southern Asia, to north-western China and its downstream area (east-central China and northeast Asia), has been identified. In terms of uplifted height, the enhanced DEC (extinction > 0.1 km^{-1}) is mainly located at an altitude range of 1–4 km above mean sea level (a.s.l). The maximum lifting height of the dust plume layer (DEC > 0.001 km^{-1}) was around 4–8 km a.s.l, spanning the area between 10°N and 60°N demonstrating the long-range transport of sand and dust.

Several severe SDS events that occurred in these hot spots in 2020 and which are presented below resulted in deaths and serious social and economic losses.

Major SDS events over various regions of the world in 2020

UNUSUAL SDS EPISODE IN FALL OVER MONGOLIA, CENTRAL AND NORTHERN CHINA

Influenced by a cyclone in Mongolia and a cold surface wind, an SDS episode swept Mongolia and central and northern China from October 19 to 21, 2020. This was the episode with the largest impact area in 2020, leading to SDS weather in Mongolia and Inner Mongolia, eastern Gansu, northern Ningxia, central and northern Shaanxi, Shanxi, central and western Heilongjiang, central and western Jilin, central

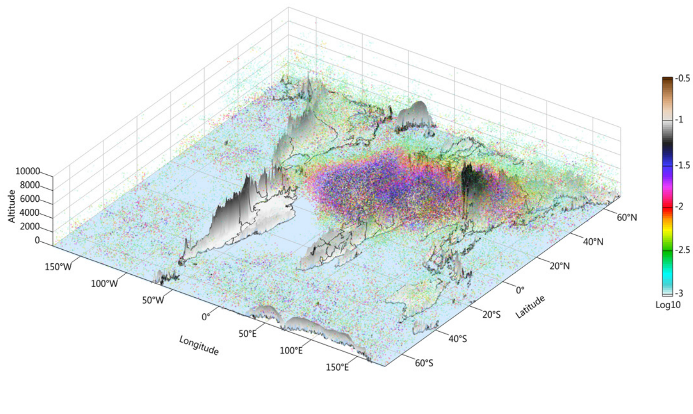

Figure 3. CALIPSO-derived global three-dimensional particles map of the dust extinction coefficient (DEC) in the spring of 2020. Note that the colour scale is converted for better visualization, corresponding to a minimum DEC of 0.001 and a maximum DEC of about 0.32.

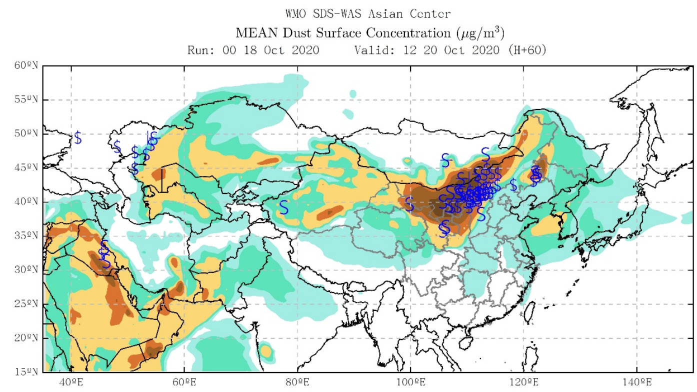

Figure 4. Comparison between observed SDS phenomenon and forecasted dust surface concentrations (μg/m³) by ensemble forecast from SDS-WAS Asian Node at 12:00 (UTC) on Oct 20, 2020. Blue symbols (S) indicate the weather stations where dust was recorded. Source: Beijing Dust Forecast Center.

and western Liaoning, Hebei, Beijing, Tianjin, Shandong, Henan, northern Anhui, and northern Jiangsu provinces of China (Figure 4).

Asian SDSs usually occur in spring from March to May. The extended event that affected large areas of China in autumn 2020 was a rare phenomenon. Multiple numerical SDS forecasting systems at the SDS-WAS Asian Regional Node successfully forecasted this SDS episode, and the ensemble forecast results (Figure 4) showed that the forecasted SDS fallout area corresponds well with the observations.

SDS OVER CANARY ISLANDS

SDS activity during winter 2020 was very intense in the Sahara Desert. An example of this would be the dust intrusions that affected the Canary Islands and Sahel countries in Western Africa. Harmattan winds and synoptic systems were responsible for these strong events.

The Canary Islands were strongly affected by two dust outbreaks in February 2020. Winter dust outbreaks in the Canary Islands are often associated with the presence of cut-off lows, deep-lows or deep troughs located in the vicinity of the Canary archipelago.

The first one was on 4 February with a PM_{10} maximum concentration around 1000 μgm^{-3}. This type of episode is usually observed in winter every 2 or 3 years and usually affects the low altitudes of some islands of the archipelago.

The second episode (Figure 5a), a couple of weeks later from 22 to 24 February, was a record event in the history of Canary dust intrusions with extremely high PM_{10} hourly concentrations, which exceeded 3 000 μgm^{-3} during the largest peak recorded on 23 February 2020 and significantly impacted aviation (cancellation of 1 000 flights), air quality, agriculture, solar energy (loss of around one million Euros) and ecological systems with an unprecedented irruption of birds and invertebrates to the islands from the neighboring African continent (more information about this event in WMO-GAW Report (WMO, 2021).

Both events were well forecasted by the MONARCH model as can be seen in Figure 5b.

SDS OVER SAHEL

The Sahel last winter season was affected by intense SDS activity and high levels of surface dust concentration which lasted several days leading to strong reduction in visibility among other impacts (Figure 6). In January, high concentration values remained for ten days (from 1st to 10th), in February for 8 days (from 8th to 15th) and in March for 4 days (from 12th to 15th), completing a season that could be described as exceptional. The model's performance was quite good during the events as can be seen in the example for January (Figure 7a and 7b).

SDS EVENT OVER WEST AND SOUTHWEST IRAN

On May 6, 2020, an SDS event was recorded which reduced visibility at stations located in the west and southwest of Iran. The event was tracked by CALIPSO's products. Figure 8a shows part of the CALIPSO's orbit (around 10:00 UTC on May 6, 2020). The high concentration of aerosols (in yellow, orange and red) is detectable in southwestern Iran (up to a height of 5 km) and western Iran (up to a height of 10 km). The vertical structure of the atmosphere (Figure 8b) in this region shows large amounts of aerosols (orange) from the surface to a height of 5 km, although some clouds are also

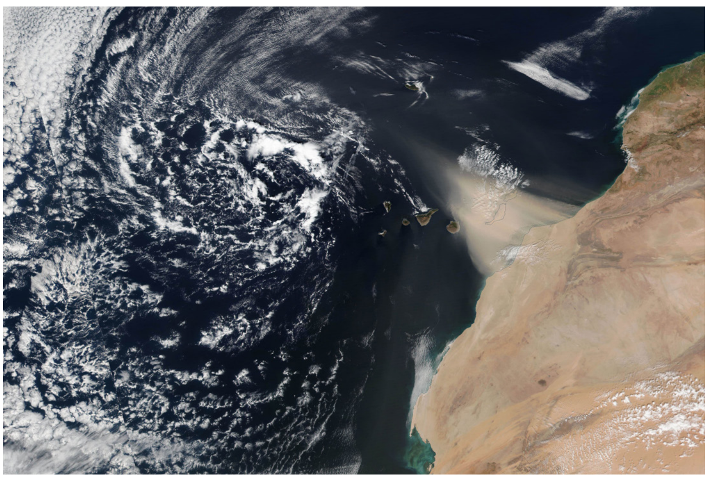

Figure 5a. Image for 22 February 2020 obtained by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor aboard the SUOMI polar satellite. Source: NASA Global Imagery Browse Services (GIBS)

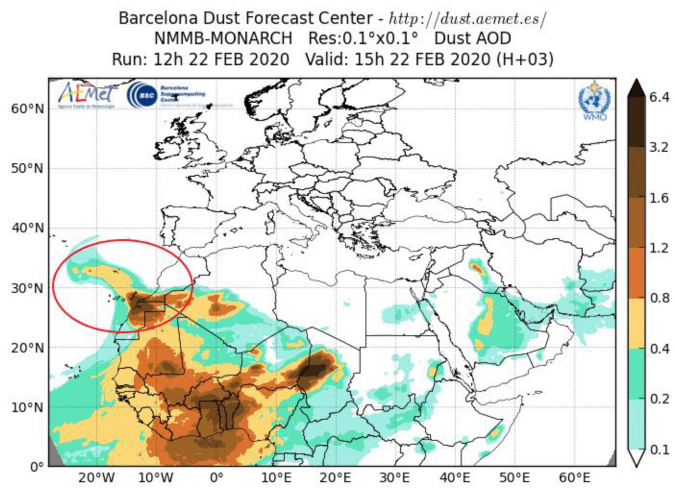

Figure 5b. NMMB-MONARCH mineral dust AOD prediction. Model prediction at 1200 UTC on 22/02/2020 for 22 February 2020 at 15UTC. Source: Barcelona Dust Forecast Center.

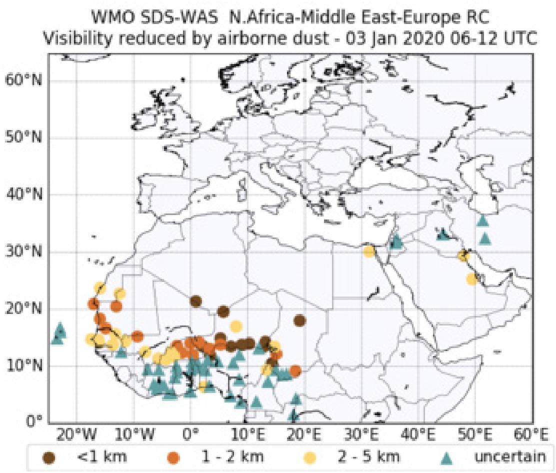

Figure 6. Visibility product for 03 Jan 2020
Source: SDS-WAS NAME RC

observed. According to Figure 8c, the observed aerosols are dust (in yellow).

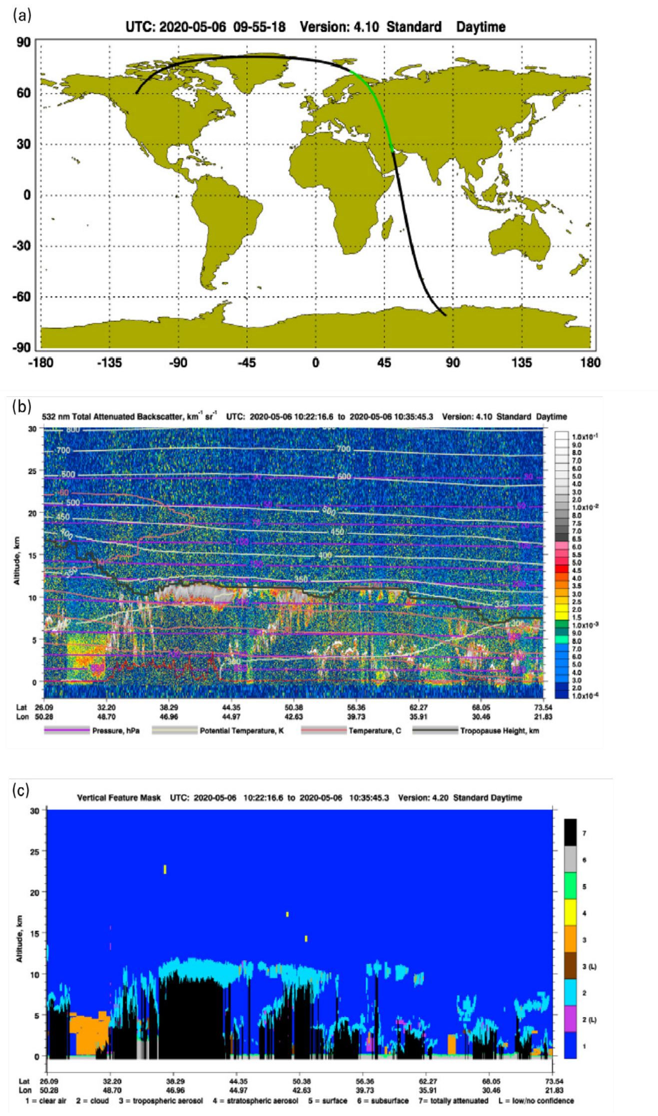

Figure 8. (a) Part of the CALIPSO satellite route, (b) Total attenuated backscatter, (c) Vertical feature mask describing the vertical distribution of aerosol layers.

THE "GODZILLA" 2020 DUST EVENT

During the summer of 2020, the Caribbean region felt the effects of an historic African (Saharan) dust plume that has been called "Godzilla"due to its large geographic extent and record amount of dust. This plume, with an area close to the size of continental USA, blanketed areas in the greater Caribbean Basin, northern South America, Central America, the Gulf of Mexico and the southern United States. It affected the region for about 15 days (June 18–July 2). The occurrence and progression of this "Godzilla" event was predicted by several dust forecast models, among them, the global GEOS-5 and the regional dust forecast model Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) from the Caribbean Institute for Meteorology and Hydrology (CIMH) (Figure 9).

According to data from the NASA CALIOP Lidar, the dust plume extended from the Earth's surface up to about 5 km altitude. As part of the NASA-funded summer 2020 intensive field phase of the Caribbean Air Quality Alert and Management Assistance System-Public Health (CALIMA-PH) project, several ground-based stations in the Greater Caribbean Basin (French Guiana, Trinidad and Tobago, Barbados, Martinique, Guadeloupe, Puerto Rico, Mérida-México and Miami-USA) collected surface aerosol data

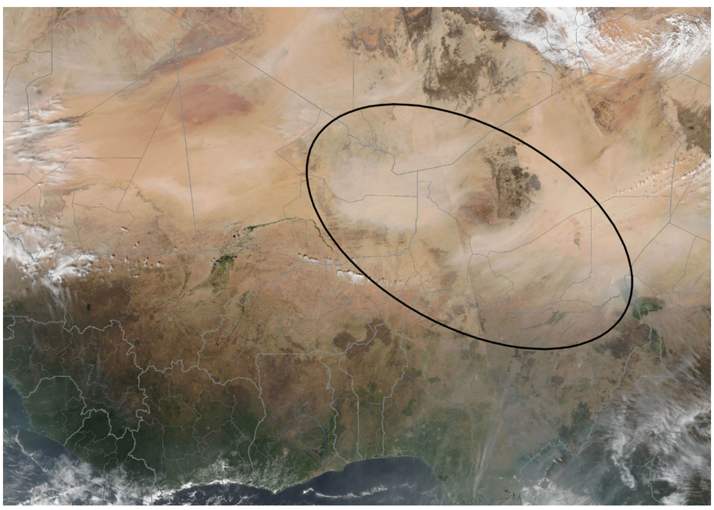

Figure 7a. SUOMI NASA Polar Satellite 01 Jan 2020
Dust storms starting in Mali and Niger and moving over the Sahel
Source: NASA Global Imagery Browse Services (GIBS)

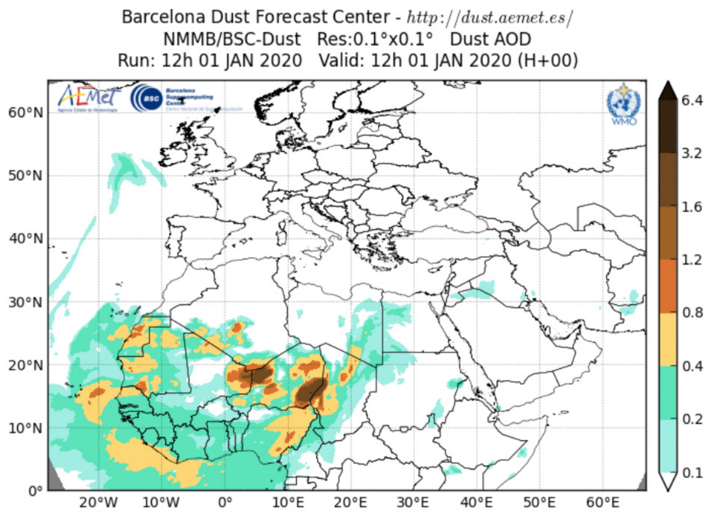

Figure 7b. MONARCH forecast for 1 Jan 2020 reproducing the dust storms that will affect the Sahel.
Source: Barcelona Dust Forecast Center

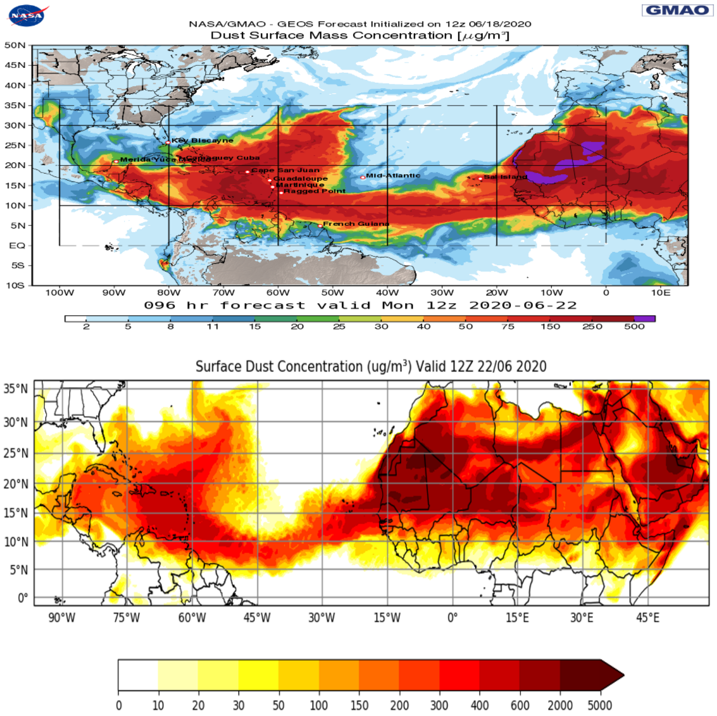

Figure 9. NASA/GMAO GEOS-5 (top) and CIMH WRF-CHEM (bottom) 96-hour predictions of surface dust concentrations initialized on June 18, 2020 12Z and valid June 22, 2020 12Z.

(e.g., PM_{10} and $PM_{2.5}$ mass concentrations, light scattering and absorption coefficients, visibility, dust concentrations) and aerosol optical depth (AOD) during the event. Those data, together with satellite observations such as those from the Moderate Resolution Imaging Spectroradiometer (MODIS), Geostationary Operational Environmental Satellites GOES-East, and CALIOP, helped to describe the movement of the dust plume through the region and assess its impact (Figure 10).

The event caused a decrease in visibility in the atmosphere's boundary layer of less than 4.8 km in some locations (Figure 11), showed record values for the aerosol optical properties in situ and in the column, and exhibited exceedances of both the US Environmental Protection Agency (EPA) air quality standard and the World Health Organization (WHO) air quality guidelines.

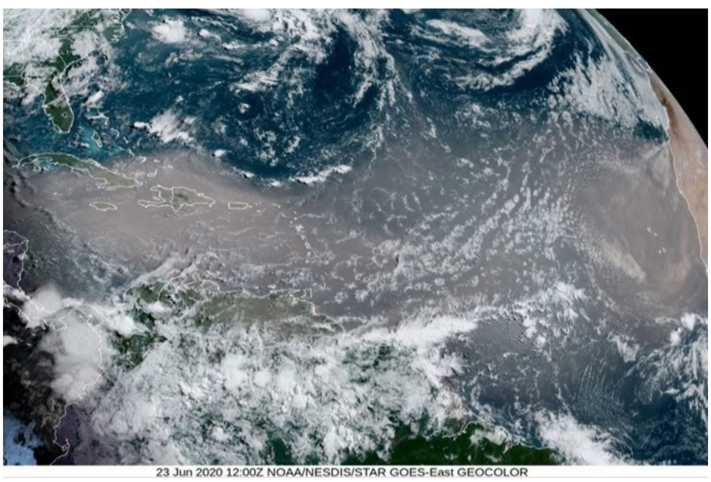

Figure 10. Satellite image of historic African dust plume ("Godzilla") moving over the Atlantic Ocean into the Caribbean region (June 23, 2020 1200Z NOAA/NESDIS/STAR GOES-East GEOCOLOR)

For several days, locations impacted by "Godzilla" were exposed to air quality conditions ranging from "Unhealthy for sensitive groups" to "Hazardous", in cases reaching PM_{10} values ca. 500 μg/m³. The event represented a public health threat for millions of people across the region.

Research highlights of 2020

PROGRESS ON THE WGNE-S2S-GAW AEROSOL PROJECT

The importance of atmospheric composition in Numerical Weather (NWP) and Climate Prediction (CP) has been addressed by many studies in the last few decades. Recognizing the role of atmospheric composition as a fundamental component to improve forecast capabilities, in 2019, the Working Group for Numerical Experimentation (WGNE), jointly with the World Weather Research Programme's Sub-seasonal to Seasonal (S2S) Steering Group and the Global Atmosphere Watch (GAW) Scientific Advisory Group on Modelling Applications (SAG-APP), launched the second phase of the Aerosol Project.

SDS-WAS joined the WGNE Aerosol Experiment to test the impact of aerosols (including dust) on weather forecasting.

The WGNE-S2S-GAW Aerosol Project encourages the participation of operational meteorological centres as well as research groups from various institutions around the world, contributing with their state-of-the-art integrated chemistry-meteorology numerical modelling.

A preliminary result of the 36h forecast of 2-meter temperature performed by the Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing of the National Observatory of Athens for day 27/10/2010 at 12:00 UTC over the Mediterranean region shows the consistent, substantial reduction of near-surface temperature over the northern portion of the Sahara Desert when interactive aerosols are considered in the regional modelling system based on WRF/ARW.

As a contribution to the Aerosol Project, Flemming et al. (2020) analyzed the differences in the skill of two sets of runs performed with the Copernicus Atmosphere Monitoring Service (CAMS). The authors performed global 5-day forecasts of atmospheric composition and meteorology considering two experiments: (i) interactive prognostic aerosols and (ii) aerosol climatology, both in the radiation scheme. Considerable mean differences were f ound over arid areas and surrounding regions associated with dust. The result shows that for mineral dust aerosols with radius bin limits between 0.03–0.55 μm, near-surface temperature mean differences are more prominent in the 5-day forecast performed with aerosol climatology compared with interactive aerosols. The findings indicated that prognostic dust aerosol was systematically lower than climatological dust aerosols leading to an increase in near-surface temperature.

The next steps of the project include the continuation of the model evaluation process to consider all the periods provided by the modelling groups. The first phase of model evaluation examines meteorological fields and atmospheric circulation patterns, linking them with the physical processes associated with the aerosols. The second phase will include the evaluation of air quality variables and optical properties of aerosols.

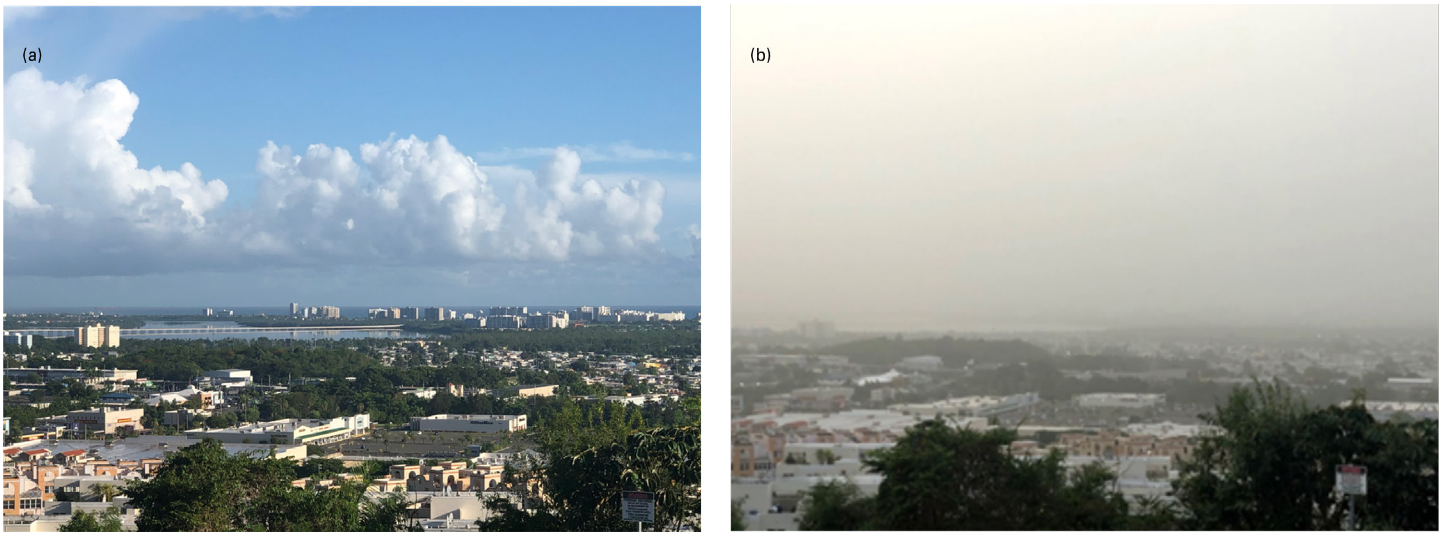

Figure 11. Photos taken in San Juan, Puerto Rico showing the impact the dust plume had on the reduction of the visibility. (a) July 21, 2019, (b) June 22, 2020 (during the "Godzilla" event). Credit. Olga L. Mayol-Bracero)

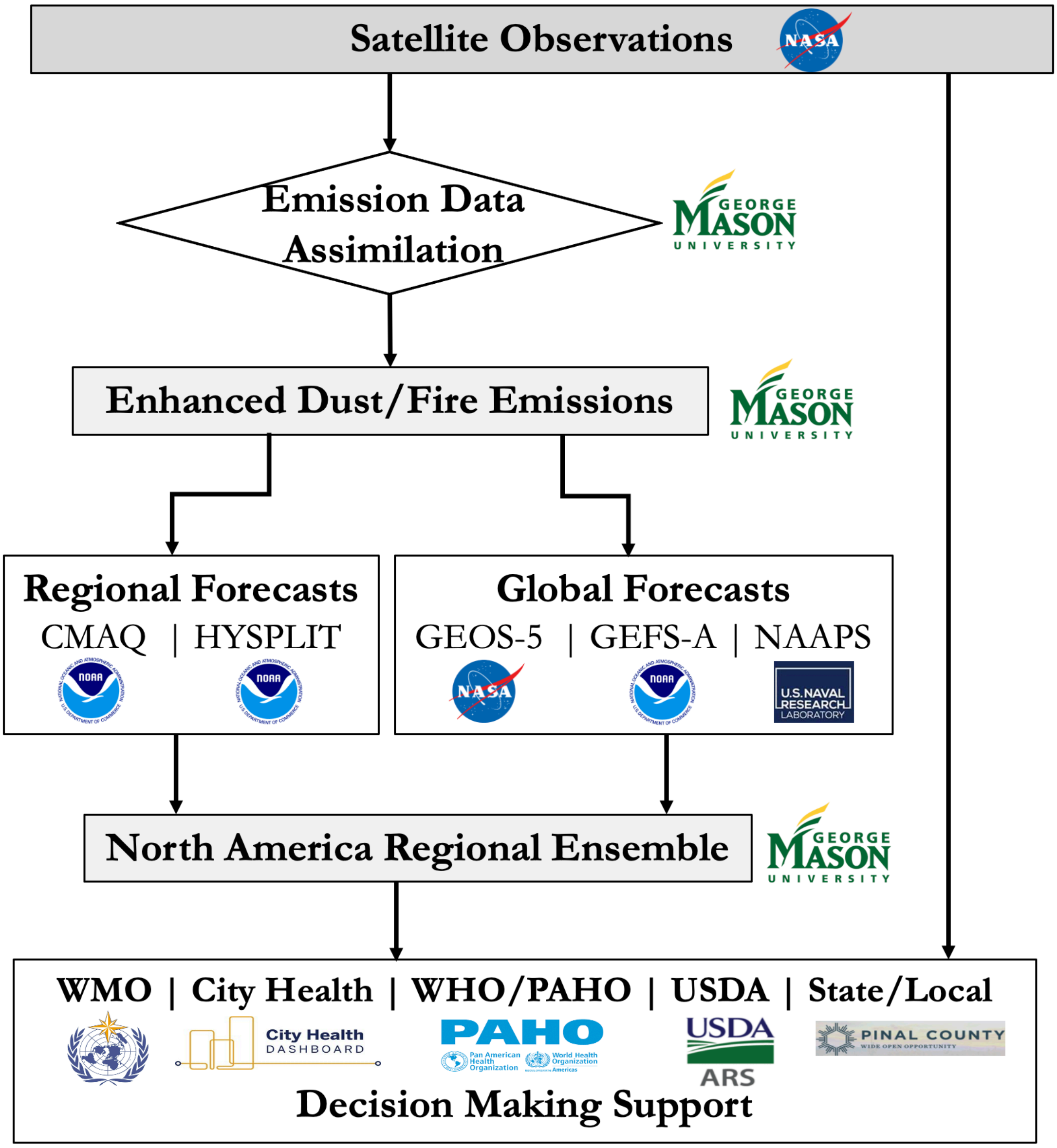

Figure 12. Conceptual design of the North America Ensemble Dust Forecast project.

ICELANDIC DUST MAKES ICE IN CLOUDS

Mineral dust from the world's deserts is well known as an aerosol that nucleates ice in clouds around the globe. However, there is emerging evidence that mineral dust from high latitude dust (HLD) sources may also be important for clouds and may be important for defining cloud-climate feedbacks (Murray et al. 2021). Dust particles can change the radiative properties of cold clouds by means of reducing their liquid water content and albedo. In a new study, Sanchez-Marroquin et al. (2020) showed that Icelandic volcanic dust generated by glacio-fluvial processes is an active ice-nucleating particle (INP). Airborne Icelandic dust sampled from an aircraft was found to be an effective ice-nucleator, exhibiting an activity comparable or exceeding low latitude dust (LLD, at temperatures above –17 °C). The ice-nucleation activity of Icelandic dust in combination with a global aerosol model showed that Icelandic dust is emitted and transported to locations and altitudes where it acts as an INP at cloud temperatures. The greatest contribution of Icelandic dust to the INP concentration occurs during the summer over large areas of the North Atlantic and the Arctic at altitudes between 3–5.5 km, where mixed-phased clouds are known to occur. In the future, increased INP concentrations would lead to a reduction in supercooled water and a decrease in the shortwave reflectivity of clouds to produce positive climate feedback. Iceland is, however, only one of many active HLD sources and the combined effect of all these sources will be a significant contribution to the INP concentration in the Arctic. Since HLD emissions are likely to increase under most climate change scenarios, this INP source might become even more significant in the coming decades.

Operational forecasting highlights of 2020

PAN-AMERICAN NODE TO LAUNCH NEW ENSEMBLE DUST FORECAST PROJECT

A new ensemble dust forecasting project has been funded by the US National Aeronautics and Space Agency (NASA), in partnership with WMO SDS-WAS Pan-American Center, WHO/Pan-American Health Organization, and several federal and local agencies, to provide real-time forecasts of dust storms and wildfires over North America. Although air quality continues to improve in this region, the frequency of high-impact extreme events, such as dust storms and wildland fires, has increased rapidly in recent decades and is projected to rise further in response to climate change.

A team of air quality forecasters, health experts and environmental managers has been assembled and tasked to assess and improve the collective predictability of these high-impact events in order to mitigate harmful effects on human health and the economy. This ensemble forecast system will leverage two operational/research programs: the National Air Quality Forecast Capability (NAQFC) and the International Cooperative for Aerosol Prediction (ICAP). Two regional forecasts (by Hybrid Single-Particle Lagrangian Integrated Trajectory model HYSPLIT and Multiple-scale Air Quality model CMAQ) from NAQFC and three global forecasts from NASA, National Oceanic and Atmospheric Administration (NOAA) and Naval Research Lab (NRL) will comprise the initial members of the ensemble. There is a plan to include more model predictions in the future.

Furthermore, this project will work with stakeholders to prepare customized data packages for three applications: (1) producing air quality metrics for the City Health Dashboard (https://www.cityhealthdashboard.com), a health initiative serving 750 largest US cities; (2) providing real-time ensemble dust forecasting as a pilot project WMO Pan-American SDS-WAS Node and (3) working with WHO/Pan-American Health Organization (PAHO) to provide forecasting and observations of wildfires and air quality to its member countries.

Report from United Nations coalition on combating sand and dust storms

The United Nations (UN) Coalition on Combating Sand and Dust Storms has made considerable progress since a global response to the issue was called for in UN General Assembly Resolution 72/225, adopted in December 2017, and the Coalition's official launch in September 2019 at the 14th Conference of Parties (COP14) to the UN Convention to Combat Desertification (UNCCD) in New Delhi, India. Core Coalition members comprise 15 UN bodies including UNCCD, the UN Food and Agriculture Organization (FAO), WMO, the UN Environment Programme (UNEP), the UN Development Programme (UNDP), the World Health Organization (WHO), the UN Economic and Social Commission for Asia and the Pacific (ESCAP) and the UN Economic and Social Commission for West Asia (ESCWA). The core members have agreed on a set of key documents to guide the Coalition's work: A Governance Framework, a Strategy, and an Action Plan. According to the Governance Framework, the chair/host of the Coalition changes every two years and the chair was formally transferred at the 3rd Coalition meeting in July 2020 from UNEP to FAO for the next two years.

Further formalities were agreed at the 4th Coalition meeting in October 2020 (moving from planning to implementation), at which the leads/co-leads of each of the Coalition Working Groups (WGs) were confirmed:

- 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 Coalition's 5th meeting in February 2021 was attended by 36 delegates representing 17 organizations, including a number of invited non-UN partners selected for their potential contributions to the working groups. Discussions focused on prioritized outputs from the Coalition's Action Plan, alongside ideas to enhance resource mobilization. The prioritized activities focused on supporting the SDS toolbox, enhancing knowledge about early warning and good practices for SDS mitigation and adaptation, risk assessment, awareness, informing policies and enhancing capacities at national and regional levels. Once resources can be identified, the intention is to commence the Coalition's global response to sand and dust storms with a number of fast-track, high-visibility, high-impact projects.

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