Letter to the Editor on Chappell et al., 2023.

Natalie Mahowald1, Paul Ginoux2, Samuel Albani3, Yves Balkanski 4, Mian Chin5,Gilles Bergametti6, Thomas F. Eck7, Carlos Pérez García-Pando 8, Antonis Gkikas9, María Gonçalves Ageitos 8,10, Dongchul Kim7, Martina Klose11, Jasper F. Kok12, Sandra LeGrand, 13,14, Longlei Li1, Beatrice Marticorena6, Ronald Miller15, Greg Okin13, Claire Ryder 14, Charles Zender16, Yan Yu16,

1. Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY 14850, USA
2. NOAA/OAR Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA.
3. Department of Environmental and Earth Sciences, University of Milano-Bicocca, Milano, Italy
4. Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, IPSL, Gif-sur-Yvette, France
5. NASA Goddard Space Flight Center, Greenbelt, MD, USA
6. LISA, UMR CNRS 7583, Université Paris Est Créteil, Université Paris Cité, IPSL, Créteil, France
7. University of Maryland Baltimore County, GESTAR II - NASA Goddard, Greenbelt, MD, USA
8. Barcelona Supercomputing Center, Barcelona, Spain

9 Research Centre for Atmospheric Physics and Climatology, Academy of Athens, 11521 Athens, Greece

10 Projects and Construction Engineering Department, Universitat Politècnica de Catalunya, Terrassa, Spain

11. Institute of Meteorology and Climate Research Troposphere Research (IMKTRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
12. Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, Los Angeles, CA, USA.
13. Department of Geography, University of California, Los Angeles, Los Angeles, CA, USA.
14. U.S. Army Engineer Research and Development Center, Geospatial Research Laboratory, Alexandria, Virginia, USA

15 NASA Goddard Institute for Space Studies, New York, NY, USA

16. Department of Meteorology, University of Reading, Reading, RG6 7BE, UK.
17. Department of Earth System Sciences, University of California, Irvine, Irvine, CA, USA.
18. Department of Atmospheric and Oceanic Sciences, Peking University, Beijing, China.

Chappell et al. (2023) recently concluded that North Africa is not the largest source of dust in the world and that the global rate of dust emission is almost two orders of magnitude smaller than estimated by numerous previous studies (e.g., 29 Tg/year versus 1200 to 9000 Tg/year in Huneeus et al., 2011; Ginoux et al., 2012; Klose et al., 2021; Kok et al., 2021; Checa-Garcia et al., 2021; Gliss et al., 2021; Zhao et al., 2022). These conclusions run counter to decades of prior research. Here we first review the data and knowledge we already have about dust, and then discuss the sources of the discrepancies between Chappell et al. (2023) and previous work.

While Chappell et al. (2023) concluded that existing dust models greatly overestimate dust emission, particularly in North Africa, their approach fails to consider the available climatological dust data, in contrast to the existing model studies and evaluations. For example, a simple back-of-the-envelope computation indicates that their estimated global annual dust emission rate is 2 orders of magnitude too small and not consistent with the known global atmospheric dust load. A relatively easily observed indicator of the atmospheric dust load is the optical depth over dust regions, which represents the amount of light that is absorbed or reflected by dust aerosols (e.g. Ridley et al., 2016). Combining their estimated

~30 Tg/year global annual emission of dust with diameter less than 10 µm (PM10) with the model-estimated dust lifetime of ~3 days (e.g., Kok et al., 2017; Gliss et al., 2021), the total amount of dust in the atmosphere would be ~0.25 Tg (3 days*30 Tg/365 days). This corresponds to a global mean dust optical depth ranging from 0.0002 to 0.0005 based on a mid-visible wavelength mass extinction coefficient varying from 0.40 to 0.96 m^2/g (Kok et al., 2021a), respectively. Such values are 2 orders of magnitude lower than observationally constrained values of global mean mid-visible dust optical depth varying from approximately 0.02 to 0.04 (Ridley et al., 2016; Voss and Evan, 2020; Song et al., 2021; Kok et al., 2021a; Gkikas et al., 2022). In order to explain their lower emissions over North Africa, Chappell et al. (2023) argue that North African dust is not transported away from sources, but recirculated in the regional atmosphere, allowing higher loads to build up. However, relating their low magnitude of emissions of ~30 Tg/year to the observationally constrained global mean dust optical depth would require a dust lifetime on the order of 300 days, which is clearly unphysical. Indeed, such a long lifetime is incompatible with well-documented evidence of the role of meteorological influence on dust transport - for example dust is transported from North African sources across the Atlantic on a timescale of 5-10 days (e.g. Knippertz & Todd 2012; Weinzierl et al. 2017). Furthermore, well-known documentation of North African wind patterns, trajectory analyses and also the same high-resolution (15min) SEVIRI satellite analyses used by Chappell et al. (2023) confirm that dust transport occurs on these time scales (e.g. Ryder et al., (2018), many others..), which disputes the findings of Chappell et al. (2023).

In addition to the clear underestimation of the global dust emission rate by Chappell et al. (2023), there is are multiple lines of evidence at that Chappell et al. (2023) underestimated dust from North Africa the regional scale, as well as the relative contribution of North African dust to the global dust cycle. Chappell et al. (2023) found that North African dust emission is small (6 Tg/year of PM10 dust) and sparsely distributed across the region. In contrast, a recent study combining model simulations with observationally informed constraints on the dust size distribution (Adebiyi and Kok, 2020), extinction efficiency, and regional dust aerosol optical depth (Ridley et al., 2016), estimated that North Africa contributes between 500 to 1600 Tg/year of PM10 dust (Kok et al., 2021a). Spaceborne observations show that the highest aerosol optical depths over oceans are recorded off the western coasts of North Africa and along the Tropical Atlantic Ocean (Remer et al., 2008; Dubovik et al., 2021; Li et al., 2022). Models and data assimilations that attempt to be consistent with the satellite aerosol optical depth and deposition records also show that North Africa is the world's largest sources of dust aerosols (Cakmur et al., 2006; Albani et al., 2014; Gelaro et al., 2017; Ridley et al., 2016, Kok et al, 2021a, b; Kaufman et al., 2005; Yu et al., 2019). In addition, both visibility and dust weather reports from synoptic stations show the largest amount of aerosols / dust activity in North Africa (Mahowald et al., 2007; N'Tchayi Mbourou et al., 1997; Shao et al., 2013). In-situ measurements in North Africa are also consistent with large dust sources (Marticorena et al., 2010; Mahowald et al., 2024) and downwind stations and field campaigns consistently show large amounts of dust from North Africa traveling across the North Atlantic (Reid et al., 2003; Rodríguez et al., 2015; Ryder et al., 2019). The few AERONET sites that are available near the main dust source areas also show high column aerosol optical depths that are consistent with model estimates (Obiso et al., 2024;Ginoux et al., 2001; Klose et al., 2021). Climatologically, the highest dust aerosol optical depths measured globally by AERONET are in North Africa and immediately downwind in the Cape Verde Islands (https://aeronet.gsfc.nasa.gov/new_web/climo_menu_new_v3.html). Even more surprising, from Figure 6 in Chappell et al. (2023), it appears that the Bodélé depression, long considered to be one of the most active dust sources in the world (Prospero et al., 2002; Koren et al., 2006; Washington et al., 2006; Todd et al., 2007; Warren et al., 2007; Yu et al., 2020) is weakly emitting dust. On the other hand, the Horn of Africa appears as the most active source in Chappell et al. (2023), contrary to more detailed studies (Kunkelova et al. 2024). One possible cause of these discrepancies is that dust emission from point source (DPS) identification using SEVIRI in dusty regions is challenging and predisposed towards omitting dust emission events obscured by an already-dusty atmosphere.

Several key dust papers over the last few decades have used satellite remote sensing to determine the dominant sources of dust (Prospero et al., 2002) as well as the importance of agricultural sources of dust (Ginoux et al., 2012). In contrast to Ginoux et al. (2012), Chappell et al. (2023) use a much coarser temporal (1 month versus 1 day) and spatial (1 degree versus 0.1 degree) resolution to extract the dust optical depth from aerosol optical depth. This makes the detection of dust from the Angstrom exponent using the approach proposed by Chappell et al. (2023) almost impossible because of the mixing of different kinds of aerosols at these coarse temporal and spatial scales: the details of the approach matter greatly to adequately determine which events are dust events. For example, Chappell et al. (2023) shows a poor relationship between MODIS dust optical depth and DPS frequency data (Chappell et al., 2023; Figure 5a). This result contradicts the more detailed analysis (done at higher spatial and temporal resolution) of Baddock et al. (2016), which showed the close relationship between the satellite-defined dust sources from Ginoux et al. (2012) and geomorphological features on the ground.

Other studies using the Chappell et al. (2023) approach use comparisons to dust point source data to demonstrate applicability of the method (e.g. Chappell et al., 2024). This highlights that dust point source data alone do not provide the best evaluations of the modeled dust cycle, since these comparisons do not show the problems with the more robust and important climatological data highlighted here based on remote sensing, in situ data and deposition data (e.g. Kok et al., 2021a).

Chappell et al. (2023) arrived at their controversial conclusions by combining a compilation of satellite observations of dust emission point sources (DPS; e.g., Schepanski et al., 2007; Hennen et al., 2019) with a dust emission scheme proposed by Hennen et al. (2022, 2023) that incorporates an albedo-based drag partition scheme developed by Chappell and Webb (2016; CW16 hereafter). For the DPS method, analysts typically track and record the location of dust plume origins through the subjective interpretation of imagery processed through dust-enhancement algorithms. The CW16 method infers surface roughness effects on wind friction speed and dust entrainment from shadows cast by subgrid-scale roughness elements derived using MODIS albedo data.

Although this is a novel approach, the CW16 and DPS methodologies upon which the new results by Chappell et al (2023) are based, have documented issues. In particular, Okin (2023) recently demonstrated through geometric-optical modeling that there is little relation between the MODIS albedo data used by Chappell et al. (e.g., Chappell and Webb (2016), Chappell et al (2018), and Ziegler et al. (2020)) and surface roughness. Indeed, Okin (2023) showed that the brightness of the underlying soil, rather than the amount of roughness, was, by far, the strongest predictor of the diagnostic parameter used by CW16 to determine an area’s normalized proportion of shadow. In addition, ultrasonic anemometer-based field measurements (Zhou et al. 2024, Figure 4) show minimal support for the albedo-based approach to correctly represent the temporal-spatial variations in surface friction velocity across various landscapes. Furthermore, a study by LeGrand et al. (2023), reviewing a weather modeling application of the CW16 method, reported concerns with the foundational theory, noting unrealistic results over forested areas, while also noting that the CW16 approach performed no better than a simple tuning constant. Finally, besides DPS, Chappell et al. (2023) did not provide an evaluation of the calculated horizontal sediment flux and vertical dust emission flux . While the DPS approach has great utility in understanding the sources and timing of dust emissions (e.g., Schepanski et al., 2009), this technique is well-known to underestimate dust sources (Sinclair and LeGrand, 2019, Baddock et al. 2021).

Because of the large biases and uncertainties inherent in the modeling approach of Chappell et al. (2023), but also in other dust emission schemes (Marticorena and Bergametti 1995; Shao, 2001; Kok et al., 2014), it is imperative that any conclusions drawn from modeling are scrutinized against a battery of independent observational data sets. This is especially the case when conclusions are drawn that run counter to a large body of prior work. Unfortunately, this was not done in Chappell et al. (2023), resulting in conclusions that are inconsistent with several lines of observational evidence. In arguing that the existing body of hundreds of papers on desert dust is incorrect, the authors of Chappell et al. (2023) set a high bar in order to make a convincing argument. Unfortunately, the authors do not engage with most of the evidence, and thus their argument of low dust emissions from North Africa and the world cannot be considered compelling.

References

Albani, S., Mahowald, N. M., Perry, A. T., Scanza, R. A., Zender, C. S., Heavens, N. G., Maggi, V., Kok, J. F., and Otto-Bliesner, B. L.: Improved dust representation in the Community Atmosphere Model, J Adv Model Earth Syst, 6, 541–570, https://doi.org/10.1002/2013MS000279, 2014. Baddock, M. C., Bryant, R. G., Acosta, M. D., and Gill, T. E.: Understanding dust sources through remote sensing: Making a case for CubeSats, J. Arid Environ., 184, 104335, https://doi.org/10.1016/j.jaridenv.2020.104335, 2021.

Baddock, M. C., Ginoux, P., Bullard, J. E., and Gill, T. E.: Do MODIS-defined dust sources have a geomorphological signature?, Geophys Res Lett, 43, 2606–2613, https://doi.org/10.1002/2015GL067327, 2016.

Balkanski, Y., Schulz M., Claquin, T., and Guibert, S.: Reevaluation of mineral aerosol radiative forcings suggests a better agreement with satellite and AERONET data, Atmos Chem Phys, 7, 81–95, 2007.

Cakmur, R.V., R.L. Miller, J.P. Perlwitz, I.V. Geogdzhayev, P. Ginoux, D. Koch, K.E. Kohfeld, I. Tegen, and C.S. Zender, 2006: Constraining the global dust emission and load by minimizing the difference between the model and observations. J. Geophys. Res., 111, D06207, doi:10.1029/2005JD005791.

Chappell, A., Webb, , N. P., Hennen, M., Schepanski, K., Ciais, P., Balkanski, Y., Zender, C. S., Tegen, I., Zeng, Z., Tong, D., Baker, B., Ekström, M., Baddock, M., Eckardt, F. D., Kandakji, T., Lee, J. A., Nobakht, M., von Holdt, J., and Leys, J. F.: Satellites reveal Earth's seasonally shifting dust emission sources, Science of the Total Environment, 883, https://doi.org/10.1016/j.scitotenv.2023.163452, 2023. Chappell, A., Webb, N. P., Hennen, M., Zender, C. S., Ciais, P., Schepanski, K., et al. (2023). Elucidating hidden and enduring weaknesses in dust emission modeling. Journal of Geophysical Research: Atmospheres, 128, e2023JD038584. https://doi. org/10.1029/2023JD038584

Checa-Garcia, R., Balkanski, Y., Albani, S., Bergman, T., Carslaw, K., Cozic, A., Dearden, C., Marticorena, B., Michou, M., Van Noije, T., Nabat, P., O'Connor, F. M., Olivié, D., Prospero, J. M., Le Sager, P., Schulz, M., and Scott, C.: Evaluation of natural aerosols in CRESCENDO Earth system models (ESMs): Mineral dust, Atmos Chem Phys, 21, 10295–10335, https://doi.org/10.5194/acp-21-10295-2021, 2021.

Dubovik, O., Fuertes, D., Litvinov, P., Lopatin, A., Lapyonok, T., Doubovik, I., Xu, F., Ducos, F., Chen, C., Torres, B., Derimian, Y., Li, L., Herreras-Giralda, M., Herrera, M., Karol, Y., Matar, C., Schuster, G. L., Espinosa, R., Puthukkudy, A., Li, Z., Fischer, J., Preusker, R., Cuesta, J., Kreuter, A., Cede, A., Aspetsberger, M., Marth, D., Bindreiter, L., Hangler, A., Lanzinger, V., Holter, C., and Federspiel, C.: A Comprehensive Description of Multi-Term LSM for Applying Multiple a Priori Constraints in Problems of Atmospheric Remote Sensing: GRASP Algorithm, Concept, and Applications, Frontiers in Remote Sensing, 2, https://doi.org/10.3389/frsen.2021.706851, 2021.

Engelstaedter, S., Kohfeld, K. E., Tegen, I., and Harrison, S. P.: Controls of dust emissions by vegetation and topographic depressions: An evaluation using dust storm frequency data, Geophys Res Lett, 30, 1294, doi:10.1029/2002GL016471, 2003, 2003.

Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Randles, C. A., Darmenov, A., Bosilovich, M. G., and Reichle, R.: The modern-era retrospective analysis for research and applications, version 2 (MERRA-2), J Clim, 30, 5419–5454, 2017.

Ginoux, P., Chin, M., Tegen, I., Prospero, J. M., Holben, B. N., Dubovik, O., and Lin, S.-J.: Sources and distribution of dust aerosols with the GOCART model, J Geophys Res, 106, 20255–20273, 2001.

Ginoux, P., Prospero, J., Gill, T. E., Hsu, N. C., and Zhao, M.: Global scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS deep blue aerosol products, Reviews of Geophysics, 50, RG3005, https://doi.org/DOI:10.1029/2012RG000388, 2012.

Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Marinou, E., Hatzianastassiou, N., Kok, J. F., and García-Pando, C. P.: Quantification of the dust optical depth across spatiotemporal scales with the MIDAS global dataset (2003-2017), Atmos Chem Phys, 22, 3553–3578, https://doi.org/10.5194/acp-22-3553-2022, 2022.

Gliß, J., Mortier, A., Schulz, M., Andrews, E., Balkanski, Y., Bauer, S. E., Benedictow, A. M. K., Bian, H., Checa-Garcia, R., Chin, M., Ginoux, P., Griesfeller, J. J., Heckel, A., Kipling, Z., Kirkevåg, A., Kokkola, H., Laj, P., Le Sager, P., Tronstad Lund, M., Lund Myhre, C., Matsui, H., Myhre, G., Neubauer, D., Van Noije, T., North, P., Olivié, D. J. L., Rémy, S., Sogacheva, L., Takemura, T., Tsigaridis, K., and Tsyro, S. G.: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- And space-based remote sensing as well as surface in situ observations, Atmos Chem Phys, 21, 87–128, https://doi.org/10.5194/acp-21-87-2021, 2021.

Hennen, M., Chappell, A., Edwards, B.L., Faist, A.M., Kandakji, T., Baddock, M.C., Wheeler, B., Tyree, G., Treminio, R., & Webb, N.P. (2022). A North American dust emission climatology (2001–2020) calibrated to dust point sources from satellite observations. Aeolian Research, 54, 100766

Hennen, M., Chappell, A., & Webb, N.P. (2023). Modelled direct causes of dust emission change (2001–2020) in southwestern USA and implications for management. Aeolian Research, 60, 100852

Huneeus, N., Schulz, M., Balkanski, Y., Griesfeller, J., Prospero, J., Kinne, S., Bauer, S., Boucher, O., Chin, M., Dentener, F., Diehl, T., Easter, R., Fillmore, D., Ghan, S., Ginoux, P., Grini, A., Horowitz, L., Koch, D., Krol, M. C., Landing, W., Liu, X., Mahowald, N., Miller, R., Morcrette, J.-J., Myhre, G., Penner, J., Perlwitz, J., Stier, P., Takemura, T., and Zender, C. S.: Global dust model intercomparison in AeroCom phase i, Atmos Chem Phys, 11, https://doi.org/10.5194/acp-11-7781-2011, 2011.

Klose, M., Jorba, O., Gonçalves Ageitos, M., Escribano, J., Dawson, M. L., Obiso, V., Di Tomaso, E., Basart, S., Montané Pinto, G., Macchia, F., Ginoux, P., Guerschman, J., Prigent, C., Huang, Y., Kok, J. F., Miller, R. L., and Pérez García-Pando, C.: Mineral dust cycle in the Multiscale Online Nonhydrostatic AtmospheRe CHemistry model (MONARCH) Version 2.0, Geosci. Model Dev., 14, 6403–6444, https://doi.org/10.5194/gmd-14-6403-2021, 2021.

Knippertz, P. and Todd, M. C.: Mineral Dust Aerosols over the Sahara: Meteorological Controls on Emission and Transport and Implications for Modeling, Rev. Geophys., 50, 2011RG000362, https://doi.org/10.1029/2011rg000362, 2012.

Kok, J.F., A.A. Adebiyi, S. Albani, Y. Balkanski, R. Checa-Garcia, M. Chin, P.R. Colarco, D.S. Hamilton, Y. Huang, A. Ito, M. Klose, D.M. Leung, L. Li, N.M. Mahowald, R.L. Miller, V. Obiso, C. Pérez García-Pando, A. Rocha-Lima, J.S. Wan, and C.A. Whicker, 2021a: Improved representation of the global dust cycle using observational constraints on dust properties and abundance. Atmos. Chem. Phys., 21, no. 10, 8127-8167, doi:10.5194/acp-21-8127-2021.

Kok, J.F., A.A. Adebiyi, S. Albani, Y. Balkanski, R. Checa-Garcia, M. Chin, P.R. Colarco, D.S. Hamilton, Y. Huang, A. Ito, M. Klose, L. Li, N.M. Mahowald, R.L. Miller, V. Obiso, C. Pérez García-Pando, A. Rocha-Lima, and J.S. Wan, 2021b: Contribution of the world's main dust source regions to the global cycle of desert dust. Atmos. Chem. Phys., 21, no. 10, 8169-8193, doi:10.5194/acp-21-8169-2021.

Koren, I., Kaufman, Y. J., Washington, R., Todd, M. C., Rudich, Y., Martins, J. V., and Rosenfeld, D.: The Bodélé depression-a single spot in the Sahara that provides most of the mineral dust to the Amazon forest, Environmental Research Letters, 1, 1–5, https://doi.org/10.1088/1748-9326/1/1/014005, 2006.

Kunkelova, T., Crocker, A. J., Wilson, P. A., and Schepanski, K.: Dust Source Activation Frequency in the Horn of Africa, Journal of Geophysical Research: Atmospheres, 129, https://doi.org/10.1029/2023JD039694, 2024.

LeGrand, S. L., Letcher, T. W., Okin, G. S., Webb, N. P., Gallagher, A. R., Dhital, S., Hodgdon, T. S., Ziegler, N. P., and Michaels, M. L.: Application of a satellite-retrieved sheltering parameterization (v1.0) for dust event simulation with WRF-Chem v4.1, Geosci. Model Dev., 16, 1009–1038, https://doi.org/10.5194/gmd-16-1009-2023, 2023.

Li, L., Derimian, Y., Chen, C., Zhang, X., Che, H., Schuster, G. L., Fuertes, D., Litvinov, P., Lapyonok, T., Lopatin, A., Matar, C., Ducos, F., Karol, Y., Torres, B., Gui, K., Zheng, Y., Liang, Y., Lei, Y., Zhu, J., Zhang, L., Zhong, J., Zhang, X., and Dubovik, O.: Climatology of aerosol component concentrations derived from multi-angular polarimetric POLDER-3 observations using GRASP algorithm, Earth Syst Sci Data, 14, 3439–3469, https://doi.org/10.5194/essd-14-3439-2022, 2022.

Mahowald, N. M., Ballantine, J. A., Feddema, J., and Ramankutty, N.: Global trends in visibility: Implications for dust sources, Atmos Chem Phys, 7, https://doi.org/10.5194/acp-7-3309-2007, 2007.

Mahowald, N. M., Engelstaedter, S., Luo, C., Sealy, A., Artaxo, P., Benitez-Nelson, C., Bonnet, S., Chen, Y., Chuang, P. Y. P. Y., Cohen, D. D. D., Dulac, F., Herut, B., Johansen, A. M. A. M., Kubilay, N., Losno, R., Maenhaut, W., Paytan, A., Prospero, J. M. J. M., Shank, L. M. L. M., and Siefert, R. L. R. L.: Atmospheric Iron Deposition: Global Distribution, Variability, and Human Perturbations, Annual Review of Marine Science of Marine Science, 1, 245–278, https://doi.org/10.1146/annurev.marine.010908.163727, 2009.

Mahowald, N. M., Li, L., Vira, J., Prank, M., Hamilton, D. S., Matsui, H., Miller, R. L., Lu, L., Akyuz, E., Meidan, D., Hess, P., Lihavainen, H., Wiedinmyer, C., Hand, J., Alaimo, G., Alves, C., Alastuey, A., Artaxo, P., Barreto, A., Barraza, F., Becagli, S., Calzolai, G., Chellam, S., Chen, Y., Chuang, P., Cohen, D. D., Colombi, C., Diapouli, E., Dongarra, G., Eleftheriadis, K., Galy-Lacaux, C., Gaston, C., González Ramos, Y., Hakola, H., Harrison, R. M., Heyes, C., Herut, B., Hüglin, C., Kanakidou, M., Kertesz, Z., Klimont, Z., Kyllönen, K., Liu, X., Losno, R., Lucarelli, F., Maenhaut, W., Marticorena, B., Mihalopoulos, N., Morera-Gomez, Y., Paytan, A., Prospero, J., Rodríguez, S., Smichowski, P., Varrica, D., Walsh, B., Weagle, C., and Zhao, X.: AERO-MAP: A data compilation and modelling approach to understand the fine and coarse mode aerosol composition, Earth System Science Data Discussions, 37, https://doi.org/10.5194/essd-2024-1, 2024.

Marticorena, B. and Bergametti, G.: Modeling the atmospheric dust cycle: 1. Design of a soil-derived dust emission scheme, J Geophys Res, 100, 16,415-416,430, 1995.

Marticorena, B., Chatenet, B., Rajot, J., Traore, S., Diallo, A., Kone, I., Maman, A., NDiaye, T., and Zakou, A.: Temporal variability of mineral dust concentrations over West Africa: analyses of a pluriannual monitoring from the AMMA Sahelian Dust Transect, Atmos. Chem. Phys., 10, 2010–8899, 2010.

Marticorena, B., et al. (2017), Mineral dust over west and central Sahel: Seasonal patterns of dry and wet deposition fluxes from a pluriannual sampling (2006–2012), J. Geophys. Res. Atmos., 122, 1338–1364, doi:10.1002/ 2016JD025995.

N'Tchayi Mbourou, G., Bertrand, J. J., and Nicholson, S. E.: The Diurnal and Seasonal Cycles of Wind-Borne Dust over Africa North of the Equator, Journal of Applied Meteorology, 36, 868–882, 1997.

Ocko, I. B. and Ginoux, P. A.: Comparing multiple model-derived aerosol optical properties to spatially collocated ground-based and satellite measurements, Atmos Chem Phys, 17, 4451–4475, https://doi.org/10.5194/acp-17-4451-2017, 2017.

Okin, G. S.: Shadow is related to roughness but MODIS BRDF should not be used to estimate lateral cover, Remote Sens Environ, 292, https://doi.org/10.1016/j.rse.2023.113581, 2023.

O'Sullivan, D., Marenco, F., Ryder, C. L., Pradhan, Y., Kipling, Z., Johnson, B., Benedetti, A., Brooks, M., McGill, M., Yorks, J., and Selmer, P.: Models transport Saharan dust too low in the atmosphere: a comparison of the MetUM and CAMS forecasts with observations, Atmos. Chem. Phys., 20, 12955–12982, https://doi.org/10.5194/acp-20-12955-2020, 2020.

Prospero, J. M., Ginoux, P., Torres, O., Nicholson, S. E., and Gill, T. E.: Environmental characterization of global sources of atmospheric soil dust identified with the NIMBUS 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product, Reviews of Geophysics, 40, 1–31, https://doi.org/10.1029/2000RG000095, 2002.

Ratcliffe, N. G., Ryder, C. L., Bellouin, N., Woodward, S., Jones, A., Johnson, B., Weinzierl, B., Wieland, L.-M., and Gasteiger, J.: Long range transport of coarse mineral dust: an evaluation of the Met Office Unified Model against aircraft observations, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-806, 2024.

Reid, E., Reid, J., Meier, M., Dunlap, M., Cliff, S., Broumas, A., Perry, K., and Maring, H.: Characterization of African dust transported to Puerto Rico by individual particle and size segregated bulk analysis, JGR-Atmospheres, 108, doi:10.1029/200dJD002935, 2003.

Remer, L. A., Kleidman, R. G., Levy, R. C., Kaufman, Y. J., Tanré, D., Mattoo, S., Martins, J. V., Ichoku, C., Koren, I., Yu, H., and Holben, B. N.: Global aerosol climatology from the MODIS satellite sensors, Journal of Geophysical Research Atmospheres, 113, https://doi.org/10.1029/2007JD009661, 2008.

Ridley, D. A., Heald, C. L., Kok, J. F., and Zhao, C.: An observationally constrained estimate of global dust aerosol optical depth, Atmos Chem Phys, 16, 15097–15117, https://doi.org/10.5194/acp-16-15097-2016, 2016.

Rodríguez, S., Cuevas, E., Prospero, J. M., Alastuey, A., Querol, X., López-Solano, J., García, M. I., and Alonso-Pérez, S.: Modulation of Saharan dust export by the North African dipole, Atmos Chem Phys, 15, 7471–7486, https://doi.org/10.5194/acp-15-7471-2015, 2015.

Ryder, C. L., Marenco, F., Brooke, J. K., Estelles, V., Cotton, R., Formenti, P., McQuaid, J. B., Price, H. C., Liu, D., Ausset, P., Rosenberg, P. D., Taylor, J. W., Choularton, T., Bower, K., Coe, H., Gallagher, M., Crosier, J., Lloyd, G., Highwood, E. J., and Murray, B. J.: Coarse-mode mineral dust size distributions, composition and optical properties from AER-D aircraft measurements over the tropical eastern Atlantic, Atmos. Chem. Phys., 18, 17225–17257, https://doi.org/10.5194/acp-18-17225-2018, 2018.

Ryder, C. L., Highwood, E. J., Walser, A., Seibert, P., Philipp, A., and Weinzierl, B.: Coarse and giant particles are ubiquitous in Saharan dust export regions and are radiatively significant over the Sahara, Atmos. Chem. Phys., 19, 15353–15376, https://doi.org/10.5194/acp-19-15353-2019, 2019.

Schepanski, K., Tegen, I., Todd, M. C., Heinold, B., Bonisch, G., Laurent, B., and Macke, A.: Meteorological processes forcing Sahran dust emission inferred from MSG-SEVERI observations of sub-daily dust source activitatio nand numerical models, J Geophys Res, 114, D10301: doi:10.1029/2008JD010325, 2009.

Shao, Y.: A model for mineral dust emission, J Geophys Res, 106, 20239–20254, 2001.

Shao, Y., M. Klose, K.-H. Wyrwoll: Recent global dust trend and connections to climate forcing, J. Geophys. Res. Atmos., 118, 1-12, doi: 10.1002/jgrd.50836

Sinclair, S.N., & LeGrand, S.L. (2019). Reproducibility assessment and uncertainty quantification in subjective dust source mapping. Aeolian Research, 40, 42-52

Song, Q., Zhang, Z., Yu, H., Ginoux, P., and Shen, J.: Global dust optical depth climatology derived from CALIOP and MODIS aerosol retrievals on decadal timescales: Regional and interannual variability, Atmos Chem Phys, 21, 13369–13395, https://doi.org/10.5194/acp-21-13369-2021, 2021.

Tegen, I. and Fung, I.: Contribution to the atmospheric mineral aerosol load from land surface modification, J Geophys Res, 100, 18,707-718,726, 1995.

Washington, R., Todd, M., Engelstaedter, S., Mbainayel, S., and Mitchel, F.: Dust and the low-level circulation over the Bodele Depression, Chad: Observations from BODEX 2005, J.GR, doi:10.1029/2005JD006502, 2006.

Weinzierl, B., Ansmann, A., Prospero, J. M., Althausen, D., Benker, N., Chouza, F., Dollner, M., Farrell, D., Fomba, W. K., Freudenthaler, V., Gasteiger, J., Gross, S., Haarig, M., Heinold, B., Kandler, K., Kristensen, T. B., Mayol-Bracero, O. L., Muller, T., Reitebuch, O., Sauer, D., Schafler, A., Schepanski, K., Spanu, A., Tegen, I., Toledano, C., and Walser, A.: The Saharan Aerosol Long-range Transport and Aerosol-cloud-interaction experiment: Overview and Selected Highlights, B. Am. Meteorol. Soc., 98, 1427–1451, https://doi.org/10.1175/Bams-D-15-00142.1, 2017.

Yu, Y., Kalashnikova, O. V., Garay, M. J., Lee, H., Notaro, M., Campbell, J. R., Marquis, J., Ginoux, P., and Okin, G. S.: Disproving the Bodélé Depression as the Primary Source of Dust Fertilizing the Amazon Rainforest, Geophys Res Lett, 47, https://doi.org/10.1029/2020GL088020, 2020.

Zender, C., Bian, H., and Newman, D.: Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology, J Geophys Res, 108, 4416, doi:10.1029/2002JD002775, 2003.

Zhao, A., Ryder, C. L., and Wilcox, L. J.: How well do the CMIP6 models simulate dust aerosols?, Atmos. Chem. Phys., 22, 2095–2119, https://doi.org/10.5194/acp-22-2095-2022, 2022.

Zhou, Z., Zhang, C., Chappell, A., Zou, X., Zhang, Z., Zuo, X., et al. (2024). Using field measurements across land cover types to evaluate albedo-based wind friction velocity and estimate sediment transport. Journal of Geophysical Research: Atmospheres, 129, e2023JD040313. https://doi.org/10.1029/2023JD040313