

A COMPARISON STUDY OF BIAS-CORRECTED MODEL DUST PARTICLE SIZE DISTRIBUTIONS WITH IN SITU MEASUREMENTS

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1. INTRODUCTION

Desert dust particles can directly alter radiation on Earth by scattering or absorption (Myrhe et al., 2013) and indirectly by modifying ice cloud properties as efficient ice nuclei (DeMott et al., 2010). In addition, they pose a health hazard upon entrance into the human respiratory system (Goudie, 2014). Size distribution of dust is a critical property in the understanding of all these effects, especially for the direct radiation effect. Particles with diameters comparable to solar wavelengths (0.2 - 2 μm) interact most efficiently with solar radiation, whereas particles with diameters greater than 4 μm interact best with terrestrial radiation (Tegen & Lacis, 1996).

Current uncertainties in aerosol radiative effects constitute a significant portion of uncertainties in Earth's radiation budget (Mahowald et al., 2006; Myrhe et al., 2013). A component of this uncertainty derives from an overestimation in dust emission size distribution of GCMs (general circulation models) in the fine size range (diameter smaller than 2 μm) of a factor of \sim 2-8 (Kok, 2011), and an underestimation in the coarse dust range (diameter greater than 5 μm) (Kok et al., 2017). Since large-scale GCMs cannot resolve non-linear small-scale processes such

as dust emission and deposition, these processes are parametrized in GCMs, giving rise to errors in size distribution at emission (Kok et al., 2017). Since the prediction of atmospheric dust size distribution depends on the assumed size distribution at emission, an overestimation of fine particles in this assumption leads to a higher portion of fine particles in the atmosphere in models than observed (Kok et al., 2017). Errors in the atmospheric dust size distribution can in turn cause uncertainties in model prediction of mass extinction efficiency and dust loading (Mahowald et al., 2014).

In order to minimize uncertainties associated with this assumption, Kok et al. (2017) developed an analytical framework which introduced an experimental constraint on the globally averaged emitted dust size distribution. Here we will demonstrate that model prediction of atmospheric size distribution computed with the corrected emitted dust size distribution lies closer to observed size distribution at various locations. Six models were used to generate atmospheric dust size distribution in mass fraction, including CESM (Community Earth System Model), GEOS-Chem (Goddard Earth Observing System Chemical Model), GISS GCM (Goddard Institute for Space Studies

General Circulation Model), WRF-Chem (Weather Research and Forecasting model coupled with Chemistry), CNRM (Centre National de Recherches Météorologiques), and IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade).

2. METHODOLOGY

For each model, size distribution was calculated as mass fraction as a function of bin number over each grid point, averaged over each air column. All models cover diameter ranges from 0.2 μm to 20 μm , but each has a different division of this range with different bins, as listed in Table 1. Model outputs were grouped in terms of seasonal averages, i.e. DJF (December – January – February), MAM (March – April – May), JJA (June – July – August), and SON (September – October – November), and climatological averages were found based on all seasons. In particular, all models have the same grid points consisting of 144 longitudes \times 96 latitudes as well as vertical layers.

In addition to the individual model outputs, a resampling method named bootstrap was employed to obtain size distribution with minimized errors associated with individual model assumptions (Efron & Gong, 1983). Specifically, size distribution in $\frac{dV}{dD}$ is computed 10000 times at each grid point by a randomly chosen model using bias-corrected parameters obtained from Kok et al. (2017).

In order to perform comparisons between model-produced size distributions

and observational measurements in as many regions and seasons as possible, 13 studies that reported dust size distribution measurements were selected. 11 of these studies were conducted in regions dominated by dust with African source regions, and 5 of them focused on properties of dust after long-transport. Both of the 2 Asian dust studies were based far from their Central Asian source region.

Normalized observational size distribution, is plotted alongside normalized individual model size distribution. Root mean square logarithmic error (RMSLE) from observational average was calculated for both the individual models and for resampled data and plotted:

$$RMSLE_k =$$

$$\sqrt{\frac{1}{N_k} \sum_{i=1}^{N_k} (\ln(Obs_{k,i} + 1) - \ln(Model_{k,i} + 1))^2}$$

,

where

$$Obs_{k,i} =$$

$$\sqrt{(D_{k,i-})(D_{k,i+})} \int_{D_{k,i-}}^{D_{k,i+}} \frac{1}{D} \frac{dV}{d \ln D} \text{observation} dD,$$

and

$$Model_{k,i} = \frac{dV(D_{k,i})}{d \ln(D_{k,i})} \text{model}.$$

3. RESULTS AND DISCUSSION

Preliminary results show that RMSLEs are reduced in the larger bins but not in the fine dust range.

Project	Time	Location	Instrumentation	Size Range (µm)	Elevation (m)	Fresh / Aged	Reference
African Monsoon Multidisciplinary Analysis, winter Special Observation Period / Dust and Biomass-burning Experiment (AMMA SOP0/DABEX)	January - February 2006	Niamey (Niger) B160N3°: 16–18.5°N, 4.9–6.7°E B165N7°: 13.6°N, 2.8–1.9°E	<i>Sampling:</i> stacked-filter units (SFUs) <i>Electron microscopy analysis:</i> scanning and transmission electron microscopes (SEM & TEM) <i>Counting:</i> HISTOLAB counting program	Geometric diameter: 0.1-9.5	600-1500 a.g.l.	Fresh	Chou et al. (2008)
African Monsoon Multidisciplinary Analysis, winter Special Observation Period / Dust and Biomass-burning Experiment (AMMA SOP0/DABEX)	January - February 2006	Niamey (Niger) B160: 13.3–18.5°N, 1.9–7.0°E B165: 13.3–17.7°N, 1.5–7.5°E	<i>Sampling:</i> Passive Cavity Aerosol Spectrometer Probe (PCASP) 100-X	Optical diameter: 0.11-9	150 a.g.l.	Fresh	Osborne et al. (2008)
Dust Outflow and Deposition to the Ocean (DODO) - 2	August 2006	Dakar (Senegal) B238: land regions in northern Mauritania 19°N, 12°W	<i>Sampling:</i> PCASP, Droplet Measurement Technology cloud droplet probe (CDP-100) <i>Electron microscopy analysis:</i> SEM	Optical diameter: 0.13-19	1000 a.g.l.	Fresh	McConnell et al. (2008)
Saharan Mineral Dust Experiment (SAMUM) - 1	May - June 2006	Ouarzazate (Morocco): 30.9°N 6.9°W	<i>Sampling:</i> condensation particle counters (CPCs), Differential Mobility Analyser (DMA), Grimm 1.109, PCASP 100-X, Forward Scattering Spectrometer Probe (FSSP) 300, FSSP-100	Geometric diameter: 0.0155-19.7	4853 a.s.l. (L02), 3703 a.s.l. (L07)	Fresh	Weinzierl et al. (2009)
NASA African Monsoon Multidisciplinary Analysis (NAMMA)	August -September 2006	Eastern North Atlantic Ocean and Western Saharan desert: 5–22°N, 10–35°W	<i>Sampling:</i> CPCs (TSI-3025, TSI-3010), Ultra-High Sensitivity Aerosol Spectrometer (UHSAS), TSI-3321 Aerodynamic Particle Sizer (APS)	Geometric diameter: 0.06-4.4	1520-3690 a.s.l.	Fresh	Chen et al. (2011)
Fennec 2011	June 2011	5 legs: 23°N, 10.5°W 1 leg: 22°N, 12°W 1 leg: 25°N, 7°W 1 leg: 22°N, 5°W	<i>Sampling:</i> PCASP 100-X, CDP, Grimm 1.129, Cloud and Aerosol Spectrometer (CAS), Cloud Imaging Probe (CIP), Small Ice Detector 2H (SID2H)	Geometric diameter: 0.13-18.5	0-5500 a.g.l.	Fresh	Ryder et al. (2013)
Desert Aerosols over Portugal (DARPO) (linked to SAMUM)	May 2006	Évora (Portugal) 38.57°N 7.91°W	<i>Sampling:</i> CPCs, DMA, Grimm 1.109, PCASP 100-X, FSSP-300, FSSP-100	Geometric diameter: 0.5-20	2300 (a.s.l.), 3245 (a.s.l.)	Aged	Wagner et al. (2008)
Saharan Mineral Dust Experiment (SAMUM) - 2	January - February 2008	Praia (Cape Verde): 14.9475°N, 23.4845°W	<i>Sampling:</i> Differential Mobility Particle Sizer (DMPS), TSI-3321 APS, single-stage impactor (SSI), free-rotating wing impactor (FWI) <i>Sizing and counting:</i> Olympus GmbH BH2 microscope with microscopy digital camera (ColorView I with analySIS 5 software)	Electrical mobility diameter: 0.026-0.8 Aerodynamic diameter: 0.57–0.5 Geometric diameter: 4-136.4	4 a.g.l. (110 a.s.l.)	Aged	Kandler et al. (2011)
Saharan Mineral Dust Experiment (SAMUM) - 2	January - February 2008	Praia (Cape Verde): 14.9°N, 23.5°W Tenerife (Canary Islands): 28.3°N, 16.6°W Dakar (Senegal): 14.7°N, 17.4°W	<i>Sampling:</i> Multi-channel CPCs, DMA, PCASP 100-X, Grimm 1.129, FSSP-300	Optical diameter: 0.005-18.26	474-1427 a.s.l.	Aged	Weinzierl et al. (2011)
Chemistry-Aerosol Mediterranean Experiment (ChArMEx)	June – August 2013	Minorca (Spain): 39.97°N, 4.08°E	<i>Sampling:</i> light optical particle counter (LOAC) with light dilatible balloon (LDB) and boundary layer pressurized balloon (BLPB), Grimm 1.129, UHSAS, FSSP-300	Optical diameter: 0.25-45	2500-4000 (LOAC–LDB, FSSP-300, and Grimm 1.129), 3100 (LOAC-BLPB)	Aged	Renard et al. (2018)
Barbados Aerosol Cloud Experiment (BACEX)	March – April 2010	Barbados 13.2°N, 59.5°W	<i>Sampling:</i> PCASP, cloud condensation nuclei (CCN) spectrometer, CPCs	Optical diameter: 0.1166-23.9047	2726 a.s.l. (April 1 st), 1289 a.s.l. (April 2 nd)	Aged	Jung et al. (2013)
N/A	April 2004	Kofu (Japan): 35.65°N, 138.57°E	<i>Sampling:</i> Nucleopore filters through a tube, OPCs <i>Sizing:</i> Multisizer-3 Coulter Counter	Geometric diameter: 0.4-12	312 a.s.l. (12 a.g.l.)	Aged	Kobayashi et al. (2007)
N/A	March 2010, May 2011, March-April 2012	2010, 2011 - Andong (Korea): 36.543°N, 128.799°E 2012 - Deokjeok Island (Korea): 37.233°N, 126.149°E	<i>Sampling:</i> high-volume sampler (Thermo Scientific) <i>Electron microscopy analysis:</i> SEM	Geometric diameter: 0.5-60	190 a.s.l. (2012), 140 a.s.l. (2010, 2011)	Aged	Jeong et al. (2014)

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