ATom: Dominant Role of Mineral Dust in Cirrus Cloud Formation

Get Data

Documentation Revision Date: 2022-03-16

Dataset Version: 1

Summary

This dataset provides: (1) In situ dust aerosol concentration measurements over remote tropical Pacific and Atlantic Oceans by NOAA Particle Analysis by Laser Mass Spectrometry (PALMS) airborne single-particle mass spectrometer combined with Aerosol Microphysical Properties (AMP) aerosol size spectrometers. Measurements were made aboard the NASA DC8 aircraft during the four ATom campaigns that occurred from 2016 to 2018 (2) Model output of dust and meteorology from the CESM global transport model extracted at the time and location of the aircraft; (3) Model output of dust, other aerosol, and meteorology from the GEOS global transport model extracted at the time and location of the aircraft; (4) CESM model global output of dust and meteorology for dust emitted by specific source regions; (5) NCEP Global Forecast System forward trajectories of air parcels initiated at the time and location of the aircraft; and (6) The location and properties of cirrus clouds formed along the forward trajectories simulated using a parcel model. These data have been applied to better understand the role of mineral dust in cirrus cloud formation.

There are 128 data files included in this dataset: 61 in comma-separated values (*.csv) and 67 in NetCDF (*.nc) formats. Also included are three companions files in comma-separated values (*.csv) format.

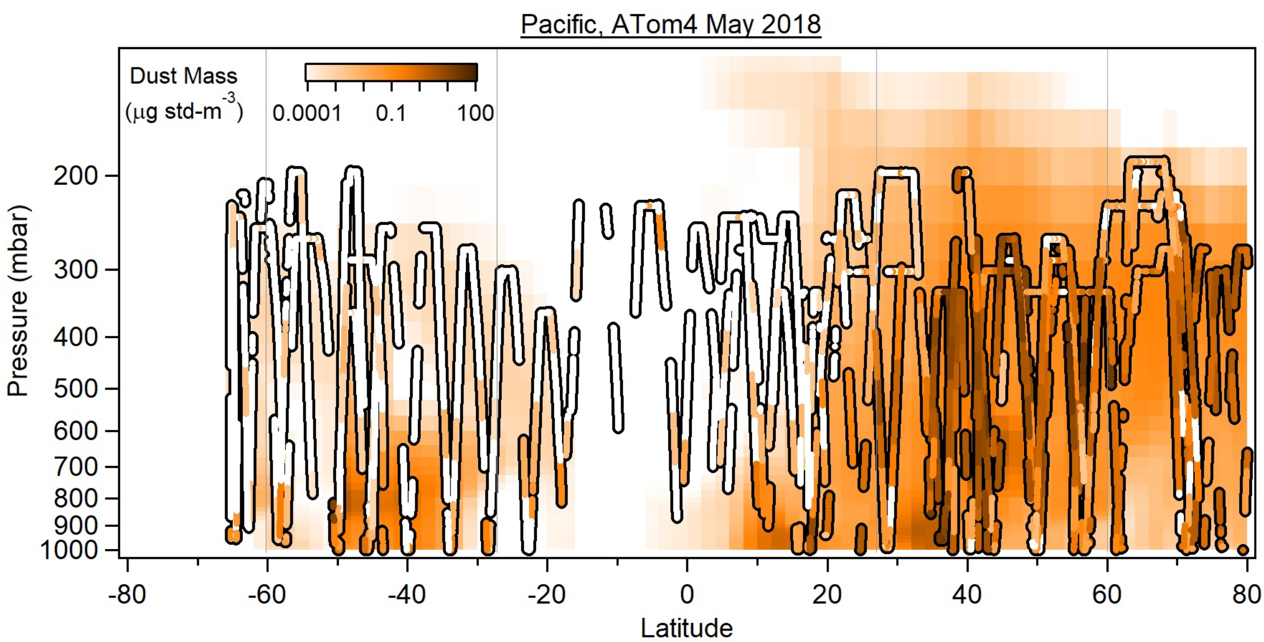

Figure 1. Dust mass observations across the Pacific Ocean made by the PALMS instrument combined with AMP aerosol size spectrometers during the ATom-4 campaign in May 2018.

Citation

Froyd, K.D., P. Yu, G.P. Schill, C.A. Brock, A. Kupc, C.J. Williamson, E. Jensen, E.A. Ray, K.H. Rosenlof, H. Bian, A.S. Darmenov, P.R. Colarco, G.S. Diskin, T.P. Bui, and D.M. Murphy. 2022. ATom: Dominant Role of Mineral Dust in Cirrus Cloud Formation. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2006

Table of Contents

1. Dataset Overview

This dataset provides: (1) In situ dust aerosol concentration measurements over remote tropical Pacific and Atlantic Oceans by NOAA Particle Analysis by Laser Mass Spectrometry (PALMS) airborne single-particle mass spectrometer combined with Aerosol Microphysical Properties (AMP) aerosol size spectrometers. Measurements were made aboard the NASA DC8 aircraft during the four ATom campaigns that occurred from 2016 to 2018 (2) Model output of dust and meteorology from the CESM global transport model extracted at the time and location of the aircraft; (3) Model output of dust, other aerosol, and meteorology from the GEOS global transport model extracted at the time and location of the aircraft; (4) CESM model global output of dust and meteorology for dust emitted by specific source regions; (5) NCEP Global Forecast System forward trajectories of air parcels initiated at the time and location of the aircraft; and (6) The location and properties of cirrus clouds formed along the forward trajectories simulated using a parcel model. These data have been applied to better understand the role of mineral dust in cirrus cloud formation.

Project: Atmospheric Tomography Mission

The Atmospheric Tomography Mission (ATom) was a NASA Earth Venture Suborbital-2 mission. It studied the impact of human-produced air pollution on greenhouse gases and on chemically reactive gases in the atmosphere. ATom deployed ;an extensive gas and aerosol payload on the NASA DC-8 aircraft for a systematic, global-scale sampling of the atmosphere, profiling continuously from 0.2 to 12 km altitude. Flights occurred in each of four seasons over a 4-year period.

Related Publication

Froyd, K.D., P. Yu, G.P. Schill, C.A. Brock, A. Kupc, C.J. Williamson, E.J. Jensen, E. Ray, K.H. Rosenlof, H. Bian, A.S. Darmenov, P.R. Colarco, G.S. Diskin, T.P. Bui, and D.M. Murphy. 2022. Dominant role of mineral dust in cirrus cloud formation revealed by global-scale measurements. Nature Geoscience 15:177–183. https://doi.org/10.1038/s41561-022-00901-w

Related Datasets

Froyd, K.D., D.M. Murphy, G.P. Schill, and C.A. Brock. 2021. ATom: Measurements from Particle Analysis By Laser Mass Spectrometry (PALMS). ORNL DAAC, Oak Ridge, Tennessee, USA.https://doi.org/10.3334/ORNLDAAC/1733

- In situ dust aerosol concentration measurements by the PALMS instrument during ATom campaigns.

Wofsy, S.C., S. Afshar, H.M. Allen, E.C. Apel, E.C. Asher, B. Barletta, et al. 2021. ATom: Merged Atmospheric Chemistry, Trace Gases, and Aerosols, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1925.

- Data from all ATom instruments and all four flight campaigns, including aircraft location and navigation data, merged to several different time bases.

Wofsy, S.C., and ATom Science Team. 2018. ATom: Aircraft Flight Track and Navigational Data. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1613

- Flightpath (location and altitude) data for each of the four campaigns provided in KML and CSV formats.

Acknowledgments

The ATom mission was supported by NASA’s Earth System Science Pathfinder Program EVS-2 funding. This work was supported by NASA awards NNH15AB12I and NNX17AG31G, NOAA climate funding, the second Tibetan Plateau Scientific Expedition and Research Program (STEP, 2019QZKK0604), the National Science Foundation, the Austrian Science Fund’s Erwin Schrodinger Fellowship J-3613, NASA's Modeling, Analysis and Prediction (MAP) program, the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center, and the MAP-funded Chemistry-Climate Modeling (CCM) project (600-17-6985).

2. Data Characteristics

Spatial Coverage: Global. Flights circumnavigate the globe, primarily over the oceans.

Spatial Resolution, Temporal Coverage, Temporal Resolution: File groupings are described in Table 1.

File Grouping	Spatial Resolution	Temporal Coverage	Temporal Resolution
1	point	2016-07-29 to 2018-05-21	3–24 minutes
2	Horizontal: 1.9 degrees x 2.5 degrees Vertical: 56 degrees	2016-07-29 to 2018-05-21	1 minute
3	Horizontal: 50 km Vertical: 72 km	2016-07-29 to 2018-05-21	10 seconds
4	Horizontal: 1.9 degrees x 2.5 degrees Vertical: 56 degrees	2014-02-01 to 2019-01-01	Monthly
5	0.25 degrees x 0.25 degrees	2016-07-29 to 2018-05-21	Hourly
6	point	2016-07-29 to 2018-05-21	Daily

Data File Information

There are 128 data files included in this dataset: 61 in comma-separated values (*.csv) and 67 in NetCDF (*.nc) formats. Also included are three companions files in comma-separated values (*.csv) format. NetCDF files conform to the NetCDF Climate & Forecast Conventions. There are 6 File Groupings (Table 1).

Table 1. File grouping and descriptions.

File Grouping	Name	Description
1	PALMS In Situ Dust Aerosol Concentration Measurements	Two comma-separated values (*.csv) files providing mineral dust mass and number concentrations measured by the PALMS instrument combined with AMP aerosol size spectrometers based on the method of Froyd et al. (2019). The data include all flight times where data products could be calculated, excluding flight segments inside clouds. Also excluded were flight segments that had final approaches to airports and other periods with strong local emission influences. The limit of detection is reported as the concentration of 1 particle detected during the sample period.
	CESM Output of Dust Aerosol &	Ten comma-separated values (*.csv) files providing (1) CESM/CARMA simulated dust mass

2	Meteorology	concentration and (2) altitude curtains of CESM dust aerosol model output.
3	GEOS Output of Dust, Other Aerosol & Meteorology	Eight NetCDF (*.nc) files providing size-resolved dust mass concentrations and other GOCART aerosol species, along with associated meteorological parameters. See Froyd et al. (2022) and Schill et al. (2020) for aerosol treatment definitions.
4	CESM Global Output of Dust & Meteorology for Dust Emitted by Specific Source Regions	Nine NetCDF (*.nc) files providing size-resolved dust mass concentrations and associated meteorological parameters.
5	NCEP Global Forecast System Forward Trajectories of Air Parcels	Fifty NetCDF (*.nc4) files providing temperature, relative humidity, and meteorological parameters for air parcels initiated at the location of the aircraft and simulated forward 10 days.
6	Parcel Model Output for Location & Crystal Concentrations of Cirrus Formed Along the Forward Trajectories	Forty-nine comma-separated values (*.csv) files providing (1) output from the cirrus ice nucleation model and (2) ambient dust aerosol concentrations, temperature, relative humidity, and pressure at the initiation point of the forward trajectories.

Table 2. File names and descriptions. In file names, **YYYYMMDD** is the flight date.

File Grouping	File Name	Description
Data Files		
1	PALMS_dust_mass_ATom1_4.csv	Measures of mineral dust mass.
	PALMS_dust_num_ATom1_4.csv	Measures of mineral dust particles.
2	dust_atom1_4_flighttrack.csv	CESM/CARMA simulated dust mass concentration over the dust diameter range 0.1–4.5 µm.
	atom#_dust_**Ocean**.csv	Altitude curtains of CESM dust aerosol model output provided as mineral dust aerosol mass concentration in units of ug std. m^{-3}. Files names include **#**, the ATom campaign, and **Ocean**, designating either "Atlantic" (longitude>-71°) or "Pacific" (longitude<-71°) ocean basins. Data were first extracted from the model at the time and location of the aircraft, then interpolated onto a 2-dimensional latitude-pressure grid, organized as 90 latitude rows and 56 pressure columns.
	lat_press_coord.csv	Latitude and pressure coordinate grid that describes the organization of value in files named atom#_dust_Ocean.csv.
3	GEOS5_atom#_**X**.nc	File names include **#**, the ATom campaign, and **X**, designating either "revised", "prev_baseline" (previous baseline), or "sensitivity_exp" (sensitivity experiment).
4	dust_S#.nc	File names include **#**, the geographic region number (Table 5).
5	ForwardTraj_10day_NCEP_**YYYYMMDD**.nc	One trajectory is initiated every 1 min of flight time.
6	atom_traj_nuc_all 20200912.csv	Cirrus formations along a unique forward trajectory that were calculated using data from the Diode Laser Hygrometer and Meteorological Measurement System. The principal simulation was conducted with two active nucleation modes: heterogeneous nucleation on dust aerosol and homogeneous freezing on aqueous aerosol. Variables *ni_het* and *ni_hom* give the initial ice crystal concentrations for cirrus formed in this simulation. A value of "0" indicates cirrus did not form via that mechanism. In a few cases, both nucleation mechanisms contributed to crystal concentrations within the same cirrus cloud. Another simulation was performed with dust heterogeneous nucleation suppressed. The variable *ni_hom_only* reports homogeneously-frozen ice crystal concentrations from this simulation for all cases in the primary simulation, including those cases where cirrus did not form in the dust-suppressed simulation.
	InSituData_**YYYYMMDD**.csv	In situ measurements aboard the DC8 aircraft, where each line represents the initial conditions of one forward trajectory that were initiated at 1-min intervals during each flight.
Companion Files		
3	GEOS_data_dictionary.csv	Data dictionary for files named GEOS5_atom#_X.nc.
4	dust_data_dictionary.csv	Data dictionary for files named dust_S#.nc.
5	ForwardTraj_data_dictionary.csv	Data dictionary for files named ForwardTraj_10day_NCEP_YYYYMMDD.nc.

Data File Details

Table 2. Variable names and descriptions for PALMS_dust_mass_ATom1_4.csv and PALMS_dust_num_ATom1_4.csv.

Variable	Units	Description
Both Files		
DateTimeUTC		UTC date and time of the measurement in DD/MM/YY hh:mm:ss format
GPSalt_km	km	GPS altitude
lat	Decimal degrees	Latitude
lon	Decimal degrees	Longitude
pr_mbar	Mbar	Ambient pressure
T_K	K	Ambient temperature
PALMS_dust_mass_ATom1_4.csv Only		
PALMS_dustmass_ug_stdm-3	ug std. m^{-3}	Mineral dust aerosol mass concentration D = 0.1-4.8 µm std = standard temperature and pressure of 0 degrees C and 1013 hPa
PALMS_dustmassLOD_ug_stdm-3	ug std. m^{-3}	Mineral dust aerosol mass limit of detection
PALMS_dust_num_ATom1_4.csv Only		
PALMS_dustnum_stdcm-3	std. cm^{-3}	Mineral dust aerosol number concentration D=0.18-4.8 µm
PALMS_dustnumLOD_stdcm-3	std. cm^{-3}	Mineral dust aerosol number limit of detection

Table 3. Variable names and descriptions for dust_atom1_4_flighttrack.csv.

Variable	Units	Description
Date		Date in YYYYMMDD format
Time	Seconds	Second of day in UTC time
Lat	Decimal degrees	Latitude
Lon	Decimal degrees	Longitude
dust_ug_per_stdm3	ug std. m^{-3}	Mineral dust aerosol mass concentration

Table 4. Variable names and descriptions for lat_press_coord.csv.

Variable	Units	Description
Lat_lowerbound	Decimal degrees	Latitude bin lower bound
Lat_mid	Decimal degrees	Latitude bin middle
Press_lowerbound	mbar	Pressure bin lower bound
Press_mid	mbar	Pressure bin middle

Table 5. Names and descriptions of geographic areas for files named dust_S#.nc.

Region Number	Geographic Area	Min Lat	Max Lat	Min Lon	Max Lon
S0	All Regions	-90	90	-180	180
S1	North Africa	10	36	-20	35
S2	North America	12	60	-130	-70
S3	Middle East	4	37	-82	-35
S4	South America	-55	12	-82	-35
S5	Asia (bounding box 1)	10	52	60.5	130
S5	Asia (bounding box 2)	37	52	44	60.5
S6	Australia	-40	-10	113	155
S7	Emissions outside of all other regions	-90	90	-180	180
S8	South Africa	-37	-14	10	40

Table 6. Variable names and descriptions for atom_traj_nuc_all 20200912.csv.

Variable	Units	Description
date		Date of nucleation event to form cirrus in YYYYMMDD format
itraj		Trajectory index
lon_nuc	Decimal degrees	Longitude of nucleation event

lat_nuc	Decimal degrees	Latitude of nucleation event
t_nuc	K	Temperature of nucleation event
ni_het	cm^{-3}	Ice crystal number concentration for cirrus formed by heterogeneous nucleation on dust particles
ni_hom	cm^{-3}	Ice crystal number concentration for cirrus formed by homogeneous freezing of aqueous aerosol particles
ni_hom_only	cm^{-3}	Ice crystal number concentration for cirrus formed by homogeneous freezing of aqueous aerosol particles for simulations with dust aerosol concentrations forced to zero

Table 7. Variable names and descriptions for files named InSituData_YYYYMMDD.csv.

Variable	Units	Description
date		Date of nucleation event to form cirrus in YYYYMMDD format
itraj		Trajectory index
lon_nuc	Decimal degrees	Longitude of nucleation event
lat_nuc	Decimal degrees	Latitude of nucleation event
t_nuc	K	Temperature of nucleation event
ni_het	cm^{-3}	Ice crystal number concentration for cirrus formed by heterogeneous nucleation on dust particles
ni_hom	cm^{-3}	Ice crystal number concentration for cirrus formed by homogeneous freezing of aqueous aerosol particles
ni_hom_only	cm^{-3}	Ice crystal number concentration for cirrus formed by homogeneous freezing of aqueous aerosol particles for simulations with dust aerosol concentrations forced to zero

3. Application and Derivation

ATom builds the scientific foundation for mitigation of short-lived climate forcers, in particular, methane (CH_4), tropospheric ozone (O_3), and Black Carbon aerosols (BC).

ATom Science Questions

Tier 1

- What are chemical processes that control the short-lived climate forcing agents CH_4, O_3, and BC in the atmosphere? How is the chemical reactivity of the atmosphere on a global scale affected by anthropogenic emissions? How can we improve chemistry-climate modeling of these processes?

Tier 2

- Over large, remote regions, what are the distributions of BC and other aerosols important as short-lived climate forcers? What are the sources of new particles? How rapidly do aerosols grow to CCN-active sizes? How well are these processes represented in models?
- What type of variability and spatial gradients occurs over remote ocean regions for greenhouse gases (GHGs) and ozone-depleting substances (ODSs)? How do the variations among air parcels help identify anthropogenic influences on photochemical reactivity, validate satellite data for these gases, and refine knowledge of sources and sinks?

Significance

ATom delivers unique data and analysis to address the Science Mission Directorate's objectives of acquiring “datasets that identify and characterize important phenomena in the changing Earth system” and “measurements that address weaknesses in current Earth system models leading to improvement in modeling capabilities.” ATom will provide unprecedented challenges to the CCMs used as policy tools for climate change assessments, with comprehensive data on atmospheric chemical reactivity at global scales, and will work closely with modeling teams to translate ATom data to better, more reliable CCMs. ATom provides extraordinary validation data for remote sensing.

4. Quality Assessment

In situ mineral dust concentration data from the PALMS instrument was previously subjected to a thorough uncertainty analysis (Froyd et al., 2019). Principal uncertainties in the derived dust mass and number concentrations include the statistical sampling of aerosol and the volume concentration measurement from size spectrometers. Generally, since the aerosol composition measurements are statistically-limited, the relative uncertainty in concentration decreases with increasing concentration. Estimated statistical uncertainties from sampling and identification of mineral dust are 50% at 0.01 µg m^{-3} and 25% at 1 µg m^{-3}. Uncertainties in aerosol size spectrometer concentrations over 3 minutes are estimated as 7–17% for number and 30–131% in volume and principally due to atmospheric variability of sparse D>0.5 µm aerosol.

Over the 3-minute sample time, typical mass limits of detection (LODs) were ~0.0001–0.01 µg m^{-3} above 3 km altitude. to increase sensitivity for dust number concentration measurements, sample times were increased to 6–24 minutes for flight segments at a constant altitude (range <1 km). Typical LODs in the UT were ~0.5–10 L^{-1}. These LODs are suitable for assessing global model biases and determining the impact of dust aerosol on cirrus formation mechanisms in the atmosphere.

A model-measurement bias analysis was performed in Froyd et al. (2022) for dust mass concentrations simulated by CESM and GEOS. Both models initially had large positive biases of ~x10–300 in the upper troposphere. Revisions to aerosol removal schemes reduced the bias in both models substantially. For example, CESM mean biases above >6 km over many broad regions were within a factor of 2.

5. Data Acquisition, Materials, and Methods

Project Overview

ATom makes global-scale measurements of the chemistry of the atmosphere using the NASA DC-8 aircraft. Flights span the Pacific and Atlantic Oceans, nearly pole-to-pole, in continuous profiling mode, covering remote regions that receive long-range inputs of pollution from expanding industrial economies. The payload has proven instruments for in-situ measurements of reactive and long-lived gases, diagnostic chemical tracers, and aerosol size, number, and composition, plus spectrally resolved solar radiation and meteorological parameters.

Combining distributions of aerosols and reactive gases with long-lived GHGs and ODSs enables disentangling of the processes that regulate atmospheric chemistry: emissions, transport, cloud processes, and chemical transformations. ATom analyzes measurements using customized modeling tools to derive daily averaged chemical rates for key atmospheric processes and to critically evaluate CCMs. ATom also differentiates between hypotheses for the formation and growth of aerosols over the remote oceans.

Aerosol Concentration

Size-resolved aerosol concentration was measured by the NOAA Aerosol Microphysical Properties (AMP) team by combining a Droplet Measurement Technologies Ultra High Sensitivity Aerosol Spectrometer (UHSAS), and a TSI, Incorporated Laser Aerosol Spectrometer (LAS). The UHSAS and LAS optical spectrometers encompass the mineral dust size range reported here, D>0.1–4.8 µm. Particle diameters were derived from optical spectrometer calibrations using ammonium sulfate, which has a refractive index that is also appropriate for many mineral dust and most other tropospheric particle types. Sample flows were 0.06 L m^{-1} and 0.1 L m^{-1}, respectively. Supermicron particle number concentrations were scaled to account for sub-isokinetic sampling and losses in instrument tubing, with typical scaling factors of x0.97–1.04 for 1 µm particles and x3.0–3.4 for 4 µm particles. Cloudy flight segments are excluded at a 1-second resolution based on data from a wing-mounted cloud particle probe.

Mineral Dust Aerosol Measurements using PALMS

The NOAA Particle Analysis by Laser Mass Spectrometry (PALMS) airborne single-particle mass spectrometer characterizes the size and chemical composition of individual aerosol particles from about 0.1–5 µm in diameter. Single-particle mass spectra are post-processed to classify each particle into a compositional type and that are then counted to determine their relative abundance. Mineral dust particles have distinct mass spectra and are identified by multiple crustal metal signatures such as silicon, aluminum, iron, and calcium, and often with trace amounts of alkalis, barium, tin, antimony, or lanthanides. A combination of automated and manual classification of the dust spectra yielded estimated misclassification errors of <5%.

Mineral Dust Quantification using PALMS & AMP

PALMS size-resolved composition was combined with size-resolved absolute concentration measured over the same size range by optical particle spectrometers instruments to determine dust mass and number concentrations using the method of Froyd et al. (2019). Particle spectrometer number distributions are converted to volume assuming spherical shape, and mineral dust density is prescribed as 2.5 g cm^{-3} to convert volume to mass.

Airborne Measurements of Gases & Temperature

Water vapor was measured by the Diode Laser Hygrometer (DLH), an external-path diode laser absorption instrument. The Meteorological Measurement System measures ambient dynamic temperature from an open wire platinum sensor, and static temperature is indirectly derived from 3D wind aero-dynamic calibration using aircraft-induced maneuvers. High-frequency raw data for both instruments were averaged over 1 min of flight time.

Global Simulations of Mineral Dust Aerosol using CESM/CARMA

The analysis uses the NSF/NCAR Community Earth System Model (CESM) coupled with the Community Aerosol and Radiation Model for Atmospheres (CARMA) sectional aerosol model. CARMA tracks 20 discrete size bins from 0.1–17.4 µm in diameter for internally mixed aerosols including mineral dust, sea salt, organic material, black carbon, and sulfate. The model runs at 1.9-degree x 2.5-degree resolution and 56 vertical layers from the surface to ~45 km. At every time step, CESM/CARMA is nudged to the Goddard Earth Observing System model v.5 (GEOS5) dynamic meteorological wind and temperature fields. Yu et al. (2019) revised CESM/CARMA convective removal of aerosol. Aerosol activation was further tuned to ATom mass concentrations in Froyd et al. (2022). Integrated dust mass concentration is extracted at the aircraft location and time and is calculated for diameters 0.1–4.5 µm for comparison with PALMS dust mass concentrations. For dust source apportionment runs, dust concentrations are calculated for the entire CARMA size range.

Global Simulations of Mineral Dust Aerosol using GEOS/GOCART

Dust is simulated in the Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) aerosol module in the Goddard Earth Observing System model v.5 (GEOS) framework. GOCART simulates BC, organic carbon, sulfate, nitrate, ammonium, dust, and sea salt. For the ATom comparisons, GEOS/GOCART was run at a global ~50-km horizontal resolution with 72 vertical pressure layers from the surface up to 0.01 mbar (~85 km). The dynamical time step was 450 s. For model-measurement comparisons, integrated dust mass concentrations are calculated by summing the first two diameter bins, 0.2–3.6 µm, using densities of 2500 and 2650 kg m^{-3}. Data are extracted from the model domain at the time and location of the aircraft. Dust wet scavenging was investigated in Shill et al. (2020) and Froyd et al. (2022) using three sets of wet removal parameters.

Forward Trajectories of Air Transport

Forward trajectories were calculated using the Traj3D model run with National Centers for Environmental Predictions (NCEP) Global Forecast System (GFS) 0.25-degree x 0.25-degree resolution meteorology. Trajectories were initialized along the flight track each minute and run forward for 10 days with a time resolution of one hour.

Cirrus Ice Nucleation Simulations

Competition between homogeneous freezing of aqueous aerosols and heterogeneous ice nucleation on dust particles was simulated using a box model. The parcel-model ice nucleation simulations are initiated for all aircraft sample points with T≤235 K and where S_{ice}>0.9 at any point along the 10-day forward trajectory. Mixing of air parcels is not considered in this analysis. If more than 90% of the dust particles are depleted by ice nucleation, and the S_{ice} has decreased to <1.03, it is assumed no further nucleation will take place. For each freezing mechanism, ice crystal concentrations are reported just after nucleation, which will generally be the maximum value over the lifecycle of a cirrus cloud.

A parameterized wave spectrum was used to superimpose high-frequency temperature perturbations to simulate gravity waves that typically define UT cooling rates. To represent a cloud, the nucleation and growth of hundreds of individual ice crystals and associated changes in water vapor are tracked. This Lagrangian approach avoids the numerical diffusion associated with growth/sublimation of ice crystals in an Eulerian (bin) model. Aqueous aerosols are represented by a log-normal size distribution with a mode radius of 0.015 µm, a standard deviation of 2, and a concentration of 100 cm^{-3}. Results are not strongly sensitive to the aqueous aerosol size distribution nor their concentration. Homogeneous freezing rates are calculated using a water activity parameterization. For the representation of heterogeneous nucleation on dust particles, the ice nucleation active site (INAS) density approach with a measurement-based parameterization of dust active site density that depends on ice saturation ratio and temperature is used. Mineral dust size distributions are taken from the ATom measurements. Dust particles are depleted from the size distribution as heterogeneous nucleation takes place.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

ATom: Dominant Role of Mineral Dust in Cirrus Cloud Formation

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

Froyd, K.D., P. Yu, G.P. Schill, C.A. Brock, A. Kupc, C.J. Williamson, E.J. Jensen, E. Ray, K.H. Rosenlof, H. Bian, A.S. Darmenov, P.R. Colarco, G.S. Diskin, T.P. Bui, and D.M. Murphy. 2022. Dominant role of mineral dust in cirrus cloud formation revealed by global-scale measurements. Nature Geoscience 15:177–183. https://doi.org/10.1038/s41561-022-00901-w

Froyd, K. D., D.M. Murphy, C.A. Brock, P. Campuzano-Jost, J.E. Dibb, J.-L. Jimenez, A. Kupc, A.M. Middlebrook, G.P. Schill, K.L. Thornhill, C.J. Williamson, J.C. Wilson, and L.D. Ziemba. 2019. A new method to quantify mineral dust and other aerosol species from aircraft platforms using single-particle mass spectrometry. Atmospheric Measurement Techniques 12:6209–6239. https://doi.org/10.5194/amt-12-6209-2019

Schill G.P., K.D. Froyd, H. Bian, A. Kupc, C.J. Williamson, C.A. Brock, E. Ray, R.S. Hornbrook, A.J. Hills, E.C. Apel, M. Chin, P.R. Colarco, and D.M. Murphy. 2020. Widespread biomass burning smoke throughout the remote troposphere. Nature Geoscience 13:422–427. https://doi.org/10.1038/s41561-020-0586-1

Yu, P., K.D. Froyd, R.W. Portmann, O.B. Toon, S.R. Freitas, C.G. Bardeen, C.A. Brock, T. Fan, R-S. Gao, J.M. Katich, A. Kupc, S. Liu, C. Maloney, D.M. Murphy, K.H. Rosenlof, G.P. Schill, J.P. Schwarz, and C.J. Williamson. 2019. Efficient In-Cloud Removal of Aerosols by Deep Convection. Geophysical Research Letters 46:1061–1069. https://doi.org/10.1029/2018GL080544