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Aerosol Optical Properties as Part of the Long-Term Aerosol Measurements in Puerto Rico (AOP-LAMP) Field Campaign Report

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December 2024

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Acronyms and Abbreviations

AERONET	Aerosol Robotic Network
AMF	ARM Mobile Facility
AOD	aerosol optical depth
AOP-LAMP	Aerosol Optical Properties as Part of the Long-Term Aerosol Measurements in Puerto Rico
ARM	Atmospheric Radiation Measurement
CCN	cloud condensation nuclei
CSJ	Cape San Juan
DOE	U.S. Department of Energy
FAP	fluorescent aerosol particles
GCB	Greater Caribbean Basin
HHS	hurricane-hardened system
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory model
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
PDE	Pico del Este
PM	particulate matter
RENEW-AR-UPRRP	Reaching a New Energy Sciences Workforce through Atmospheric Research at the University of Puerto Rico-Rio Piedras
SP2-XR	single-particle soot photometer-extended range
UPR-RP	University of Puerto Rico-Rio Piedras
WHO	World Health Organization
WIBS	waveband integrated bioaerosol sensor

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1.0 Summary

The University of Puerto Rico-Rio Piedras Campus (UPR-RP) has been measuring aerosol optical, chemical, and microphysical properties at Cape San Juan (CSJ, also known as CPR) since 2004. This site has also hosted several intensive field campaigns, with context provided by the long-term measurements. Hurricane Maria largely destroyed the station on September 20, 2017, forcing a cessation of the measurements. The scientific focus of this intensive operational period was to use a U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) aerosol shelter to enable the resumption of long-term aerosol measurements. This AMF shelter is now the main aerosol shelter for CSJ operations. It is used to:

- Characterize long-term trends and variability of aerosol climate-forcing properties
- Link those properties to aerosol sources and long-range transport, and
- Study the influence of aerosols at CSJ on cloud chemical and microphysical properties at the companion site on Pico del Este (PDE) cloud forest, above and downwind of CSJ (See Figures 1-3).

The experimental methods of the CSJ AMF are nearly identical to those used in the first ARM Mobile Facility (AMF1) system, which provides measurements with 1-minute time resolution of aerosol number concentration, total and backwards-hemispheric light scattering coefficients, light absorption coefficients at three wavelengths and two size ranges (e.g., PM_{10} and PM_1), multi-wavelength aerosol optical depth and derived column-averaged aerosol properties (NASA's Aerosol Robotic Network [AERONET] retrievals), and cloud condensation nuclei concentrations. With the support of the National Oceanic and Atmospheric Administration (NOAA) Global Model Laboratory (GML) and JA Ogren (scientist, retired from NOAA), a hurricane-hardened system (HHS) was customized and installed in the AMF aerosol shelter. The HHS can be solar-power operated and comprises two low-cost sensors, providing size-resolved aerosol mass concentrations and meteorological data even after power outages from hurricane impact. In addition, collected filter samples are analyzed for carbonaceous aerosols (thermal/optical analysis), water-soluble ions (ion chromatography), trace metals (inductively coupled plasma), elemental composition (X-ray fluorescence), and mass concentrations (gravimetric analysis). The CSJ AMF aerosol shelter has been operational at CSJ since June 2018 and has been key in resuming long-term measurements at this location.

In 2023, UPR-RP was also awarded the DOE project: Reaching a New Energy Sciences Workforce through Atmospheric Research at the University of Puerto Rico-Rio Piedras (RENEW-AR-UPRRP). This Is a four-year project in collaboration with Brookhaven and Argonne National Laboratories and connected to their joint science focus area.

The overarching science question of the RENEW-AR-UPRRP project is how does African dust affect the regional aerosol distributions and climate effects in the Greater Caribbean Basin (GCB) through interactions with radiation and clouds? To answer this, research projects involving observations and/or modeling activities are/or will be taking place. These involve the characterization of the daily, seasonal, and long-term trends of African dust properties in the GCB, the study of the vertical distribution of African dust, and estimations of the direct radiative effects of African dust over the GCB, constrained by observations.

RENEW-AR-UPRRP engages graduate and undergraduate students in semester and summer activities supported by a proposed co-mentoring model. RENEW-AR-UPRRP uses the ARM-like infrastructure at the CSJ atmospheric observatory. The training of students and the measurements started on June 5, 2023.

1.1 Collaborators

E Andrews – NOAA Global Monitoring Division – support with data acquisition and processing

JA Ogren – NOAA Global Monitoring Division, retired – aerosol measurements

D Baumgardner – Droplet Measurement Technologies – cloud measurements

Yan Feng – Argonne National Laboratory – aerosol radiative forcing modeling

Maria Zawadowicz – Brookhaven National Laboratory – aerosol mass spectrometry

JM Prospero, C Gaston, P Zuidema – Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami – aerosols and dust

D Farrel, A Sealy – Caribbean Institute for Meteorology and Hydrology, Barbados – World Meteorological Organization Sand and Dust Storm Warning Advisory and Assessment System

P Colarco, H Yu, B Holben, J Welton, T Hanisco – NASA Goddard Space Flight Center

Sara Lance – University of Albany – aerosol-cloud interactions

1.2 Notable Event

A notable event that we monitored was the so-called “Godzilla” mega-dust event of June 2020. This plume, with an area close to the size of the 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). At CSJ, and using the AMF aerosol container, we collected surface aerosol data (e.g., PM_{10} and $PM_{2.5}$ mass concentrations, light scattering and absorption coefficients, visibility, dust concentrations) and column aerosol data (i.e., aerosol optical depth: AOD) during the event. This mega-dust event showed record values for the aerosol optical properties in situ and at the column and exhibited exceedances in both the U.S. Environmental Protection Agency air quality standard and the World Health Organization (WHO) air quality guidelines (Mayol-Bracero et al. 2024, in review). In addition, fluorescent aerosol data were also recorded to identify the possible bioaerosol signature in the African dust (Sarangi et al. 2024).

Another notable event was observed in October 2021. A volcanic eruption occurred at Cumbre Vieja (Canary Island, La Palma region, near the west coast of North Africa) on 21 September 2021. The satellite imagery highlighted that the ash plume was transported farther west toward the Caribbean. However, the CSJ site recorded the aerosol optical properties (coarse-mode dominance) as well as a significant amount of fine-fraction aerosol loading. The HYSPLIT air mass back trajectories and satellite measurements showed that African dust could possibly influence the Caribbean site (González Ramos et al. 2022).

1.3 Instrument Issues

The ARM cloud condensation nuclei (CCN) counter experienced several technical problems; therefore, we could not record continuous data from the instrument because the measurements were interrupted several times. The ARM CCN counter was operational at 0.3 % supersaturation. In June 2021, the CCN concentration decreased drastically even though the supply bottle had water. It appeared that we had a problem with the solenoid pump (supply). There was no water supply for the CCN column. We contacted ARM about the CCN issue in May 2021. ARM suggested testing the supply pump (if needed, replace it). ARM said if the pump is not the issue, then the electronic board could be the problem (which is rare). We tested the supplied voltage from the electronic board to the supply pump, which was fine. We thought the problem was the supply pump so we purchased a replacement and installed it on the counter, but more was needed to solve the problem.

The UPR electrical engineer was asked to check electronic boards that regulate supply pumps and others. Later, it appeared that the issue was with the CCN circuit board. The CCN counter was then shipped to the vendor for repair as instructed by ARM. The counter was repaired at the manufacturer's site. They proposed the replacement of the ABD-0146 board and the laser window (OP-0143). It is encouraging to note that all the pumps were in good condition. The counter recently arrived in Puerto Rico and will soon resume operation at CSJ. The CCN counter will be mounted to the CPR aerosol measurement system at CSJ and continue long-term measurement of aerosol-cloud condensation nuclei and study of aerosol-cloud microphysics.

The UPR nephelometer (TSI 3563) failed to operate because of technical problems with the main circuit board and the power adapter. The nephelometer model has already been phased out by the manufacturer (TSI) and technical support and service are no longer available from their end. ARM loaned one of their nephelometers (TSI 3563) to replace the existing nephelometer at CSJ (AOP-LAMP AFC). The scientific focus was to use the ARM nephelometer to replace the one UPR owns to enable resumption of the long-term measurements of aerosol optical properties at CSJ. The UPR nephelometer was later repaired at UPR by JA Ogren with the help of the ARM nephelometer (used as a reference). Now both nephelometers are used for aerosol measurements and training for the RENEW workforce.

2.0 Results

Examples of PM_{10} and $PM_{2.5}$ mass concentrations measured at various sites (including CSJ) during the passage of Godzilla dust event over the GCB in June 2020 are provided in Figure 1.

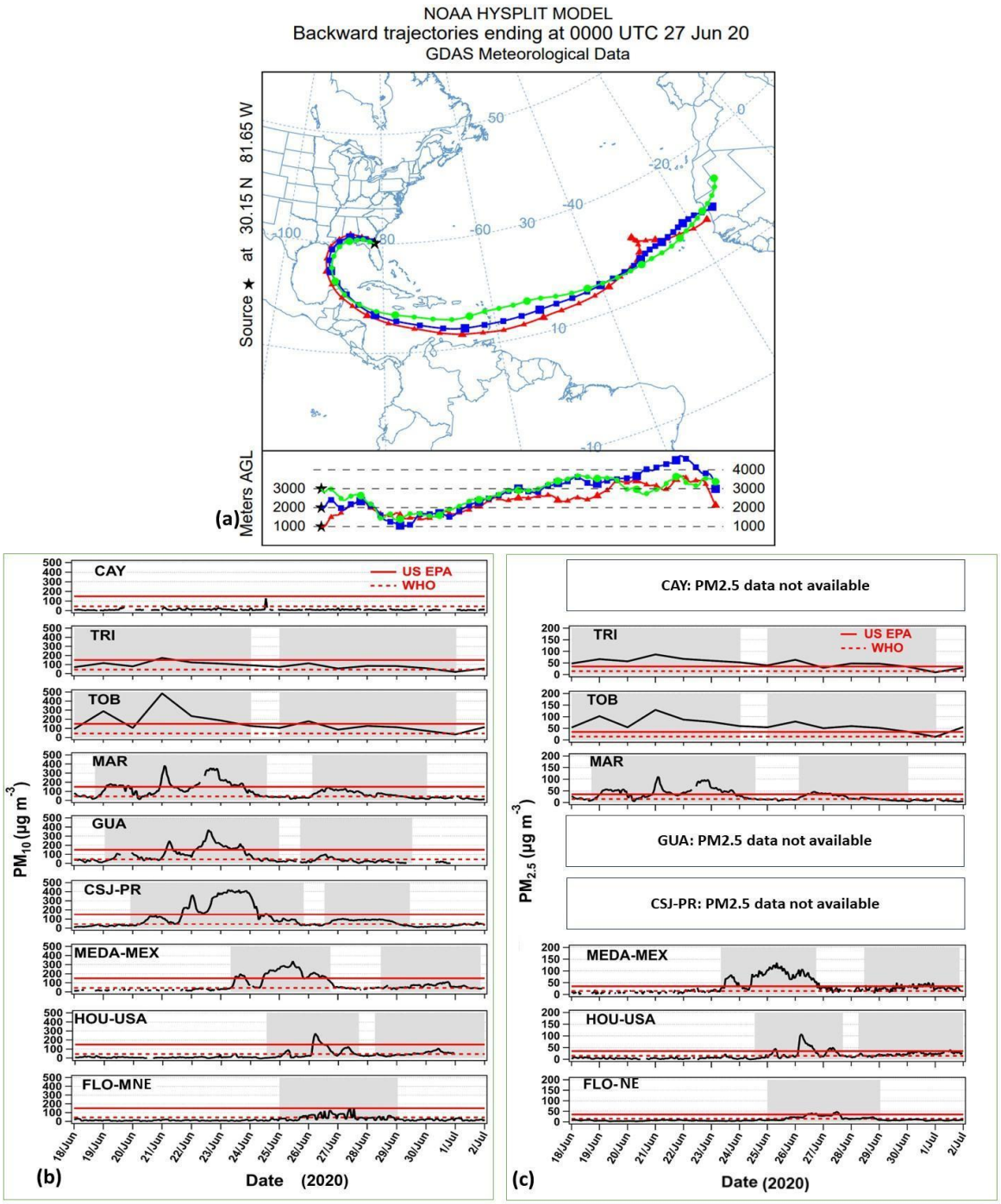

Figure 1. (a) Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) 10 days air mass back trajectories drawn at three different heights (1000, 2000, and 3000 m) above ground level. (b) and (c) represent the Lagrangian path (top to bottom) of the Godzilla dust event represented by PM_{10} (b) and $PM_{2.5}$ (c) mass concentrations observed at Cayenne (CAY), Trinidad (TRI), Tobago (TOB), Martinique (MAR), Guadeloupe (GUA), Cape San Juan, Puerto Rico (CSJ PR), Merida, Mexico (MEDA-MEX), Houston (HOU-USA), and Florida-Jacksonville (FlO-NE). The gray-shaded region in the background represents the duration of the two main dust events at the different stations.

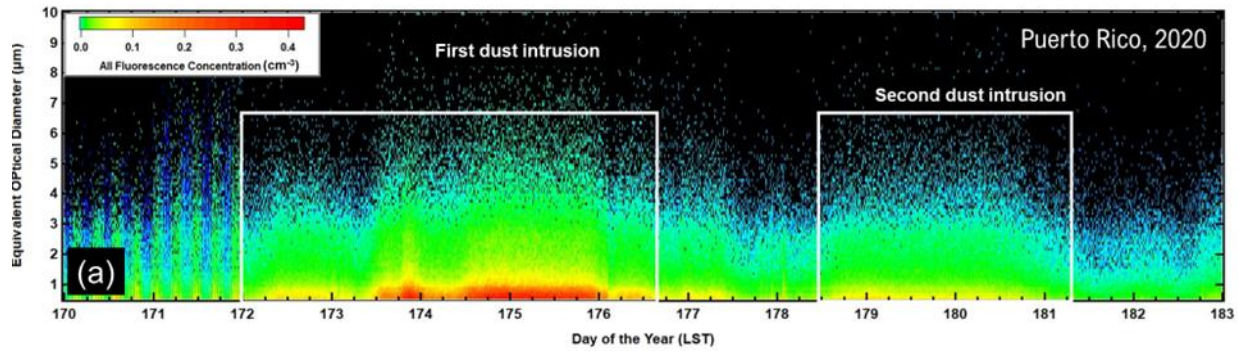

Figure 2. Time series of the size distributions of fluorescent aerosol particles (FAP) number concentrations measured at CSJ, Puerto Rico.

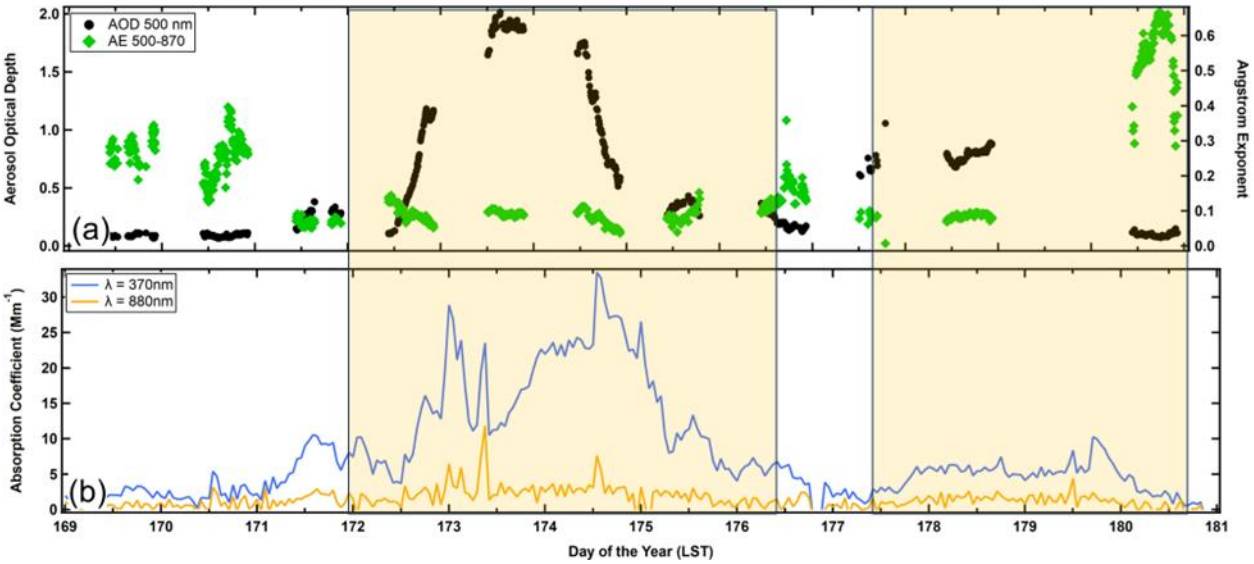

Figure 3. Time series in Puerto Rico of (a) AOD at 500-nm wavelength (black markers), Ångström exponent derived from the 500-nm and 870-nm AODs (green markers) and (b) absorption coefficients at wavelengths of 370 nm (blue) and 880 nm (orange). The shaded areas demarcate the periods when African dust was in the region.

2.1 Further Research Opportunities

While the complement of instruments at CSJ and PDE sites is much less comprehensive than at the ARM supersites or AMF deployments, the long-term nature of the CSJ and PDE measurements will provide the context for possible future AMF deployments in a different climate regime from those emphasized by ARM. Furthermore, public access to the CSJ and PDE measurements through the ARM Data Center and the WMO World Data Center for Aerosols will facilitate discovery and use of these data by Atmospheric System Research and other investigators. The CSJ AMF could also provide for the use of additional instruments that can be connected to the ARM sampling manifold to study, for example, bioaerosols (e.g., waveband integrated bioaerosol sensors [WIBS]) and soot (e.g., single-particle soot photometer-extended range [SP2-XR]). This will provide research opportunities for the study of bioaerosols and anthropogenic aerosols during the long-range transport of air masses from different sources year-round.

3.0 Publications and References

3.1 Peer-Reviewed Publications

Sarangi, B, D Baumgardner, B Bolaños-Rosero, and OL Mayol-Bracero. 2022. "Measurement report: An exploratory study of fluorescence and cloud condensation nuclei activity of urban aerosols in San Juan, Puerto Rico." *Atmospheric Chemistry and Physics* 22(14): 9647–9661, https://doi.org/10.5194/acp-22-9647-2022

Sarangi, B, D Baumgardner, AI Calvo, B Bolaños-Rosero, R Fraile, A Rodríguez-Fernández, D Fernández-González, C Blanco-Alegre, C Gonçalves, ED Vicente,, and OL Mayol Bracero. 2024. "Measurement Report: Comparative Analysis of Fluorescing African Dust Particles in Spain and Puerto Rico." *EGUsphere* preprint, https://doi.org/10.5194/egusphere-2024-446

Torres-Delgado, E, D Baumgardner, and OL Mayol-Bracero. 2021. "Measurement report: Impact of African aerosol particles on cloud evolution in a tropical montane cloud forest in the Caribbean." *Atmospheric Chemistry and Physics* 21(23): 18011–18027, https://doi.org/10.5194/acp-21-18011-2021

3.2 Manuscript under Review/Preparation

Mayol-Bracero et al. 2024. "'Godzilla,' the extreme African dust event of June 2020: Origins, Transport, and Impact on Air Quality in the Greater Caribbean Basin." *Bulletin of the American Meteorological Society*, under review.

Mayol-Bracero et al. "Air Quality Degradation in Puerto Rico post-Hurricane Maria".

Sarangi et al. "Aerosol optical characteristics during extreme dust events in Puerto Rico."

Sarangi et al. "A Mountaintop Observatory to Investigate Aerosols and Clouds Properties in the Caribbean."

Sarangi et al. "Chemical and Fluorescent Characteristics of Submicron and Coarse Aerosols in East-Central Long Island, New York."

3.3 Presentations (Conference Abstract)

Sarangi, B, D Baumgardner, and D Hughes. 2023. "Fluorescent characteristics of historical African dust event: the Godzilla dust plume in June 2020." Atmospheric Dust – DUST, 13, 80.

Sarangi, B, MA Zawadowicz, OL Mayol-Bracero, and AC McComiskey. 2022. "Chemical and Fluorescent Characteristics of Submicron and Coarse Aerosols in East Central Long Island, New York." A45J-1968, American Geophysical Union Fall Meeting Abstracts.

Mayol-Bracero, OL, JM Prospero, P Zuidema, B Sarangi, and J Rosas-Nava. 2022. “African dust research in the Caribbean: Integration of aerosol ground-based measurements, satellite observations, and forecast models during the" Godzilla" dust event.” A52E-01, American Geophysical Union Fall Meeting Abstracts.

Calvo, AI, B Sarangi, D Topping, D Baumgardner, and R Hagen. 2022. “Observational Evidence for Long-Range Transport of Bioaerosols by African Dust.” 102, International Aerosol Conference.

González Ramos, Y, B Sarangi, A Barreto, S Rodríguez, and OL Mayol-Bracero.2022. “Optical properties of volcanic aerosols transported over the Atlantic from the Cumbre Vieja eruption.” 1336, International Aerosol Conference.

Sarangi, B, RL Colon D Baumgardner, E Torres-Delgado, JC Gonzalez, IA Guadallupe-diaz, I. JA Ogren, and OL Mayol-Bracero. 2021. “Development of an Aerosol and Cloud Analysis System in the Caribbean.” American Geophysical Union, Fall Meeting.

Sarangi, B, RL Colon D Baumgardner, E Torres-Delgado, JC Gonzalez, A Guadallupe-diaz, JA Ogren, and OL Mayol-Bracero. 2021. “Development of an Aerosol and Cloud Analysis System in the Caribbean.” 16th International Global Atmospheric Chemistry Conference.

Sarangi, B, RL Colon D Baumgardner, JC Gonzalez, /IA Guadallupe-diaz, JA Ogren, and OL Mayol-Bracero. 2021. “Development of an Aerosol and Cloud Analysis System in the Caribbean.” Global Atmosphere Watch Symposium.

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