An annual time series of weekly size-resolved aerosol properties in the megacity of Metro Manila, Philippines

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Size-resolved aerosol samples were collected in Metro Manila between July 2018 and October 2019. Two Micro-Orifice Uniform Deposit Impactors (MOUDI) were deployed at Manila Observatory in Quezon City, Metro Manila with samples collected on a weekly basis for water-soluble speciation and mass quantification. Additional sets were collected for gravimetric and black carbon analysis, including during special events such as holidays. The unique aspect of the presented data is a year-long record with weekly frequency of size-resolved aerosol composition in a highly populated megacity where there is a lack of measurements. The data are suitable for research to understand the sources, evolution, and fate of atmospheric aerosols, as well as studies focusing on phenomena such as aerosol-cloud-precipitation-meteorology interactions, regional climate, boundary layer processes, and health effects. The dataset can be used to initialize, validate, and/or improve models and remote sensing algorithms.

Background & Summary
The composition and size distribution of ambient particulate matter (PM) influence how particles impact air quality and public health1, climate2, the hydrological cycle3, and geochemical cycling of nutrients and contaminants4. Depending on particle size and composition, an inhaled particle can deposit in the extrathoracic (head), tracheobronchial (TB), or pulmonary (PUL) regions, which can have serious implications for health5–8. Similarly, size and composition of particles impact their radiative properties, ability to act as cloud condensation nuclei (CCN), and also the ability to be transported between regions.

Since seasonal changes in meteorology, transport pathways, and emissions can impact a given region, annual PM cycles are important to characterize. A summary of past long-term (> three-month period) size-resolved PM substrate-based sampling efforts are provided in Online-only Table 1. There are a scarcity of annual time series data with at least weekly frequency regardless of global region. Most substrate-based sampling efforts for size-fractionated PM cover periods of one to three months with a sample collection duration between 24 to 96 hours per set, which were not included in Online-only Table 1. Longer sampling periods for individual sets, reaching up to a week9,10, are required in regions with less pollution in order to achieve sufficiently high mass concentrations (i.e. above limits of detection) for targeted species. The difficulty in obtaining long-term records of size-resolved PM composition with high temporal frequency is largely due to the labor-intensive nature of such measurements, which include several pre- and post- sampling steps and subsequent chemical analyses.

The megacity of Metro Manila in the Philippines consists of 16 cities containing approximately 12.88 million people, with a collective population density of about 20,800 km−2. Quezon City, the location where sampling...
took place, is one of the most populated cities in the region, with a population of about 2.94 million people and a population density of approximately 17,000 km$^{-2}$, which is among the highest in the world. Metro Manila is an ideal location for examining locally produced urban anthropogenic PM often mixed with a host of other air masses of marine and continental origin that are transported over both short and long distances to Metro Manila$^{13}$. One aspect that makes the PM in Metro Manila unique is that black carbon levels are among the highest in the world$^{11,14,15}$. The elevated black carbon is mainly due to vehicular emissions, more specifically the jeepneys, large trucks, and outdated vehicles$^{11}$. The Philippines serves as a representative southeastern Asian country in terms of high population density, rapid urbanization, outdated vehicle usage and technology, and more lenient air regulations$^{11}$.

The goal of this work is to present a 16-month size-resolved PM dataset for Metro Manila, Philippines. The unique geographic position of Metro Manila coupled to the wide ranging meteorology and transport patterns makes this dataset highly valuable in terms of examining numerous topics related to PM physics and chemistry with general implications for other regions: (i) impacts of PM on regional climate, clouds, and monsoonal activity, (ii) PM removal via wet deposition, (iii) aqueous processing of PM, (iv) source apportionment, (v) effects on PM properties due to mixing of varying air masses, (vi) catalytic and destructive effects of metals on inorganic/organic species, (vii) impacts of extreme events (e.g., biomass burning, dust storms, fireworks, typhoons) on regional PM, and (viii) public health implications.

### Methods

#### Field study description.

The dataset presented is a 16-month, size-resolved, chemical characterization of PM as part of a pre-campaign initiative for the Cloud, Aerosol, and Monsoon Processes Philippines Experiment (CAMP$^2$Ex) titled CAMP$^2$Ex weather and Compositional Monitoring (CHECSM) study. The CHECSM campaign took place between July 2018 through October 2019, within which August through October 2019 coincides with the airborne component of CAMP$^2$Ex.

#### Study site description.

The CHECSM study occurred at the Manila Observatory (MO; 14.64°N, 121.08°E) located at the Ateneo de Manila campus in Quezon City, Philippines. The site was segregated from surrounding urban areas, including a major roadway, by a grove of trees circling the campus. However, it was clearly impacted by local urban emissions and long-range transport based on results from the first six months of data collected$^{16-18}$. Sampling took place on the 3rd floor of the MO office building, which was approximately 85 m above sea level. Figure 1 shows a timeline of sampling, which occurred in four identified seasons: the 2018 southwest monsoon/wet season (18 June–4 October)20, a transitional period (5–25 October), the northeast monsoon/dry season (26 October 2018–10 June 2019)21, and the 2019 southwest monsoon/wet season (11 June–7 October)22,23. The southwest monsoon is characterized by relatively high temperatures, high humidity, frequent and heavy rainfall, and winds coming predominantly from the southwest. The northeast monsoon is characterized by moderate rainfall, low humidity, lower temperatures, and winds affecting the eastern side of the country. The characteristics of the monsoons listed above are general traits, but the major determining factor is rainfall. The measured temperature, humidity, and rainfall during sampling period collected at MO ranged from 25.4–30.2 and 24.2–30.9 °C, 59–94 and 54–85%, and 0–78.4 and 0–32.6 mm for the southwest and northeast monsoons, respectively, with average values of 27.6 and 27.7 °C, 72 and 64%, and 18.8 and 2.1 mm. Although the focus of this data descriptor is the size-resolved PM composition dataset, additional instrumentation co-located at MO during CHECSM is summarized in Table 1.

### Table 1. List of instruments deployed at Manila Observatory (MO) before and during CAMP$^2$Ex and the associated measurement parameters.

| Instrument | Parameters |
|------------|------------|
| Aerosol Robotic Network (AERONET) | Aerosol optical depth (AOD), single-scatter albedo (SSA), absorption angstrom exponent (AAE), scattering angstrom exponent (SAE), and water vapor pressure, and precipitation |
| Disdrometer | Droplet size and vertical velocity |
| Arctic High Spectral Resolution Lidar (AHSRL) | Backscatter coefficient, depolarization ratio, and backscatter ratio |
| DustTrak and (2) Tactical Air Samplers (TAS) | Real-time and 24-hour total PM$_{10}$ mass concentration with chemical speciation |
| Solar Spectral Flux Radiometer (SSFR) | Shortwave and longwave radiance and irradiance |
| All-Sky Camera | Hemispheric sky imaging |
| Particle Soot Absorption Photometer (PSAP) | Black carbon absorption and concentration |
| Automated Weather Station (AWS) | Temperature, relative humidity, wind speed, wind direction, solar radiation, pressure, and precipitation |
| Davis Rotation Uniform-Cut Monitor (DRUM) | Size segregated elemental composition of PM |
| Electronic Beta Attenuation Monitor (e-BAM) | Real-time PM$_{10}$ mass concentration |
| Kipp and Zonen CMP22 Pyranometer | Solar radiation (broadband irradiance) |
| Kipp and Zonen CGR4 Pyrgeometer | Solar radiation (infrared irradiance) |
| SPN1 Shadow Pyranometer | Solar radiation (shadow broadband irradiance) |
| SP1-F Narrowband Shadow Pyranometer | Solar radiation (shadow narrowband irradiance) |
Instrument description.  Size-resolved PM was collected using a pair of Micro-Orifice Uniform Deposit Impactors II (MOUDI II 120 R, MSP Corporation, Marple et al.\textsuperscript{24}) on Teflon substrate filters (PTFE membrane, 2 μm pores, 46.2 mm diameter, Whatman). The MOUDI-II is a 10-stage impactor with aerodynamic cutpoint diameters ($D_p$) of 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18, 0.10, and 0.056 μm with a pre-impactor (> 18 μm) and an after-filter (< 0.056 μm). Refer to Table 2 for the associated stage numbers, collected diameter ranges, and cutpoint diameters. The instruments operated at a nominal flowrate of ~30 L min$^{-1}$, with measured flowrates for each set reported in Table 3. Each stage, except for the pre-impactor and after-filter, continuously rotates to allow for uniform deposition of particles. Pressures for each stage were measured and recorded to ensure pressure drops were within acceptable ranges. An identical pair of MOUDIs were deployed for two reasons: (i) there would be no delay in sampling when a unit required maintenance, and (ii) simultaneous measurements allowed for additional analyses of collected PM.

MOUDI sets were collected weekly over a 48-hour period with the exception of sets MO1, MO2, MO3/4, MO5, MO31/32, and MO51, which were collected for 24, 54, 119, 42, 49, and 50 hours, respectively. MOUDI sets labeled MO#/# refer to the sets that were simultaneously collected so that both chemical analysis and

![Timeline of size-resolved aerosol measurements at the Manila Observatory.](https://www.nature.com/scientificdata/)

Fig. 1  Timeline of size-resolved aerosol measurements at the Manila Observatory. Light blue boxes represent the southwest monsoon/wet seasons, the light green box represents the transitional period, and the orange box represents the northeast monsoon/dry season. Dark colored boxes represent MOUDI sampling periods and black boxes represent parallel MOUDI sampling periods.
Cationic and anionic water-soluble PM speciation and quantification was conducted using a 2 mm IC system at a flowrate of 0.4 mL min⁻¹. The cationic species measured were Na⁺, NH₄⁺, Mg²⁺, Ca²⁺, dimethyleamine (DMA), trimethylamine (TMA), and diethylamine (DEA) using an eluent of methanesulfonic acid. The anionic species measured were methanesulfonate (MSA), pyruvate, adipate, succinate, maleate, oxalate, phthalate, Cl⁻, ...
Table 3. MOUDI sample set operating data. The table includes average flowrates, total sample run time, average operating temperature of the MOUDI cabinet, relative humidity (RH), and the days of the week sampling occurred. The start/end times varied between 13:00 and 15:00 local time for standard sets and 5:00 local time for dual gravimetric/IC sets. Sets with a label of (G) are gravimetric sets and the set labeled (AL) was collected for SEM analysis. All other sets were only measured with IC and/or ICP-QQQ.

| Sample ID | Avg. Flow (L/min) | Run Time (hr) | Avg. Temp. (°C) | Avg. RH (%) | Days of the Week | Sample ID | Avg. Flow (L/min) | Run Time (hr) | Avg. Temp. (°C) | Avg. RH (%) | Days of the Week |
|-----------|-------------------|---------------|-----------------|-------------|-----------------|-----------|-------------------|---------------|-----------------|-------------|-----------------|
| MO1       | 29.6              | 24            | 30.5            | 59.0        | Th-F            | MO34      | 29.4              | 48            | 35.3            | 57.9        | M-W             |
| MO2       | 29.6              | 54            | 31.7            | 66.8        | M-W             | MO35 (G)  | 25.6              | 48            | 36.6            | 56.8        | T-Th            |
| MO3 (G)   | 28.6              | 119           | 34.9            | 69.0        | W-M             | MO36      | 29.3              | 48            | 39.9            | 56.8        | T-Th            |
| MO4       | 30.3              | 119           | 34.4            | 69.0        | W-M             | MO37      | 30.0              | 48            | 38.8            | 55.1        | W-F             |
| MO5       | 28.8              | 42            | 33.5            | 66.7        | M-W             | MO38      | 29.6              | 48            | 36.4            | 54.0        | S-M             |
| MO6       | 27.1              | 48            | 34.6            | 63.3        | M-W             | MO39 (G)  | 26.4              | 48            | 39.0            | 57.6        | M-W             |
| MO7       | 27.9              | 48            | 34.9            | 78.3        | T-Th            | MO40      | 29.6              | 48            | 41.4            | 57.6        | M-W             |
| MO8       | 29.0              | 48            | 35.7            | 78.2        | W-F             | MO41      | 29.1              | 48            | 38.7            | 57.7        | T-Th            |
| MO9       | 27.5              | 48            | 34.9            | 68.4        | S-M             | MO42      | 29.1              | 48            | 40.3            | 53.7        | W-F             |
| MO10      | 29.0              | 48            | 36.7            | 65.2        | M-W             | MO43 (G)  | 26.8              | 48            | 36.1            | 59.8        | S-M             |
| MO11      | 27.1              | 48            | 35.8            | 68.3        | T-Th            | MO44      | 28.6              | 48            | 37.0            | 59.8        | S-M             |
| MO12      | 27.5              | 48            | 37.0            | 70.9        | W-F             | MO45      | 28.7              | 48            | 37.3            | 61.8        | W-F             |
| MO13 (G)  | 29.8              | 48            | 35.1            | 73.1        | S-M             | MO46      | 28.7              | 48            | 39.0            | 72.2        | T-Th            |
| MO14      | 26.1              | 48            | 32.0            | 73.1        | S-M             | MO47      | 28.9              | 48            | 39.3            | 64.5        | W-F             |
| MO15      | 29.7              | 48            | 37.3            | 67.6        | M-W             | MO48      | 28.0              | 48            | 38.9            | 62.6        | S-M             |
| MO16      | 29.2              | 48            | 37.6            | 67.7        | T-Th            | MO49 (G)  | 25.5              | 48            | 38.1            | 62.6        | S-M             |
| MO17      | 30.0              | 48            | 36.5            | 60.6        | W-F             | MO50      | 28.8              | 48            | 39.2            | 64.4        | M-W             |
| MO18      | 29.5              | 48            | 36.7            | 61.9        | S-M             | MO51      | 27.8              | 50            | 36.2            | 77.1        | T-Th            |
| MO19      | 31.4              | 48            | 35.8            | 61.4        | M-W             | MO52 (G)  | 24.9              | 48            | 36.6            | 60.9        | W-F             |
| MO20      | 30.2              | 48            | 34.8            | 60.8        | T-Th            | MO53      | 26.9              | 48            | 38.8            | 60.9        | W-F             |
| MO21      | 30.5              | 48            | 34.8            | 72.0        | W-F             | MO54      | 28.8              | 48            | 36.8            | 66.4        | S-M             |
| MO22      | 29.6              | 48            | 32.7            | 78.5        | S-M             | MO55      | 28.8              | 48            | 38.0            | 75.4        | M-W             |
| MO23      | 26.4              | 48            | 29.7            | 81.8        | M-W             | MO56      | 26.7              | 48            | 35.0            | 76.1        | T-Th            |
| MO24      | 30.2              | 48            | 35.8            | 84.6        | M-W             | MO57      | 27.5              | 48            | 33.0            | 94.1        | W-F             |
| MO25 (AL) | N/A               | 2.75          | N/A             | N/A         | M-T             | MO58 (G)  | 24.5              | 48            | 33.4            | 94.1        | W-F             |
| MO26      | 24.1              | 48            | 35.0            | 77.2        | T-Th            | MO59      | 28.2              | 48            | 37.8            | 85.9        | S-M             |
| MO27      | 23.9              | 48            | 36.2            | 65.3        | W-F             | MO60      | 28.2              | 48            | 37.3            | 92.7        | M-W             |
| MO28      | 25.0              | 48            | 33.1            | 63.5        | S-M             | MO61      | 29.4              | 48            | 36.3            | 62.1        | T-Th            |
| MO29      | 29.5              | 48            | 34.5            | 63.3        | M-W             | MO62      | 27.8              | 48            | 36.5            | 77.0        | W-F             |
| MO30      | 29.8              | 48            | 34.4            | 60.7        | T-Th            | MO63 (G)  | 24.4              | 48            | 35.0            | 77.0        | W-F             |
| MO31      | 29.9              | 49            | 35.8            | 65.7        | W-F             | MO64      | 27.0              | 48            | 37.5            | 67.2        | S-M             |
| MO32 (G)  | 24.4              | 49            | 37.0            | 65.7        | W-F             | MO65      | 27.2              | 48            | 38.4            | 65.3        | M-W             |
| MO33      | 29.8              | 48            | 34.3            | 58.1        | S-M             | MO66 (G)  | 23.9              | 48            | 37.7            | 57.9        | M-W             |

Fig. 2 Flow chart of steps leading from MOUDI substrate collection to compilation of final data. The more commonly used single MOUDI sampling strategy follows only the top branch after “MOUDI” while the less frequent dual MOUDI sampling approach encompasses both the top and bottom branches. Rounded boxes represent instrument and analytical analyses steps while the standard boxes represent other processing steps.
using IC (ions). LODs and LOQs in ppb are aqueous concentrations while LODs and LOQs in µg m⁻³ are air equivalent concentrations. Species were quantified for at least 24 hours. After the equilibration time, each substrate was passed near a 210Po antistatic tip for 30 sec-then weighed again after sampling ended. Before weighing took place, the filters were equilibrated in the room at 30–40% relative humidity with an airlock buffer. Clean substrates were weighed prior to sample collection and SDd is the standard deviation of the difference, SDb is the standard deviation of the substrate before sampling, and SDa is the standard deviation of the substrate after sampling. The percent standard deviations across all stages and sets averaged out to be approximately 7%.

Water-soluble species analyzed with their respective recoveries ± standard deviations (SD), limits of detection (LOD), and limits of quantification (LOQ) in aqueous concentration units. The subsequently weighed substrates were then analyzed using a Multi-wavelength Absorption Black Carbon Instrument (MABI; Australian Nuclear Science and Technology Organisation). The MABI is an optical instrument used to quantify the mass concentration of black carbon by detecting the absorption for seven elements. Water-soluble elements were speciated and quantified using ICP-QQQ after being acidified in 2% nitric acid. The elements quantified were: Ag, Al, As, Ba, Cd, Co, Cr, Cs, Cu, Fe, Hf, K, Mn, Mo, Nb, Ni, Pb, Rb, Se, Sn, Sr, Ti, Tl, V, Y, Zn, and Zr. The recoveries, LOD, and LOQ for these species can be found in Table 4.

Gravimetric. Gravimetric analysis was performed using a Sartorius MA5-F microbalance with a sensitivity of ±1 µg. The microbalance was located in a temperature and humidity-controlled room at 20–23 °C and 30–40% relative humidity with an airlock buffer. Clean substrates were weighed prior to sample collection and then weighed again after sampling ended. Before weighing took place, the filters were equilibrated in the room for at least 24 hours. After the equilibration time, each substrate was passed near a 210Pb antistatic tip for 30 seconds to minimize measurement bias due to electrostatic charge at the surface of the substrate. Each substrate was weighed twice, once initially and then again 24 hours later. If the difference between these two weighings exceeded 10 µg, the substrate was weighed again 24 hours later and this process was repeated until the difference between weighings was less than 10 µg. The percent standard deviations for the weighings before and after sampling, respectively, were relatively negligible, with the highest being 0.005%. The PM mass was derived from the difference of the average substrate weight after sampling minus the average substrate weight before sampling. The standard deviation of the change in weight was then calculated for each PM substrate using the following error propagation equation:

$$SD_d = \sqrt{SD_b^2 + SD_a^2}$$ (1)

where SDd is the standard deviation of the difference, SDb is the standard deviation of the substrate before sampling, and SDa is the standard deviation of the substrate after sampling. The percent standard deviation across all stages and sets averaged out to be approximately 7%.

Black carbon. The subsequently weighed substrates were then analyzed using a Multi-wavelength Absorption

| Ion          | Recovery ± SD (%) | LOD (ppb) | LOQ (ppb) | LOD (µg m⁻³) | LOQ (µg m⁻³) |
|--------------|-------------------|-----------|-----------|--------------|--------------|
| Adipate      | 101 ± 4           | 22.655    | 75.517    | 2.10E-03     | 6.99E-03     |
| Ammonium     | 100 ± 17          | 42.434    | 141.447   | 3.93E-03     | 1.31E-02     |
| Calcium      | 100 ± 5           | 45.229    | 150.763   | 4.19E-03     | 1.40E-02     |
| Chloride     | 103 ± 7           | 2.144     | 7.147     | 1.99E-04     | 6.62E-04     |
| DMA          | 100 ± 2           | 52.709    | 175.697   | 4.88E-03     | 1.63E-02     |
| Magnesium    | 104 ± 8           | 36.925    | 123.083   | 3.42E-03     | 1.14E-02     |
| Maleate      | 100 ± 3           | 6.970     | 23.233    | 6.45E-04     | 2.15E-03     |
| MSA          | 102 ± 6           | 12.316    | 41.053    | 1.14E-03     | 3.80E-03     |
| Nitrate      | 106 ± 12          | 8.917     | 29.723    | 8.26E-04     | 2.75E-03     |
| Oxalate      | 100 ± 2           | 12.312    | 41.040    | 1.14E-03     | 3.80E-03     |
| Phthalate    | 99 ± 2            | 20.685    | 68.950    | 1.92E-03     | 6.38E-03     |
| Pyruvate     | 102 ± 6           | 63.754    | 212.513   | 5.90E-03     | 1.97E-02     |
| Sodium       | 104 ± 8           | 43.476    | 144.920   | 4.03E-03     | 1.34E-02     |
| Succinate    | 98 ± 9            | 11.046    | 36.820    | 1.02E-03     | 3.41E-03     |
| Sulfate      | 101 ± 3           | 11.982    | 39.940    | 1.11E-03     | 3.70E-03     |
| TMA & DEA    | 102 ± 4           | 315.164   | 1050.550  | 2.92E-02     | 9.73E-02     |

Table 4. Water-soluble species analyzed with their respective recoveries ± standard deviations (SD), limits of detection (LOD), and limits of quantification (LOQ) in aqueous concentration units. The exceptions to this is for sets MO57-MO65 where K from the IC was used due to lack of ICP-QQQ data.
wavelengths (405, 465, 525, 639, 870, 940, and 1050 nm). The following equation was used to calculate black carbon concentration:

\[
BC(\text{ng m}^{-3}) = \frac{10^6[A(cm^2)]}{[\varepsilon(m^2 \text{ g}^{-1})][V(m^3)]} \ln \left( \frac{I_0}{I} \right)
\]  

(2)

where \(\varepsilon\) is the mass absorption coefficient, \(A\) is the substrate collection area, \(V\) is the volume of air sampled, \(I_0\) is the measured light transmission through the blank substrate, and \(I\) is the measured light transmitted through the sample substrate. The mass absorption coefficient was provided in the MABI manual, collection area was retrieved based on impaction rings on the substrates, volume was calculated from flowrate and sample time, and light transmission was produced directly from the MABI.

Data processing. IC and ICP-QQQ areas were converted to concentrations using Excel sheets formatted to use calibration curves, unit operations, and sampling information. The concentration files were then organized using an assortment of MATLAB codes to produce the data into the published state with gravimetric and black carbon data. Excel and MATLAB processing files are available upon request.

Data Records
The dataset, located on figshare \(^{40}\), is in a specialized format used by the National Aeronautics and Space Administration (NASA) for field data, which is referred to as the ICARTT file format. The file name consists of the associated campaign, instrument used, sampling method, start date, revision number, and the end date. The format includes data notes in a README tab. These notes include the data principal investigator (PI), affiliated institution, mission name, the start date of data collection, the last data revision date, the number of variables, data flags, sampling platform and location, instrument information, brief description of the data, and revision log. The revision log states what revision the data is currently on and lists the previous revisions and their relative status. Additional tabs include the MOUDI stage cutpoints and size ranges, uncertainties and LODs, and the variable list and units. Data include ions, elements, gravimetric weights, and MABI measurements separated by stages in air equivalent mass concentrations (\(\mu g \text{ m}^{-3}\)). Note that the reported data are in air equivalent concentrations and typically are converted to dC/dlog \(D_p\) to properly look at the size distributions.

Table 5. Same as Table 4 but species were quantified using ICP-QQQ (elements). Species marked with ‘—’ in their respective recovery and standard deviation columns were not measured for recovery purposes. LODs and LOQs in ppt are aqueous concentrations while LODs and LOQs in \(\mu g \text{ m}^{-3}\) are air equivalent concentrations.
Technical Validation

A number of experimental and data processing techniques were implemented to validate and better characterize the final data. The flowrate for each set was measured using a flowmeter (Mesa Labs Definer 220 series) three times both prior to and after each sampling period. The overall average of these values was used as the flowrate for each set. Additionally, pressures for each stage were measured at the beginning and end of sampling to ensure there was no significant change in the pressure drop. To keep the flowrate as close to 30 L min\(^{-1}\) as possible, the MOUDI nozzle plates were removed and cleaned regularly and especially if the flowrate dropped below 27 L min\(^{-1}\). The nozzle plates were cleaned by soaking the plates in either a methanol-water solution or in pure methanol for 24 hours or more. They were then removed and rinsed with methanol, followed by placement in a clean area to let the methanol evaporate. However, towards the ending of the sampling campaign the flowrate dropped to about 24 L min\(^{-1}\) and subsequent cleanings did not alleviate the problem. The issue was likely due to one or both of the lower nozzle plates (0.056 and 0.1 \(\mu\)m cutpoint diameters) being heavily clogged with the black carbon rich air and unable to be cleared without a more aggressive cleaning method.

Chromatogram peaks were automatically drawn by the IC and ICP-QQQ system software. However, for the IC only, the operator would view each chromatogram to adjust peak areas and add in missing species. LOD and LOQ were calculated using 3 \(S_b\) and 10 \(S_b\) methods, respectively, where \(S_b\) is the standard deviation of the response and \(b\) is the slope of the calibration curve\(^4\). Recoveries were calculated by taking the ratio of the mass of a specific measured species to the known amount of that species in that sample\(^6\). Recoveries for IC and ICP-QQQ were all above 93% with repeatability ranging from 2% to 18% (Tables 4 and 5). During data analysis, \(dc/d\log D_p\) plots (stages 2–11) were examined to ensure a normal distribution was obtained. If the first (stage 2) or last stage (stage 11) was higher than the next (stage 3) or previous stage (stage 10), respectively, then that stage was not considered for a particular set and viewed as having unreliable data. If a species was not measured for a stage, a value of −9999 was inputted. Similarly, if a species was below the LOD for a stage, a value of −8888 was inputted. A summary of the relative number of data points either missing (i.e., no ICP-QQQ data for last seven sets) or below the LOD for a specific species and stage can be seen in Table 6.

A charge balance was also performed by converting each species to moles, multiplying by their respective charges, and then summing up all cations and all anions in a stage. It should be noted that only IC species, with the exception of K from ICP-QQQ, were used to measure the overall charge balances. The reasons for these are (i) the majority of the ICP-QQQ species are transition metals which have varying oxidation states and, without pH measurements, the proper charge cannot be assigned, and (ii) the majority of these species are very low in concentration and do not significantly affect the overall charge balances. All the stages were then plotted per set and a trend line was applied to test if there was a linear correlation. The charge balance \(R^2\) values in Table 7 reveal strong linear correlations (> 0.90), verifying that the data are valid. Additionally, Fig. 3 shows the overall charge balance for every set. All of the sets agree with the trend, with the exception of set 24, which can be seen deviating from the rest of the data. This set coincided with New Year’s fireworks, which produce a large amount of anionic species such as sulfate and nitrate as well as cationic metals, such as Fe and Cu. The combination of large anionic concentrations and the presence of cationic metals not included in the calculation lead to a charge balance slope below unity (i.e. more anions than cations).

Usage Notes

The data provided can be used to conduct various studies to improve understanding of regional PM effects and implications. The dataset can be synchronized with the other CHECSM instruments set up by the Air Quality Dynamics-Instrumentation and Technology Development (AQD-ITD) laboratory, the AErosol ROBotic NETwork (AERONET) station\(^43\), and meteorological and precipitation chemistry data collected by MO (Table 2).

There are a host of previous (7 SouthEast Asian Studies (7-SEAS) 2010–2018; Biomass-burning Aerosols & Stratocumulus Environment: Lifecycles and Interactions Experiment (BASELInE) 2013–2015) and ongoing (CAMP2Ex) research activities in southeast Asia from which this dataset can provide additional context. The dataset also has relevance for all global regions in that process-level understanding can be improved using a summary of the relative number of data points either missing (i.e., no ICP-QQQ data for last seven sets) or below the LOD for a specific species and stage can be seen in Table 6.

A few papers have been produced using portions of this dataset already. Cruz et al.\(^18\) looked at size-resolved PM composition during the 2018 southwest monsoon season and conducted positive matrix factorization (PMF) to identify PM sources, which were attributed to aged PM, sea salt, combustion emissions, vehicular/resuspended dust, and waste processing emissions. Braun et al.\(^16\) presented case examples of long-range transport of PM from east and southeast Asia, such as biomass burning from the Maritime Continent and transport from continental East Asia. They also presented examples of different transport pathways of pollution to the study site which yielded concentration differences for species such as K, Rb, Ba, V, Pb, Mo, and Sn. Azadi/Aghdam et al.\(^17\) analyzed sea salt PM in Metro Manila and found that sea salt concentrations varied during the wet season and appeared to be contaminated by crustal and anthropogenic sources. Building off these limited examples using just a subset of the overall dataset, there are a significant number of topics that this dataset can be used to address, such as the following:

- Impacts of PM on regional climate, clouds, and monsoon activity by (i) comparing PM composition to other cities around the world with and without monsoon seasons, (ii) combining the dataset with meteorological data from satellites and models to understand influences on aerosol composition via mechanisms such as photochemical processing, and (iii) relating surface PM concentrations to AOD from AERONET and satellite sensors to examine the vertical nature of aerosol in the region as has been done in other regions (e.g. ref. \(^44\)).
Aqueous processing of PM by looking at the changes of PM concentrations in the dry vs the wet season and effects associated with mixing of varying air masses (e.g. ref. 50) by identifying (i) what air masses influence the each species and stage. These counts exclude gravimetric and microscopy sets where chemical analysis was not performed. Refer to Table 3 for cutpoint diameters and diameter ranges.

Table 6. Summary of the number of data points either missing (outside parenthesis) or below the LOD (inside parenthesis) for a given species and MOUDI stage. Note that there were a total of 54 possible data points for each species and stage. These counts exclude gravimetric and microscopy sets where chemical analysis was not performed. Refer to Table 3 for cutpoint diameters and diameter ranges.

- Removal of PM via wet deposition by looking at what species are most effectively scavenged using precipitation data (e.g. refs. 45-46).
- Aqueous processing of PM by looking at the changes of PM concentrations in the dry vs the wet season and additionally as a function of cloud coverage and aerosol liquid water amounts (e.g. refs. 47,48).
- Source apportionment of PM by (i) observing seasonal changes in emissions (e.g. ref. 49) and (ii) comparing the emission sources determined by techniques such as PMF for the 2018 southwest monsoon season versus the 2019 southwest monsoon season.
- Effects associated with mixing of varying air masses (e.g. ref. 50) by identifying (i) what air masses influence the city and during what times of year, (ii) if synergistic effects of mixing air masses can be seen year round, and (iii) if satellites and models that speciate aerosol can capture the behavior of mixing air masses in the region as reflected in the MOUDI data.
Catalytic and destructive effects of metals on inorganic (e.g. refs. 51–53) and organic species (e.g. refs. 54–56).

Impacts of extreme events on regional PM by examining (i) sets where holidays occurred (e.g. New Year's) and (ii) sets influenced by typhoons, which have been shown to impact aerosol in the general region, such as was shown in previous studies in Taiwan57.

Public health implications related to PM by examining the characteristic size distributions of species posing negative effects such as heavy metals and their general prevalence in Metro Manila.

| Set #  | Slope | $R^2$ | Set #  | Slope | $R^2$ |
|--------|-------|-------|--------|-------|-------|
| MO1    | 0.89  | 0.92  | MO31/32| 1.19  | 0.94  |
| MO2    | 1.42  | 0.99  | MO33  | 1.26  | 0.95  |
| MO3/4  | 1.21  | 1.00  | MO34  | 1.43  | 0.98  |
| MO5    | 1.36  | 0.99  | MO35/36| 1.36  | 1.00  |
| MO6    | 1.32  | 0.98  | MO37  | 1.37  | 0.94  |
| MO7    | 1.36  | 0.99  | MO38  | 1.29  | 0.95  |
| MO8    | 1.36  | 1.00  | MO39/40| 1.50  | 0.97  |
| MO9    | 1.26  | 0.99  | MO41  | 1.50  | 0.99  |
| MO10   | 1.35  | 1.00  | MO42  | 1.46  | 0.96  |
| MO11   | 1.26  | 0.84  | MO43/44| 1.44  | 1.00  |
| MO12   | 1.33  | 0.99  | MO45  | 1.35  | 1.00  |
| MO13/14| 1.29  | 1.00  | MO46  | 1.47  | 1.00  |
| MO15   | 1.30  | 0.99  | MO47  | 1.60  | 0.99  |
| MO16   | 1.42  | 0.98  | MO48/49| 1.70  | 0.97  |
| MO17   | 1.39  | 0.96  | MO50  | 1.94  | 0.99  |
| MO18   | 1.33  | 0.98  | MO51  | 1.43  | 0.94  |
| MO19   | 1.47  | 0.98  | MO52/53| 1.63  | 0.94  |
| MO20   | 1.29  | 0.95  | MO54  | 1.46  | 1.00  |
| MO21   | 1.36  | 0.97  | MO55  | 1.38  | 0.98  |
| MO22   | 1.27  | 0.97  | MO56  | 1.57  | 0.94  |
| MO23   | 1.27  | 0.94  | MO57/58| 1.24  | 0.96  |
| MO24   | 0.82  | 1.00  | MO59  | 1.45  | 1.00  |
| MO26   | 1.46  | 0.91  | MO60  | 1.29  | 0.96  |
| MO27   | 1.55  | 1.00  | MO61  | 1.39  | 0.97  |
| MO28   | 1.17  | 0.97  | MO62/63| 1.24  | 0.97  |
| MO29   | 1.50  | 0.87  | MO64  | 1.36  | 1.00  |
| MO30   | 1.66  | 0.91  | MO65/66| 1.44  | 0.99  |

Table 7. Slope and coefficient of determination ($R^2$) of the water-soluble charge balance for each MOUDI set. Values above 1 indicate there is an anion deficit. Only IC species and K from ICP-QQQ are taken into consideration for the charge balance calculations.

Fig. 3 Charge balance plot for the cumulative MOUDI dataset using individual stages of all MOUDI sets. Red dots represent every stage of every set, with the exclusion of set 24, which is represented as green squares. The blue dashed line represents the line of best fit with a slope of 1.38 ± 0.01 and a $R^2$ value of 0.97, excluding set 24, which was associated with New Year's fireworks containing elevated anions and cationic transition metals.

- Catalytic and destructive effects of metals on inorganic (e.g. refs. 51–53) and organic species (e.g. refs. 54–56).
- Impacts of extreme events on regional PM by examining (i) sets where holidays occurred (e.g. New Year’s) and (ii) sets influenced by typhoons, which have been shown to impact aerosol in the general region, such as was shown in previous studies in Taiwan57.
- Public health implications related to PM by examining the characteristic size distributions of species posing negative effects such as heavy metals and their general prevalence in Metro Manila.
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Author contributions
C.S. organized the dataset and led the conception and writing of the manuscript. All authors contributed to field data collection and quality control of dataset. C.S. conducted a final round of quality control on all datasets. All authors helped in the editing of the manuscript.

Competing interests
The authors declare no competing interests.

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