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Atmospheric Aerosols and Air Quality in the 2022 Dry Season in Huancayo-Perú

Aerossóis Atmosféricos e Qualidade do Ar na Estação Seca de 2022 em Huancayo-Perú

Roberto Angeles Vasquez[1], Julio Miguel Angeles Suazo[2], Hugo Abi Karam[3], Jose Luis Flores Rojas[4], Luis Suarez Salas[4], Carmencita Lavado-Meza[5], Nataly Angeles Suazo[6], Fernando Boza Ccora[1], Leonel De la Cruz-Cerron[7], Rosa Zarate Quiñones[8]

[1]Universidad Nacional del Centro del Perú, Facultad de Ingeniería Civil, Huancayo, Perú
[2]Universidad Nacional Autónoma de Tayacaja Daniel Hernández Morillo, Facultad de Ingeniería Forestal y Ambiental, Pampas, Perú
[3]Universidade Federal do Rio de Janeiro, Instituto de Geociências, Departamento de Meteorologia, Rio de Janeiro, RJ, Brasil
[4]Instituto Geofísico del Perú, Ate, Perú
[5]Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa, Escuela Profesional de Ingeniería Ambiental, Chanchamayo, Perú
[6]Universidad Tecnológica del Perú, Facultad de Ingeniería de Sistemas, Lima, Perú
[7]Universidad Continental, Facultad de Ingeniería, Huancayo, Perú
[8]Universidad Nacional del Centro del Perú, Facultad de Ciencias Forestales y del Ambiente, Huancayo, Perú

E-mails: roanvas@hotmail.com; julio_as_1@hotmail.com; hugo@igeo.ufrj.br; jflores@igp.gob.pe; lsuarez@igp.gob.pe; clavado@uniscjsa.edu.pe; nati2643@hotmail.com; fboza@uncp.edu.pe; ldelacruz@continental.edu.pe; rzarate@uncp.edu.pe
Corresponding author: Julio Angeles Suazo; julio_as_1@hotmail.com

Abstract
This work presents results of Aerosol Optical Depth (AOD) and Direct Radiative Force (DRF) at the top of the atmosphere (TOA), obtained during monitoring campaigns carried out at the Huancayo Observatory of the Geophysical Institute of Peru (OH-IGP) in April and August 2022. In these campaigns, a Sun CIMEL photometer was used to measure the microphysical and optical properties of aerosols at wavelengths ranging from 340 to 1020 nm, and a low-cost Purple-air sensor to quantify the concentration of material particulate (PM), in fine and coarse modes. The AOD results indicated values in the range 0.06-0.22. The daily averages of PM2.5 and PM10 did not exceed Peru's current Environmental Quality Standards (50 μg/m^3 and 100 μg/m^3). The air quality index (AQI) calculated for PM2.5 and PM10 was classified as good. On some days during the campaigns, the air quality was classified as moderate. These results contribute to a better understanding of the current climatic conditions of the Peruvian Altiplano.

Keywords: Particulate matter; Balance energy; Purple air Sensor

Resumo
Este trabalho apresenta resultados observacionais de Profundidade Óptica de Aerossóis (AOD) e Força Radiativa Direta (DRF) no topo da atmosfera (TOA), obtidos durante campanhas de monitoramento realizadas no Observatório Huancayo do Instituto Geofísico do Peru (OH-IGP) em Abril e agosto de 2022. Nessas campanhas, um fotômetro Sun CIMEL foi usado para medir as propriedades microfísicas e ópticas de aerossóis, em comprimentos de onda variando de 340 a 1020 nm, e um sensor Purple-air de baixo custo para quantificar a concentração de material particulado (MP), nos modos fino e grosso. Os resultados de AOD indicaram valores na faixa de 0.06-0.22. As médias diárias de PM2.5 e PM10 não excederam os atuais Padrões de Qualidade Ambiental do Peru (50 μg/m^3 e 100 μg/m^3). O índice de qualidade do ar (IQA) calculado para PM2.5 e PM10 foi classificado como bom. Em alguns dias das campanhas, a qualidade do ar foi classificada como moderada. Esses resultados contribuem para uma melhor compreensão das atuais condições climáticas do Altiplano peruano.

Palavras-chave: Material particulado; Balance de energia; Sensor purple ar

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1 Introduction

The urban pollution sources are quite variable in space and time. Atmospheric aerosols cause an impact on the environment and regional and global air quality. Atmospheric aerosols play an important role in the global energy balance by scattering and absorbing the solar and terrestrial radiation (direct effect), as well as by acting as cloud condensation nuclei (indirect effect) ([Masson-Delmotte et al. 2021; IPCC 2007). It can be derived from natural as well as anthropogenic sources especially the urban pollution which is quite variable in space and time.

Aerosols are known to affect the air quality, human health and Earth radiation budget. The direct effect due to aerosols as effect of both natural and anthropogenic on the radiation budget primarily due to scattering and absorption of radiation by aerosols and is measured in terms of watts per square meter (W/m^2) or also known as aerosol radiative forcing (ARF) (Srivastava et al. 2012).

Aerosol particles play a vital role in global climate change, ecosystem, and human health (Habib et al. 2019; Kuttippurath & Raj 2021). To date, there has been increasing worry about the high aerosol concentration events in the atmosphere in all regions of Peru, which cause air pollution and health problems.

Ground radiometric measurements offer key information which complements that provided by satellites. A successful example of surface aerosol measurements is the global sunphotometer of red Aerosol Robotic Network (AERONET), coordinated by NASA (Holben et al. 1998). For example, Direct sun measurements with a CIMEL sunphotometer belonging to the AERONET network have been performed in the Huancayo Observatory, Peru.

The month with the maximum AOD monthly average is September, and in 2016, the absolute maximum value of 0.91 was registered. The mean AOD value for the study period is 0.10 ± 0.07 and the alpha mean value is 1.49 ± 0.36, indicating presence, of small size aerosols. The aerosol size distribution revealed a bimodal character with a slight predominance of the fine mode, related to the two main types of aerosols: continental and biomass (Estevan et al. 2019).

Suazo et al. (2020) describe the results of the study of aerosol optical depth (AOD) and Direct Radiative Forcing (DRF) in Top Of Atmosphere (TOA), in the Metropolitan Huancayo Area in the months of June and July 2019, used the BF5 sensor. This instrument measured Direct, Diffuse and Global Radiation in low wavelength. The results calculated of AOD presents the value maximum that is 0.58 (11 of June) and minimum that is 0.19 (12 June).

The Angstrom coefficient presents the mean value varied from 0 to 1.8, that indicated the presence the aerosols types biomass burning and industrial. Recorded optical properties used to estimate the direct aerosol radiative forcing (DARF) at the top of the atmosphere. The results indicates that the direct aerosol radiative forcing in Huancayo is between [0 20] W/m^2.

Álvarez-Tolentino and Suárez-Salas (2020) evaluated the temporal variation and source zones of PM2.5 through the use of low-cost sensors installed at three sites in the city of Huancayo (August 2018 to June 2019). The results show in dry season mean of 28.5 ± 13 $\mu g/m^3$ (2018–2019). The present research work calculate the properties aerosols atmospheric, its quality of air and radiative forcing direct in dry season 2022 in observatory of Huancayo, Perú.

2 Methods

2.1 Site Description

Meteorological and aerosol measurements are developed at the Observatory of Huancayo of the Geophysical Institute of Peru, located at the province of Chupaca that is part of the Department of Junín, Peru (Figure 1).

2.2 Instrument

2.2.1. AERONET network

The Aerosol Robotic Network (AERONET) is a global measurement network of ground-based sun photometers supported by NASA's and other international institutions (Bedareva, Sviridenkov & Zhuravleva 2014; Holben et al. 1998), which is designed to provide long-term, continuous measurements on microphysical and optical properties of aerosols at wavelengths ranging from 340 to 1020 nm (Gobbi et al. 2007).

2.2.2. The Purple Air PA-II Low-Cost PM Monitor

The PurpleAir (PA-II) sensor is a low-cost optical particle counter for PM1.0 PM2.5 and PM10 mass concentrations in air in $\mu g\ m^{-3}$, incorporating a pair of Optical Particle Counter (OPC) sensors laser (Plantower Ltd., Beijing, China), together with a temperature, relative humidity and barometric pressure sensor, connected to a microcontroller equipped with a communication module of wireless network. The device records and transmits data via Wi-Fi to a cloud-based platform (Ardon-Dryer et al. 2020; Sayahi et al. 2019)

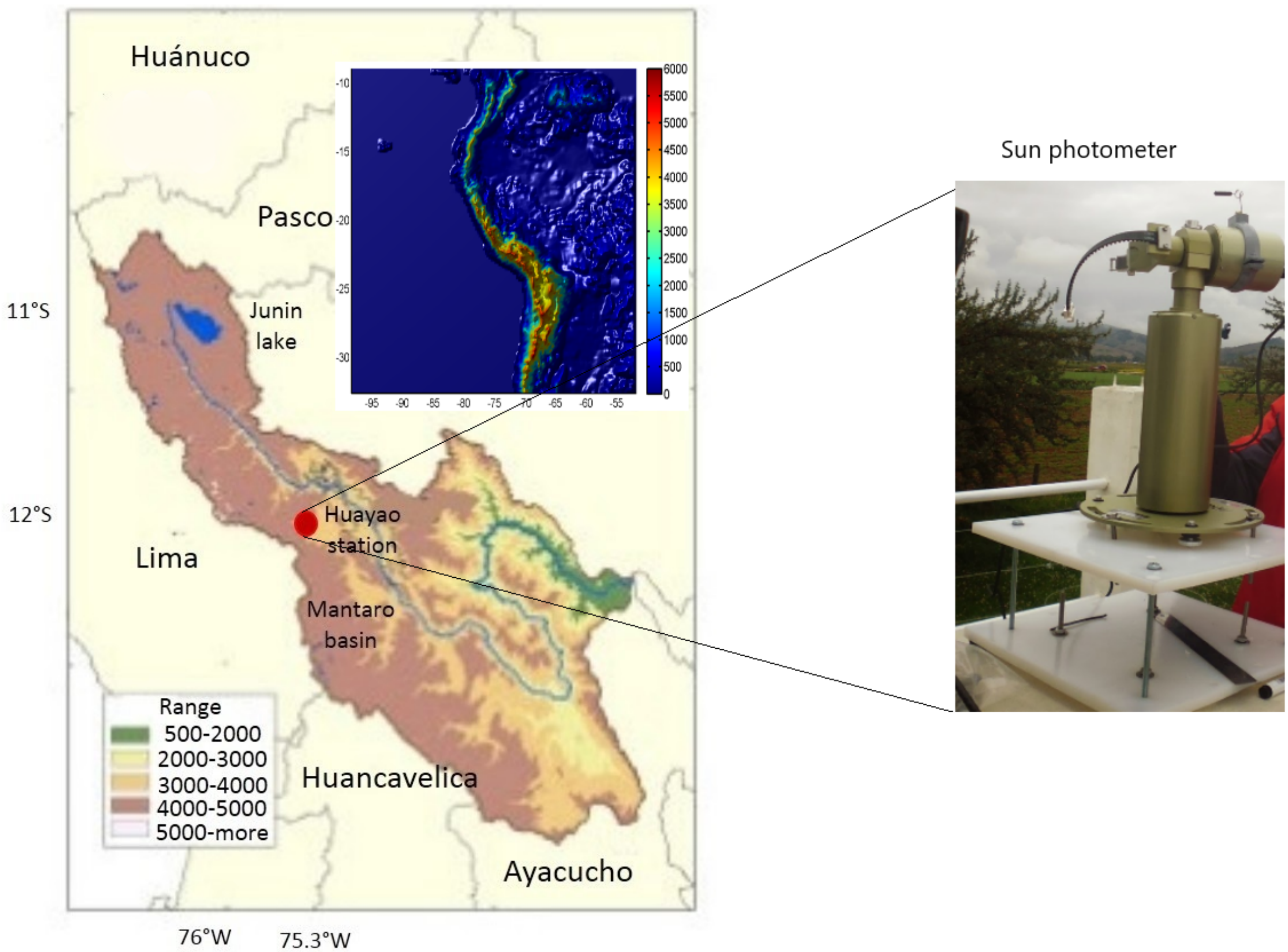

Figure 1 Location map of the Observatory of Huancayo (OH) indicated by a red circle.

2.3 Direct Radiative Forcing

The attenuation of aerosols during clear sky conditions is known as the 'direct' influence of aerosols on climate. This effect results from backscattering and absorption of radiation by the aerosol particles themselves (Charlson et al. 1992; Haywood & Boucher 2000). Although many monitoring efforts the broad range of estimates due to aerosol direct radiative forcings still remains large and an important source of uncertainty in climate models ([Masson-Delmotte et al. 2021; Forster et al. 2010).

The annual mean at the top of the atmosphere direct shortwave aerosol radiative forcing, DF, can be roughly estimated using Equation 1 and some values suggested by (Haywood & Shine 1995).

$$\Delta F = -DSoT_{at}{}^{2}(1-Ac)\omega\beta\tau\left((1-R_s)^2 - \frac{2R_s}{\beta}\left(\frac{1}{\omega}-1\right)\right) \qquad (1)$$

where

- D is the fractional day length (0.5 to OH),
- So is the solar constant (1370 Wm^{-2}),
- T_{at} the atmospheric transmission (0.76),
- Ac fractional cloud cover (0.35 to OH respectively, based on the mean daily record of Cloud_Fraction from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor for King George Island site),
- Rs the surface reflectance (0.20 to OH based on the mean daily record of Effective surface reflectivity at 360 nm (%) from Ozone Monitoring Instrument (OMI) sensor),
- ω, the single scattering albedo, calculate with AERONET inversion code provides aerosol optical properties in the total atmospheric column derived from the direct and diffuse radiation measured by AERONET Cimel sun/sky-radiometer (Dubovik & King 2000; Holben et al. 2006)
- β, the upscatter fraction (0.27, based on measurement of medium latitudes),
- τ, the aerosol optical depth.

2.4 Air Quality Index

To standardize and simplify the air quality assessment, the computation of the air quality index (AQI) was carried out for each pollutant, according to the Equation 2 following the recommendations of the Brazilian Ministry of Environment. Depending on the index obtained, the air quality score could be ranked with good, regular, poor, very poor, or terrible.

$$AQI = I_{ini} + \frac{I_{fin} - I_{ini}}{C_{fin} - C_{ini}} * (C - C_{ini}) \quad (2)$$

where, I_{ini} is a value that corresponds to the initial concentration of the range, I_{fin} is a value that corresponds to the final concentration of the range, C_{ini} is the initial concentration of the range in which the measured concentration is located, C_{fin} is the final concentration of the range in which the measured concentration is located and C is the measured pollutant concentration (Beringui et al. 2022, 2023).

The daily AQIs are calculated based on the 24-h average concentration for PM2.5 and PM10 the ranges of AQI values related to air quality can be classified into five classes as presented in Table 1.

Table 1 Air quality index (AQI) range and air classification according to index values.

Class	Range	Air classification	Color identification
I	0-40	Good	green
II	41-81	Moderate	yellow
III	81-120	Poor	orange
IV	121-200	Very poor	Red
V	201-400	terrible	purple

3 Results

3.1 Aerosol Optical Depth

Also in urban cities, values of AOD vary from 0.25 to 1.7 (Castro et al. 2001), and much lower that records during biomass burning season where values can have values as high as 2.4 for the same wavelengths (Eck et al. 2003). Then, the Figure 2A, in relation to AOD in OH, presents the value maximum that is 0.24 (April) and minimum that is 0.05 (June).

Likewise, other investigations carried in Huancayo obtain the month with the maximum AOD monthly average is September, and in 2016, the absolute maximum value of 0.91 was registered. The mean AOD value for the study period is 0.10 ± 0.07 and the alpha mean value is 1.49 ± 0.36, indicating presence, of small size aerosol (Estevan et al. 2019).

3.2 Coefficient Angstrom

Angstrom coefficient α is useful to compare and characterize the wavelength dependence of AOD and columnar aerosol size distribution (Eck et al. 1999). Smaller values represent bigger particles, for example dust. On the other hand, higher values represent smaller particles like smoke and/or burning particles (Shifrin 1995).

One way to discriminate if the aerosols are mainly composed by particles of medium – small radius, smaller than 1 mm, or higher is to calculate the Ångström for the evaluated days. Values of α that are in the range of 0.12 and 0.4 indicates the presence of particles of big size (Otero et al. 2006), as it is shown in Figure 2B from for the OH. The mean value for Angstrom coefficient (α) varied from 0.03 to 1.6 (April) that represents a low variability that can be both to instrumental and atmospheric properties.

3.3 Size Distribution

The aerosol volume-size distribution is derived from the irradiance measurements of the sky using the AERONET inversion algorithms (Dubovik & King 2000).

Figure 2C shows the average values of the aerosol volume-size distribution for April at August. The distribution has a bimodal character with a slight predominance of the coarse mode. The coarse mode is centered, on average, at a radius equal to 7 µm, while the fine mode (large particles) is centered at a radius of 0.5 µm.

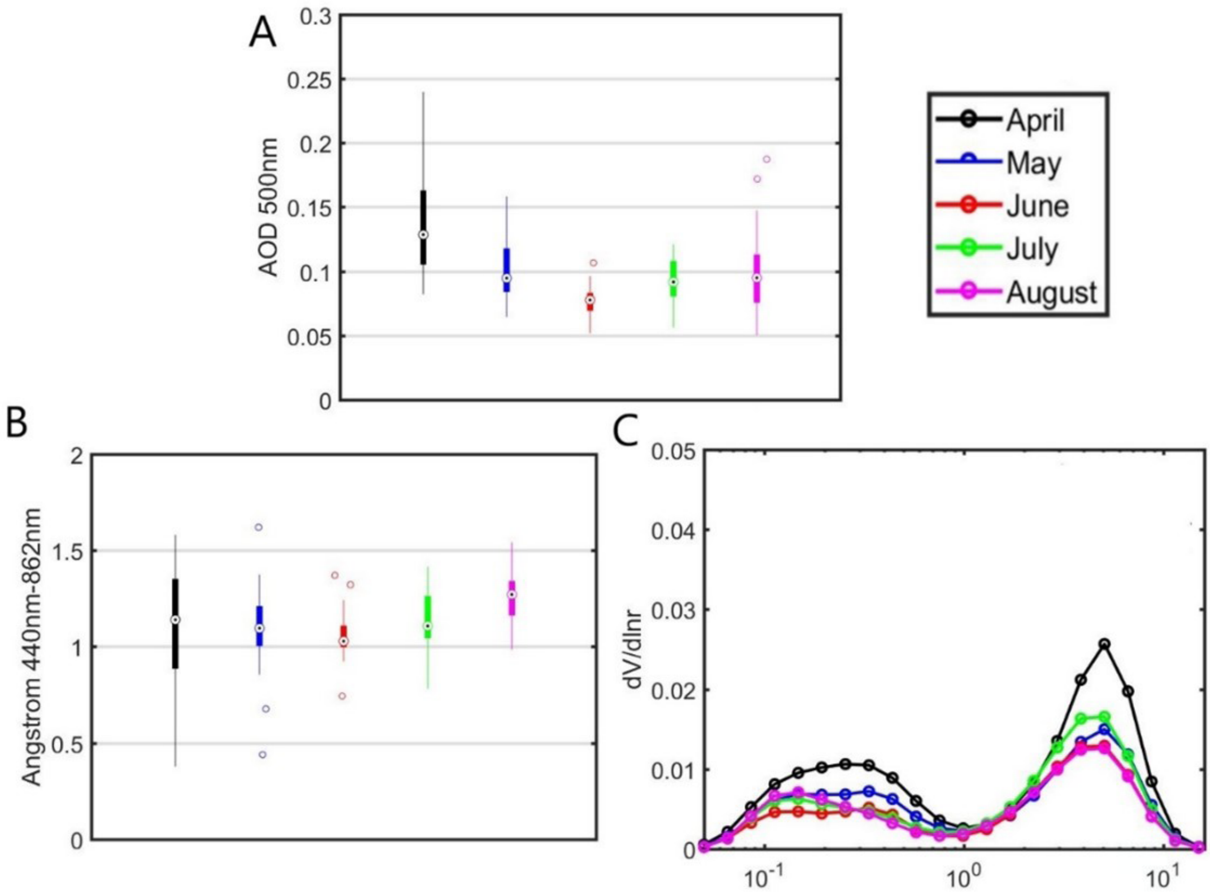

Figure 2 Monthly variation of: A. AOD at 500 nm; B. Coefficient angstrom; C. Size distribution to OH.

Average monthly values of the aerosol volume-size distribution are shown in Figure 3. Maximum values correspond to the coarse mode, be found between the months of April and August with magnitudes higher than 0.06 μm^3 μm^{-2} and correspond to the coarse mode (Figure 3A). The fact that maximum values of coarse mode appear in April and not in August attracts attention. The possible answer to this is related to the amount of aerosols suspended in the atmosphere due to scarce rains in the dry season.

3.4 Single Scattering Albedo

The aerosol single scattering albedo (SSA) is the most important intensive particle parameter controlling aerosol direct radiative forcing (Chýlek et al. 2000).This is a variable correlated with the radiative forcing of the Earth's atmosphere and is defined as the amount of dispersion in relation to the total extinction in a small volume of aerosols.

Values of SSA close to 0 correspond to purely absorbing particles, while values close to unity are related to purely scattering particles (Estevan et al. 2019; Olcese, Palancar & Toselli 2014). The SSA decreases in months of July (0.84) and incremented in month of April (0.99) and August (0.97) (Figure 4A). This is due to the low rainfall and also to the fact that in the months of May to August the number of biomass fires increases (Estevan et al. 2019).

3.5 Concentration of Particulate Matter

Regarding the monthly variation of PM2.5, the maximum and minimum averages were recorded in the month of April (19 $\mu g/m^3$) and June (9 $\mu g/m^3$) respectively. Likewise, the maximum and minimum values of PM10 were recorded in the month of April (35 $\mu g/m^3$) and June (1 $\mu g/m^3$) respectively.

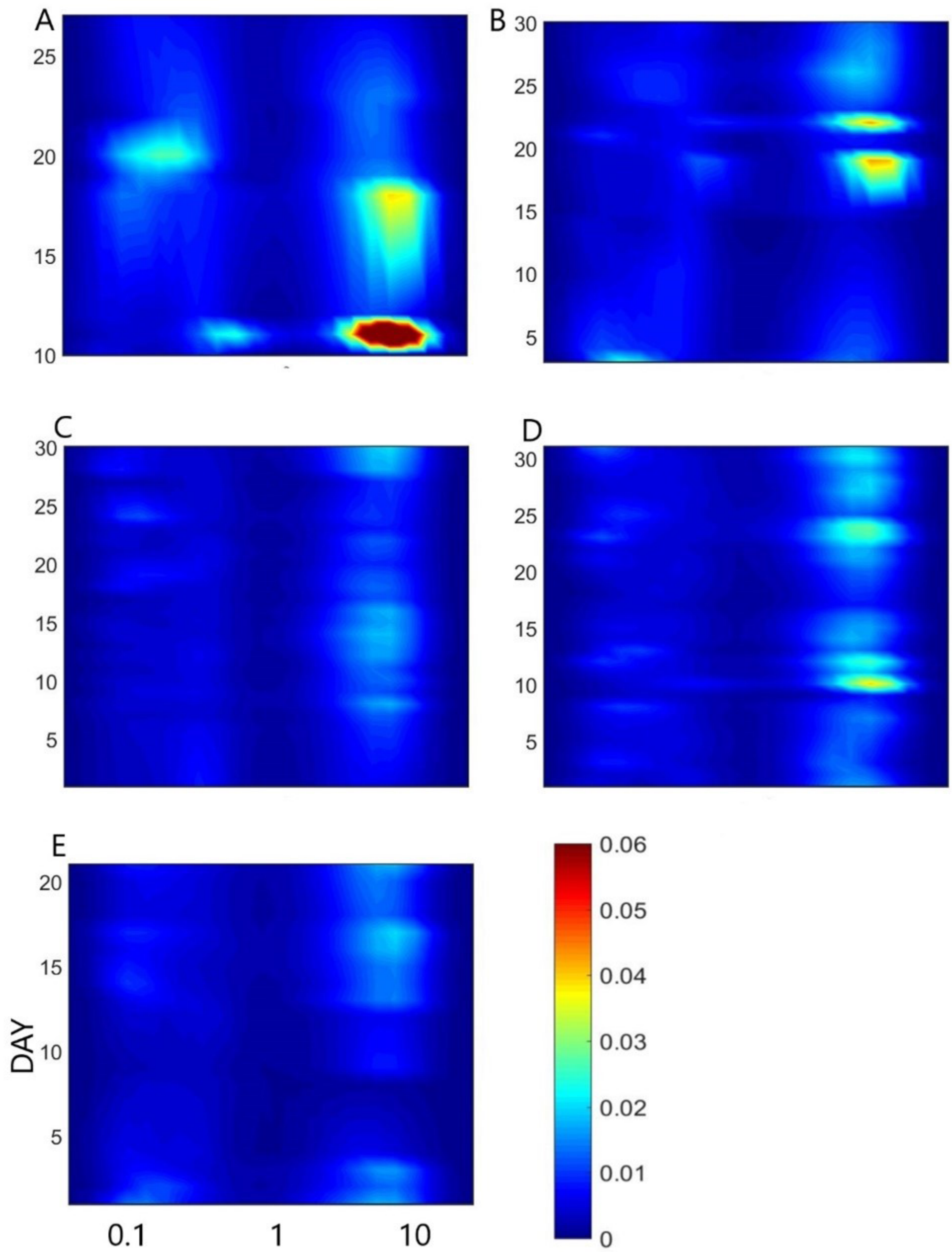

Figure 3 Size distribution for year 2022 in: A. April; B. May; C. June; D. July; E. August.

Notwithstanding the monthly variation of PM10, the maximum and minimum averages were recorded in April (23 µg/m^3) and June (12 µg/m^3) respectively (Figure 5). Likewise, the maximum and minimum values of PM10 were recorded in the month of April (44 µg/m^3) and June (2 µg/m^3) respectively.

Comparing the daily averages of PM2.5 and PM10 with the Environmental Quality Standards of the Peruvian regulations (50 µg/m^3 and 100 µg/m^3), it was determined that it was not exceeded.

3.6 Air Quality Index

The Air Quality Index (AQI) was calculated for PM2.5, and PM10, during April - August 2022. AQI to PM2.5 presented values lower than 40, which is classified as "good" 98% of the time (Figure 6). AQI to PM10 were also ranked as "good" in most days of the evaluated period. In a few random days, the air quality was classified as "moderate".

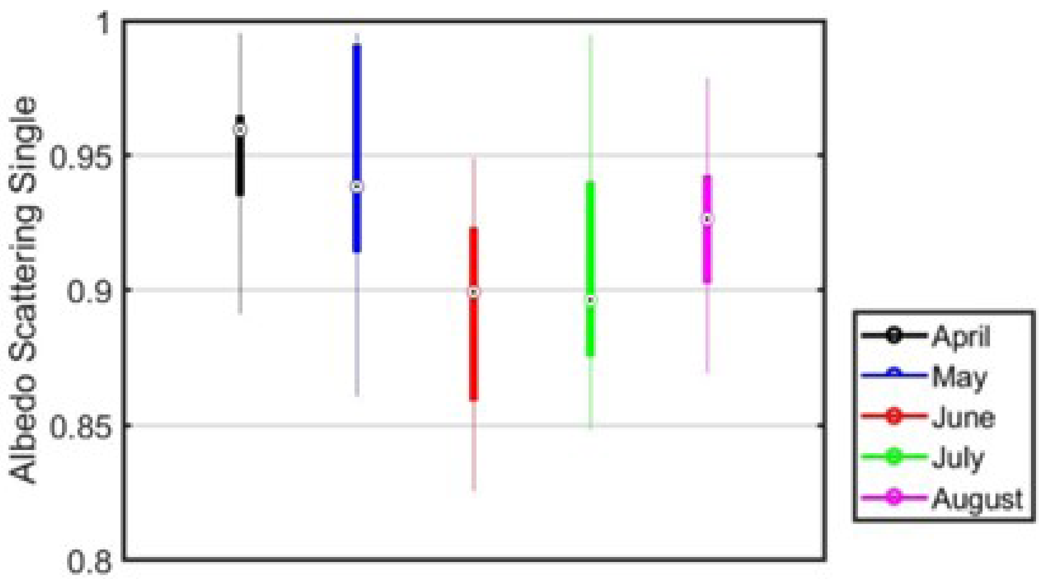

Figure 4 Scattering single Albedo to April, May, June, July and August 2022.

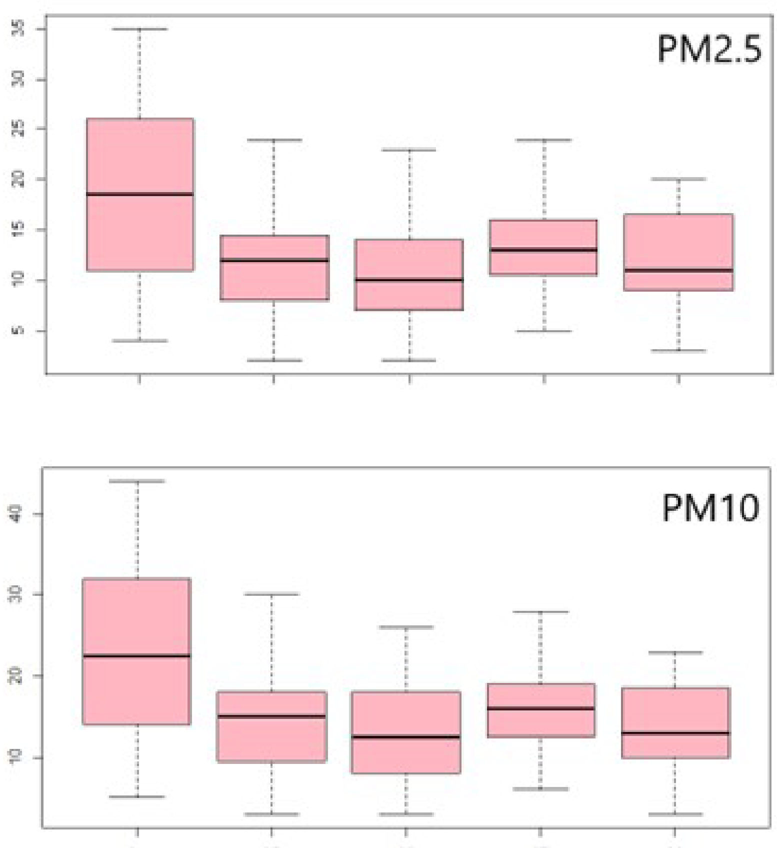

Figure 5 Boxplot of concentrations of PM2.5 and PM10 monthly to 2022.

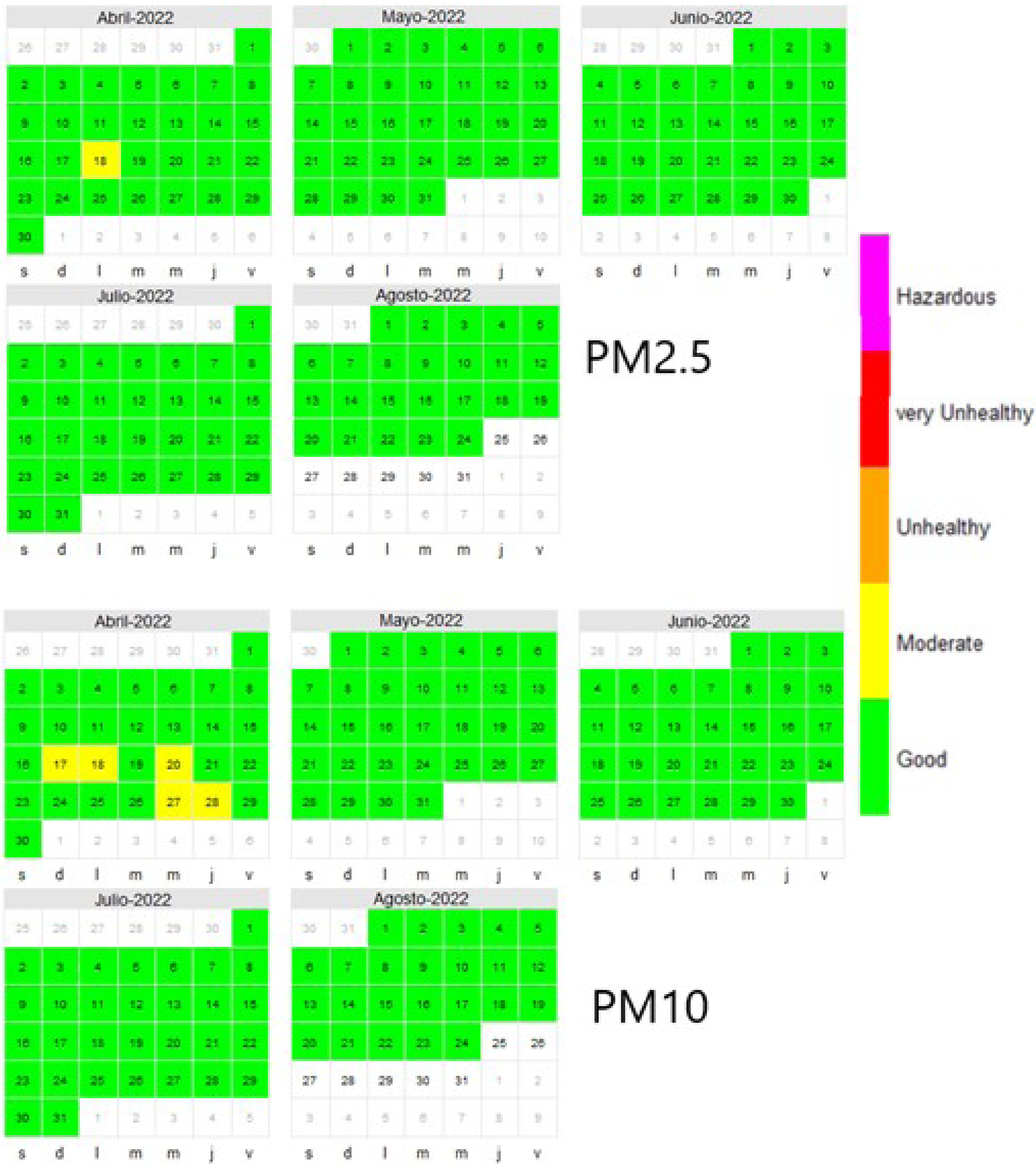

Figure 6 Index quality air of PM2.5 and PM10 during April–August 2022.

3.7 Aerosol Direct Radiative Forcing

The TOA Aerosol Direct Radiative Forcing (ADRF) is strongly dependent of AOD (τa) and of single scattering albedo (SSA, ω0), that it is a measure of scattering and absorption processes of solar light caused by aerosols becoming a key variable for ADRF calculate.

Comparing the forcing estimates with AOD values, we find that the radiative forcing is primarily governed by the magnitude of AODs which varied from a low value of 0.06 to high values above 0.22 at 0.5 um.

For evaluating and estimating the ADRF it was used the median of AOD (at 500 nm) as it is the most representative value due to this non-parametric distribution. Our estimation based on the Equation 1 the direct aerosol radiative forcing is between [-0.5 2.5] W/m^2 Also, the Figure 7 shows minimum values of ADRF product of maximum values of AOD and SSA.

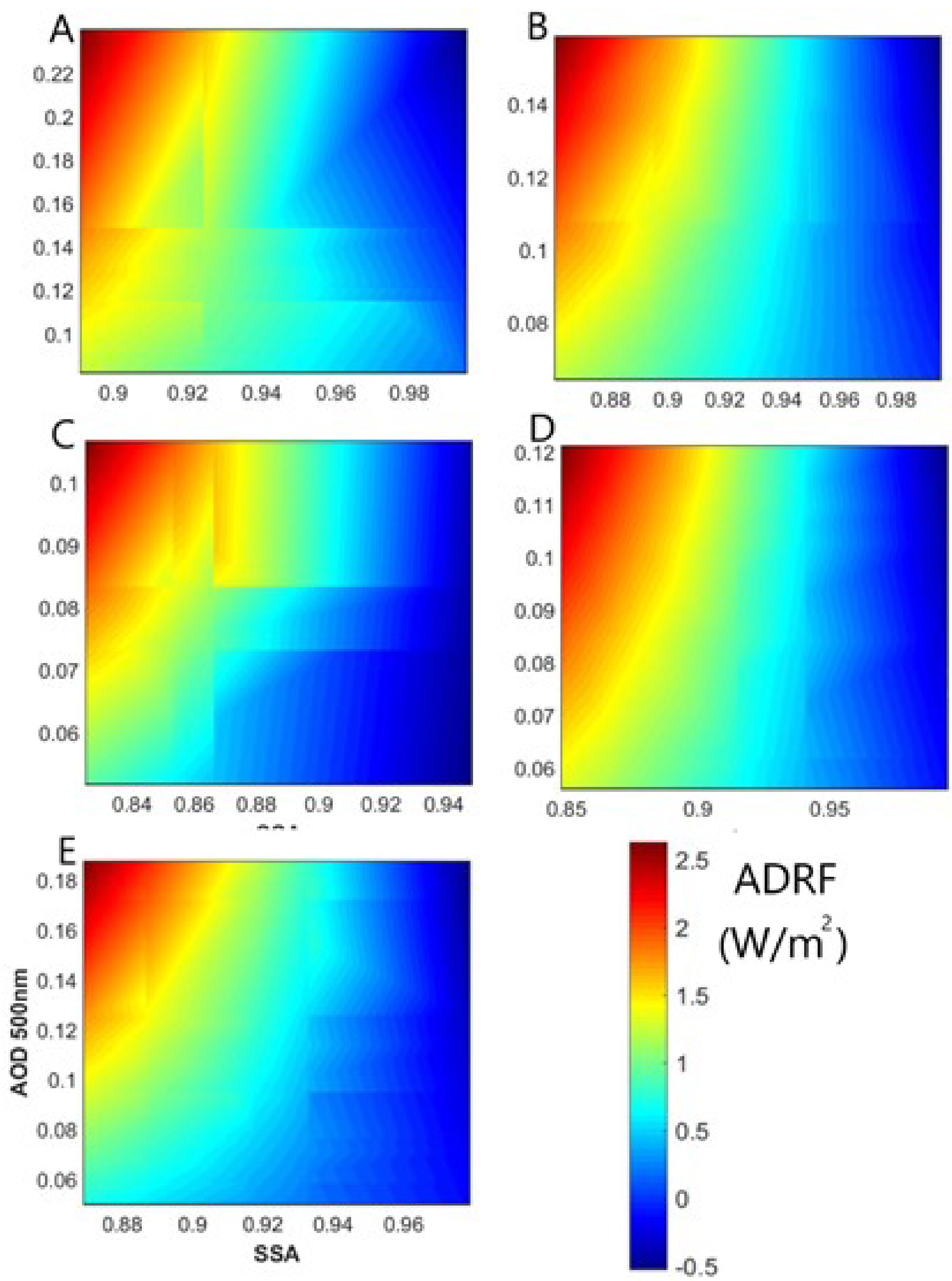

Figure 7 Dependence of single scattering albedo (ω) and AOD on the direct aerosol radiative forcing for OH in 2022 in the: A. April; B. May; C. June; D. July; E. August.

4 Discussion of Results

Atmospheric particles (PM10 and PM2.5) are responsible for serious problems in human health. For this reason, PM10 and PM2.5 exceed the Environmental Quality Standard for Air of Peruvian legislation, for both particle sizes.

In total, five emission sources have been detected for the urban sites of the Mantaro Valley: soil dust (Al, Ca, Si, Fe, Ti, Mn and K), biomass burning (Cl, Br, K), vehicles (Cu , Zn, Cl, Cr), fuel-oil (Ni) and foundry (Pb, Zn, As and Cu), with soil dust being the main source of PM10 and PM2.5 (Álvarez-Tolentino & Suárez-Salas 2020).

The PM2.5 concentration in Huancayo was 17.1 ± 5.15 μg/m^3(Lizarraga-Isla et al. 2019). On the other hand, the mean annual concentration of PM2.5 in Huancayo has ranged (average) from 3.4 to 36.8 μg/m^3 (16.6 ± 6.8 μg/m^3) and exceeded the annual thresholds of the Organization World Health Organization and national air quality standards (De La Cruz et al. 2019).

The influence of PM10 particles on the optical thickness of aerosols in the central Andes of Peru, the results showed an increase in PM10 concentrations with an increase in the number of fire outbreaks and in the AOD during July, August and September. In contrast, in October there was a slight decrease in PM10 concentrations. In addition, the meteorological conditions did not favor the occurrence of fire outbreaks in the Mantaro Valley during the entire study period; however, an increase in precipitation reduced aerosol concentrations in October. Although the vertical movements that prevailed over the central Andes were ascending, they descended along the Peruvian coast, favoring and hindering the dispersion of aerosols (Navarro-Barboza et al. 2020).

On the other hand, studies that used the same methodology to estimate air quality during the COVID-19 pandemic, such as in Rio de Janeiro, air quality was classified as “good”. Brazilian air quality standards for SO_2, O_3, and NO_2 were not exceeded at any of the monitoring stations during the partial shutdown due to COVID-19. Also note that the improvements in air quality during the partial closure due to COVID-19 can be mainly attributed to a reduction in emission sources rather than weather conditions (Beringui et al. 2023). Also note that during the COVID-19 pandemic, the partial closure contributed to improving air quality in the city of Rio de Janeiro, which means that changes in the work format can be an alternative to reduce air pollution in large cities, since the home office contributes to the reduction of mobility and, consequently, to vehicle emissions (Beringui et al. 2022).

5 Conclusions

Measurements of optical properties of aerosols performed during dry season 2022. During this period, values of AOD (500 nm) varied between 0.06 to 0.22, presented value maximum that is 0.24 (April) and minimum that is 0.05 (June).

The Angstrom coefficient shows the mean value for Angstrom coefficient (α) varied from 0.03 to 1.6 (April). Also, average monthly values of the aerosol volume-size distribution maximum values correspond to the coarse mode (radius < 10 μm). They can be found between the months of April and August with magnitudes higher than 0.06 μm3 /μm2 and correspond to the coarse mode.

The daily average values of PM2.5 and PM10 are compared with the Environmental Quality Standards of the Peruvian Regulations (50 μg/m^3 and 100 μg/m^3), where it is determined that they are not exceeded. Nevertheless, the AQI was calculated for PM2.5, and PM10 during April - August 2022, presented AQI values classified as “good” and “moderate. Also, recorded optical properties were used to estimate ARDF at the top of the atmosphere. The results indicate that the ARDF is between [-0.5 2.5] W/m^2.

The development of a low-cost sensors represents a potential alternative that can complement reference air quality monitor stations worldwide because of the low cost and minimal maintenance requirements during operation (Romero, Velásquez & Noel 2020).

The study allows us to indicate the state of air quality in Huancayo from the levels of pollution of PM2.5 and PM10. Therefore, any planning strategy aimed at reducing air pollution must consider its current state of development and, based on which, design its future plan.

With the present investigation, continuous monitoring of atmospheric particles, for this reason it is necessary to implement air quality management measures for the Mantaro valley

6 Acknowledgments

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Author contributions

Roberto Angeles Vasquez: conceptualization; formal analysis; methodology; writing-original draft; writing – review and editing; visualization; conceptual discussions. **Julio Angeles Suazo:** conceptualization; formal analysis; methodology; writing-original draft; validation; conceptual discussions. **Hugo Abi Karam:** formal conceptual analysis; conceptual discussions. **Jose Luis Flores Rojas**: conceptual discussions. **Luis Suarez Salas:** formal conceptual analysis; conceptual discussions. **Carmencita Lavado Meza**: conceptual discussions. **Nataly Angeles Suazo:** conceptual discussions. **Fernando Boza Ccora:** conceptual discussions. **Leonel de la Cruz Cerron:** conceptual discussions. **Rosa Zarate Quiñones:** conceptual discussions.

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