AIR QUALITY OBSERVATIONS IN THE EAST OF QUITO, ECUADOR IN 2018–2020: COMPARISONS BETWEEN PRE- AND POST-COVID-19 CONDITIONS

MARIA CAZORLA*
Universidad San Francisco de Quito USFQ, Colegio de Ciencias e Ingenierías,
Instituto de Investigaciones Atmosféricas, Ecuador

ABSTRACT
Ozone, NO, NO_2 as well as meteorological observations are continuously monitored at the Atmospheric Measurement Station (EMA, Spanish acronym) at Universidad San Francisco de Quito (USFQ) in Ecuador. The monitoring station is sited in Cumbayá, an Andean urban area in the valley east of Quito. In 2020, namely after the onset of the COVID-19 pandemic, primary emissions decreased due to various mobility restrictions and strategies applied in the city to try to curb the spread of the disease. These changes had an impact in ambient levels of NO and NO_2 (collectively called NO_x), which were recorded at EMA USFQ. On the other hand, an increase in ozone was detected when compared with measurements from previous years. In this work, the differences in NO_x and ozone in 2020 with respect to levels observed in 2018 and 2019 are explored. To this end, an analysis that includes 10-minute measurements of the three species is presented along with meteorological data for 2018–2020. In addition, the typical diurnal patterns of the three species are analysed under regular traffic conditions as well as under different mobility restrictions adopted in 2020. Moreover, the seasonality of the three species is characterized within the context of weather patterns in the study region. Finally, an explanation of the observed levels of ozone, based on insight gained recently in regard to ozone production mechanisms in Quito, is presented.
Keywords: ozone, NO_x, air quality, Quito, Ecuador, COVID-19.

1 INTRODUCTION

In the wake of the COVID-19 sanitary emergency, many countries applied restrictions to citizens' free mobility in an effort to curb the spread of the disease, while waiting for more permanent solutions such as massive vaccination. In Ecuador, different mobility restrictions were applied as early as March 2020. Restrictions were imposed for the entire country by a national emergency committee (COE, Spanish acronym), although local governments also applied measures according to each city's needs. In this work, different mobility restrictions imposed in the capital city of Quito in year 2020 and their impact on levels of NO, NO_2, and ozone are examined.

Quito is a city located within the complex topography of the Ecuadorian Andes. It spreads North to South, along the base of Pichincha volcano, with an altitude that varies from about 2,400 masl (meters above sea level) in the eastern valleys to about 2,800 masl at higher regions. Busy residential neighbourhoods as well as the business centre and the historical centre occupy this active urban area. Detailed topographic maps and cross sections can be found in previous publications [1], [2].

In Quito, a mid-size city of about 2.78 million inhabitants [3], the public transportation is mainly composed by a fleet of diesel buses. Public transportation is used by most of the population (over 60%) for their daily mobility needs [4]. Nevertheless, the number of private vehicles, which mostly use gasoline, have increased substantially in the past decade.

* *ORCID: https://orcid.org/0000-0001-5295-2968*

WIT Transactions on Ecology and the Environment, Vol 252,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR210161

Crowded by busy traffic, Quito is a city where regulations on mobility of private vehicles are not foreign to citizens. In 2010, the city issued a rule to restrict mobility during the morning and evening rush hours. Ever since, owners of private vehicles became familiar with not driving one day a week from 07:00 to 09:30 and from 16:00 to 19:30. In July 2019, the local government extended the restriction to 15 hours to ease work of repaving streets [5]. As the year ended and 2020 began with disturbing news about the COVID-19 pandemic, the new mobility regulations in Quito merged with national decrees and strict measures to restrict citizen's free mobility, which we discuss in this work.

The footprint of traffic in Quito is observable in the diurnal patterns of air quality observations, for example of NO and NO_2 [1], [6]. During the morning rush hour, emissions become trapped in a shallow boundary layer, whose evolution varies seasonally depending on surface conditions [2]. Under regular traffic conditions, the makeup of primary pollutants in the ambient air is such that high ambient NO_x induce ozone levels that are generally below 50–55 ppbv (10-minute data). This effect is due to atmospheric chemistry in a NO_x-saturated regime as has been proposed in previous work [1]. However, in 2020, there was a change. As the urban fleet of buses and private vehicles abandoned the streets due to a variety of COVID-19-related restrictions, the proportion of urban emissions (VOCs to NO_X) shifted. A recent study [6] demonstrates that mobility restrictions caused the chemistry of ozone production in Quito to shift towards a more NO_x-limited regime. This latter study was done upon the onset of the COVID-19 pandemic in Ecuador, with a subset of data taken in March and April 2020, which is usually a rainy period.

The present work contains not only the rainy season, but the entire set of conditions observed in 2020 and documents the signature of NO_x observations in relation to the main mobility restrictions. Moreover, the meteorological context within which restrictions took place is discussed. Finally, ozone levels in 2020 are examined in connection to ambient NO_x and observations are compared to pre-pandemic years 2018 and 2019.

2 METHODS

Air quality and meteorological observations are continuously measured on the main campus of Universidad San Francisco de Quito (USFQ) at EMA station (Spanish acronym for Atmospheric Measurement Station). The coordinates of the measuring site are 0.196°S, 78.4°W, and 2,414 masl.

Meteorological data used in this work correspond to solar radiation, temperature, and precipitation. Solar radiation is measured with a certified second class Kipp & Zonen pyranometer model CMP3, while temperature is measured with a Vaisala HUMICAP probe that also detects humidity, although those data are not presented. The rate of acquisition for the pyranometer is 1 s^{-1}, while for the temperature sensor it is 0.033 s^{-1}. Precipitation is measured with a Texas Electronic rainfall sensor model TR-525 M. Data quality is ensured through periodic calibrations of the entire meteorological station. More details on instrumentation can be found in Cazorla and Tamayo [7].

NO_x measurements at EMA are taken with a Teledyne chemiluminescence sensor model T200. Quality assurance of NO_x data is done through periodic in-lab calibration using a certified NO standard (4.794 ppmv) and preparing calibration mixtures with zero air for a range observed in the ambient air between 0 to 200 ppbv. Linearity of the calibration curve is carefully checked. Data is collected at a rate of 1 s^{-1}. Data are presented for the time period 2018 to 2020. In 2019, NO_x data was lost from June to October due to a damage of the sensor that needed part replacement.

Ambient ozone is continuously measured at EMA with a Thermo 49i UV photometer. Data quality assurance is done through continuous intercomparisons against independent

www.witpress.com, ISSN 1743-3541 (on-line)

methods. First, ozone measurements are intercompared at EMA against a 2B Technologies ozone monitor. Second, ozone readings are checked against electrochemical concentration cells that are used periodically for vertical profiling [8]. Finally, measurements are compared against those publicly available from a neighbouring station (Tumbaco) run by Quito's Air Quality Network [9]. Data from the 49i sensor are collected at a 1 s^{-1} rate. Ozone data are presented for years 2018 to 2020. There are missing data in June as well as in September and part of October 2019 due to a halt in EMA operations related to expansion work.

To process data, the original resolution of the different measurements was reduced to 10-minute. Typical patterns of variables during a season or a time period were obtained as median diurnal variations (MDV). To this end, 10-minute data for the entire time period (for example a month) were overlapped in a 24-hour plot and the median was computed for every hour. Thus, the MDV of solar radiation for every month of years 2018 to 2020 is presented. Ambient temperature is depicted in a yearly plot with the average of daily maxima in every month of years 2018 to 2020. Precipitation was calculated as cumulative rainfall every month of the study time period.

In regard to air quality data, the MDV of NO_x was obtained from 10-minute data for every month of 2018 to 2020 as the addition of NO and NO_2. NO_x levels were discussed in light of a table in which the main mobility restrictions in 2020 were summarized. Ozone data are presented in monthly plots in which 10-minute observations for years 2018 to 2020 are overlapped in order to visualize main differences in fine resolution data. Finally, years with the most complete data sets (2018 and 2020) were used to compare main differences before and after COVID-19 conditions. Hence, MDV curves for NO, NO_2, and ozone from March to December in years 2018 and 2020 were overlapped to compare pre- and post-pandemic features as diurnal patterns of ozone precursors and ozone.

3 RESULTS AND DISCUSSION

3.1 Meteorological context

Meteorological conditions are critical to understand air quality data due to their influence in the mixing volume where air pollutants become mixed, the effect that solar radiation has in photochemistry, and the cleansing action of precipitation.

At high altitude on the equator, solar radiation is intense year-round. Seasonality of solar radiation and sky conditions at the measuring site are determined by the time of year and the sudden formation of clouds at this highly complex mountainous site. Fig. 1 depicts the solar radiation MDV for every month during years 2018–2020, which illustrates the range of variability in sky conditions. Usually, two cloudy and rainy seasons take place around March and November, while summer starts in July and extends to mid-September. Occasionally, a "little summer" happens at the end of December into January.

In 2020, the pandemic year, January was a sunny month along with August. July and November were atypical in the sense that in July was mostly cloudy, while November had mostly sunny skies in the morning until noon, while storms developed in the early afternoon. These latter conditions are usually observed in mid-September and October, while November is usually a cloudier month. Sunny mornings and middays in November had an influence in air quality under pandemic mobility restrictions. A discussion is presented in the following section.

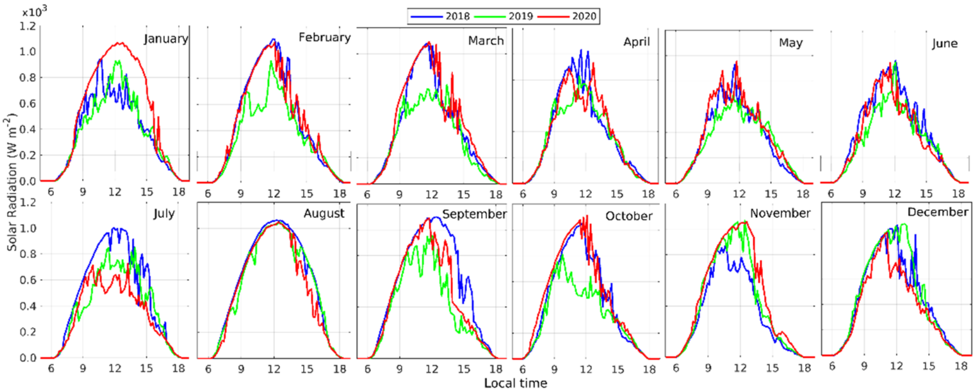

Figure 1: Median diurnal variation (MDV) of solar radiation for every month of years 2018 (blue), 2019 (green), and 2020 (red) observed at EMA USFQ in Quito, Ecuador.

Solar radiation impacts surface temperature, but this variable is influenced by high altitude at this Andean site, which keeps ambient temperatures at pleasant levels in spite of the equatorial latitude. The left panel of Fig. 2 depicts the average of daily temperature maxima per month for years 2018 to 2020. As indicated, month-to-month variability is restricted to a range between 22°C to just over 25°C (1-hour data) with cooler temperatures in April–May and higher temperatures in August–September. Cloud cover conditions, presented in Fig. 1, are reflected in mean ambient temperature maxima in Fig. 2. In regard to precipitation, year 2020 had the most cumulative rainfall when compared to 2018 and 2019. Also, the main temperature in the summer was cooler than, for example, in 2018.

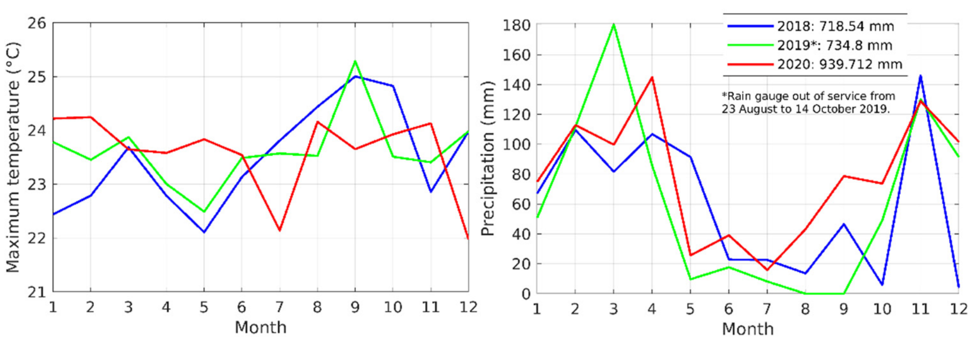

Figure 2: Left: average of maximum daily temperature per month for years 2018 to 2020. Right: total monthly precipitation.

3.2 NO_x observations in connection with mobility restrictions

The signature of traffic emissions at the study site in years 2018 to 2020 is observable in ambient measurements of NO_x depicted in monthly panels in Fig. 3. As indicated before, monthly NO_x MDV curves were obtained from 10-minute NO and NO_2 data. Thus, under pre-pandemic conditions (2018, 2019 and January to February 2020), the morning rush hour NO_x signal is very distinctive and usually ranges between 15 to 45 ppbv, on average, although in October 2018 it reached 80 ppbv. It is important to remark that curves in Fig. 3 are monthly MDVs, while individual 10-minute data could be higher than 100 ppbv.

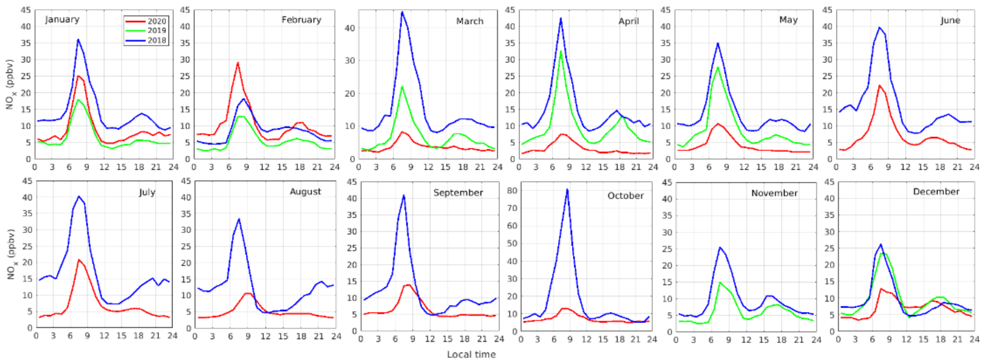

Figure 3: NO_x median diurnal variation (MDV) for every month of years 2018 (blue), 2019 (green), and 2020 (red) obtained from 10-minute data taken at EMA USFQ.

Starting March 2020, ambient NO_x substantially decreased as mobility restrictions and school closures took place. There was a variety of measures applied in the city to try to curb the COVID-19 contagion. Table 1 summarizes the main regulations adopted by authorities, which had an effect observable in NO_x measurements. Thus, on 17 March mobility was generally restricted and public transportation suspended with the exception of vehicles for essential activities. This confinement in Quito lasted 78 days. As a result, morning NO_x substantially decreased to below 10 ppbv as can be observed in Fig. 1 in panels that depict data for March, April, and May. On 3 June, the city opened up some activities and public transportation resumed with controls in the number of passengers per bus. This latter measure is evident in air quality data as the morning rush hour peak increased to over 20 ppbv, on average. There was a new outbreak of COVID-19 infections in July and August in Quito. Thus, in August new restrictions were adopted that shortened the hours of service of municipal transportation. Measures in this month had the effect of shifting the morning rush hour peak of NO_x from 07:00 to 09:00 as can be observed in the August panel in Fig. 3. In September, the decree to limit the constitutional right to free mobility expired. Nevertheless, regulations to reduce traffic continued in the city by applying different strategies that used the last digit of the plate number.

3.3 Ambient ozone observations

As stated in the introduction section, 10-minute ozone observations in Quito are usually below 55 ppbv, which leads to hourly averages that most of the time meet the Ecuadorian air quality standard for ozone (50.9 ppbv, 8-hour mean) [1], [6]. Such ozone levels at an urban site with equatorial insolation has been attributed to a NO_x-saturated environment [1], [6]. However, as discussed before, NO_x emissions substantially decreased after March 2020

Table 1: Summary of some of the main mobility restrictions imposed in Quito in 2020.

17 March–May	School closures in effect. Public transportation suspended in Quito. The national government issued a decree to restrict citizens' constitutional right to free mobility [10]. Curfew: 14:00–05:00. The general lockdown lasted 78 days.
3 June	Public transportation resumes. Mobility of private vehicles is restricted by the last digit of the plate number in a way that cars are only allowed to drive three times a week Curfew: 21:00–05:00 [11].
August	New restrictions in schedule of public transportation managed by the municipality of Quito from 05:00–19:30 on weekdays and 06:00–17:30 on Friday and Saturday, no circulation on Sunday. Curfew: 19:00–05:00. Private vehicles could drive only on authorized days according to the last digit of the plate number [12].
September–December	End of decree to generally restrict citizens' free mobility. Bus schedule extended. Curfew: 23:00–05:00. Circulation of private vehicles still restricted through different strategies that used the last digit of the plate number [13]. Other restrictions were applied during holidays.

when compared to pre-pandemic conditions. Being an ozone precursor, this significant decrease in NO_x had an impact in ozone production. Recently published work that used a chemical box model and ozone data until April 2020 [6] showed that with less abundant NO_x, the chemistry of ozone production shifted to a more NO_x-limited regime. It was proposed that such shift in precursors had the potential to increase the chemical production of ozone, which could accumulate in the ambient air given favourable meteorological conditions. Looking into 10-minute ozone data in year 2020 after April (Fig. 4) and comparing with data in 2018 and 2019, the prediction proposed in Cazorla et al. [6] was met in June, October, and mainly in November 2020.

The month of November 2020 presents a true departure from the usual annual pattern of ozone levels in Quito. As depicted in Fig. 4 (2018, 2019 data) and as documented previously [1], under regular traffic and weather conditions, the month of November

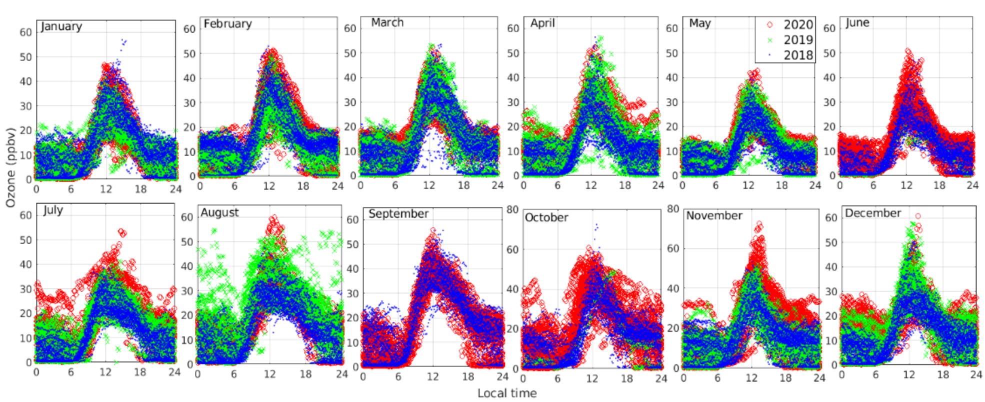

Figure 4: Ambient ozone (10-minute data) measured at EMA USFQ every month of years 2018 (blue), 2019 (green), and 2020 (red).

(usually rainy) is not a time period when events of high ozone are expected. Usually, if a high ozone episode is to be observed, it takes place in September and occasionally the first days of October, as happened in 2018 (a few 10-minuted ozone readings on the 1st of October 2018 surpassed 60 ppbv). As discussed in Section 3.1, the month of November 2020 was peculiar in the sense that it was a seasonally rainy month (over 120 mm of precipitation), but had atypical mornings and middays that were very sunny. This meteorological factor combined with a shift in the proportion of ozone precursors led to increased photochemical rates of ozone production according to Cazorla et al. [6]. As a result, in the 10-minute time series, there is a new record of 15 days in November 2020, when ozone maxima ranged between 55 and 72 ppbv (the latter reading took effect on 14 November).

As an additional comparison, Fig. 5 illustrates overlapped mean levels of NO, NO_2 and ozone from March to December 2018 (left) and 2020 (right). Thus, abundant NO during regular traffic (2018) rapidly titrates ozone in the morning rush hour. With daylight, NO_2 undergoes photolysis. However, ozone production is non-linear with respect to levels of precursors [14]. As investigated in previous work [6], [14], a high NO_x environment leads to lower ozone production rates because precursors (NO_x and free radicals hydroxyl, OH, and hydroperoxy, HO_2) are lost to the formation of other by-products such as nitric acid [14]. This mechanism explains usual (rather low) ozone levels in a busy equatorial urban area such as Quito. In contrast, when COVID-19 mobility restrictions were applied, fresh NO levels in the morning rush hour decreased five times and stayed low in the day along with NO_2, as can be observed in the right panel in Fig. 5. The ozone titration effect with NO lessened not only in the morning, but also in the evening. With less abundant NO_x in the environment, there is more availability of radicals to produce secondary NO_2 followed by immediate photolysis and more rapid ozone production. This latter statement was proposed in Cazorla et al. [6] with the clarification that meteorological conditions are key to induce ozone accumulation in the ambient air. In this work, it is proposed that higher ozone in 2020, in particular in November, is the result of an enhanced ozone production mechanism whose chemistry is shifted to a more NO_x-limited regime. At the moment, observational evidence of higher levels of ozone in connection with predictions stated in previous work [6] in regard to potential scenarios for increased ozone is presented. However, additional

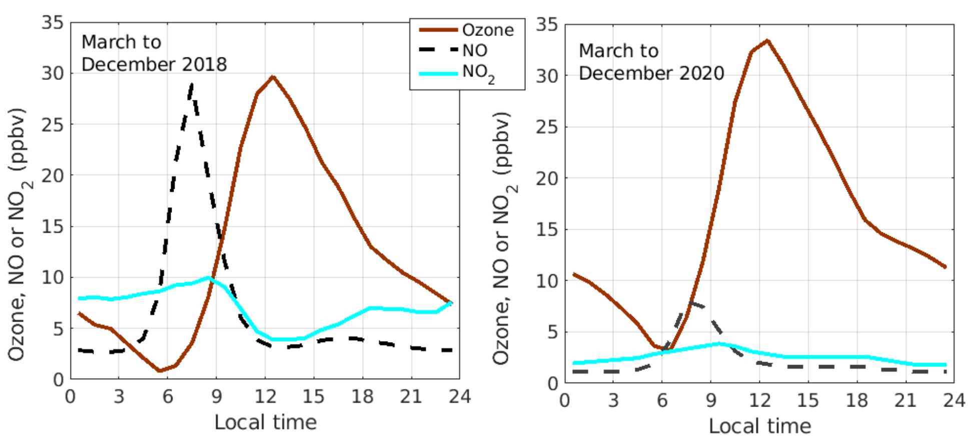

Figure 5: Levels of NO, NO_2, and ozone from March to December 2018 (left) and 2020 (right) as median diurnal variations from data taken at EMA USFQ.

research that incorporates chemical and transport modelling is needed in the future to scrutinize the underlying chemistry and the influence of meteorological factors particularly in November 2020 in Quito.

4 CONCLUSIONS

In 2020, the COVID-19 pandemic forced nations to confine their citizens to somewhat constrain massive contagion. Ecuador was not an exception. In the capital city of Quito, different mobility restrictions were imposed since mid-March and lasted, to different extents, the entire year. From data collected at Universidad San Francisco de Quito, the overall decrease in the abundance of NO_x in the ambient air from March to December 2020, when compared to 2018, was by a factor of 5. Limitations in schedules for public transportation and authorized days to drive private vehicles caused a shift in the rush hour peak of NO_x from 07:00 to 09:00 in August 2020. Work that analysed the effect on ozone photochemistry in Quito, done with initial lockdown data (March–April 2020) [6], predicted the potential for increased ozone with reduced NO_x due to a shift in the chemical regime of ozone production. From an observational perspective, this prediction was met mainly in November 2020, when there was a record of 15 days when ozone maxima ranged from 55 to 72 ppbv in the 10-minute time series. This consistent departure from the peak baseline for this month (below 50 ppv) points to atmospheric chemistry as the underlying reason. At the moment this unseasonal change is reported and it is proposed that, based on previous work [6], a shift to a more NO_x-limited regime of ozone production explains observations in November 2020, but additional research needs to be performed in the near future to prove this hypothesis.

ACKNOWLEDGEMENTS

Since 2020 ozone observations at EMA USFQ were significantly augmented thanks to equipment and funds under the support of the Vienna Convention Trust Fund and through an agreement (No. 224581) with the World Meteorological Organization. Thanks to Edgar Herrera for continuous operations and data processing at EMA USFQ.

REFERENCES

[1] Cazorla, M., Air quality over a populated Andean region: Insights from measurements of ozone, NO, and boundary layer depths. *Atmospheric Pollution Research*, **7**, pp. 66–74, 2016.

[2] Cazorla, M. & Juncosa, J., Planetary boundary layer evolution over an equatorial Andean valley: A simplified model based on balloon-borne and surface measurements. *Atmospheric Science Letters*, **19**(8), p. e775, 2018.

[3] INEC Instituto Nacional de Estadísticas y Censos, www.ecuadorencifras.gob.ec/. Accessed on: 15 May 2021.

[4] Gestión Digital, https://www.revistagestion.ec/sociedad-analisis/quito-por-que-privilegiar-al-transporte-privado-si-la-mayoria-usa-el-publico. Accessed on: 15 May 2021.

[5] El Comercio, https://www.elcomercio.com/actualidad/quito/pico-placa-municipio-jorge-yunda.html. Accessed on: 10 May 2021.

[6] Cazorla, M., Herrera, E., Palomeque, E. & Saud, N., What the COVID-19 lockdown revealed about photochemistry and ozone production in Quito, Ecuador. *Atmospheric Pollution Research*, **12**(1), pp. 124–133, 2020.

[7] Cazorla, M. & Tamayo, E., Atmospheric measurement station at universidad San Francisco de Quito (EMA): Ground-based physical meteorology instrumentation and assessment of initial measurements. *ACI Avances en Ciencias e Ingenierías*, **6**(2), pp. C21–C30, 2014.
[8] Cazorla, M., Ozone structure over the equatorial Andes from balloon-borne observations and zonal connection with two tropical sea level sites. *Journal of Atmospheric Chemistry*, **74**, pp. 377–398, 2017.
[9] Secretaría de Ambiente de Quito, http://www.quitoambiente.gob.ec/ambiente/index.php/descarga-datos-historicos. Accessed on: 1 May 2021.
[10] El Comercio, https://www.elcomercio.com/tendencias/sociedad/restriccion-movilidad-excepcion-ecuador-coronavirus.html. Accessed on: 20 May 2021.
[11] El Comercio, https://www.elcomercio.com/actualidad/quito/coronavirus-movilidad-quito-amarillo.html. Accessed on: 20 May 2021.
[12] El Comercio, https://www.elcomercio.com/actualidad/quito/transporte-municipal-quito-cambio-horario.html. Accessed on: 20 May 2021.
[13] El Comercio, https://www.elcomercio.com/actualidad/quito/vigencia-hoy-circula-vehiculos-quito.html. Accessed on: 20 May 2021.
[14] Kleinman, L.I. et al., Sensitivity of ozone production rate to ozone precursors. *Geophysical Research Letters*, **28**(15), pp. 2903–2906, 2001.