

Evaluation of Aircraft Emissions at Bucharest Henri Coanda Airport

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ABSTRACT

This study presents the influence of aircraft movements on air quality by highlighting the contribution of landings and/or takeoffs at Henri Coanda Airport, Bucharest. An experimental campaign was carried out using a mobile laboratory equipped with reference instruments for the main air pollutants (NO , NO_2 , NO_x , SO_2 , CO , and O_3) and a meteorological station to measure wind speed and direction, air temperature, pressure, and relative humidity at a height of 10 m above the ground. The mobile testing laboratory was located inside the airport near the passenger embarking area, and measurements were carried out for 7 days. Air sampling was carried out at a height of 3.5 m above the ground. Pollutant levels were continuously measured throughout the measurement period, with high-precision equipment and a 10-second interval. The results obtained showed an increase in pollutant concentrations during takeoffs and/or landings, providing an initial assessment of gaseous pollutant levels and hourly distribution. Airport authorities can use this assessment to balance aircraft and passenger movements to minimize human exposure to gaseous pollutants. Furthermore, this study used the Pearson correlation between each pollutant and meteorological parameters to establish the best conditions for passengers to be present on the airport premises. The results showed that wind speed and direction directly influence the distribution of gaseous pollutants, especially during landings and takeoffs.

Keywords-emissions;airport; pollutants; wind; correlation; Romania

I. INTRODUCTION

With the rapid increase in air traffic, aircraft emissions have attracted widespread attention as an important source of air pollution [1]. Aircraft emissions originate from the fuel burned in the aircraft engines. Aircraft gas turbine engines, which like many other vehicle engines, produce nitrogen oxides, hydrocarbons, carbon dioxide, water vapor, sulfur oxides, particulates, and other trace compounds. Carbon monoxide is formed as a result of incomplete combustion of the carbon in fuel. Nitrogen oxides (NO and NO_2) are produced when fuel is burned at high temperatures, as in the combustion process [2]. In [3-10], the mechanisms for gaseous pollutant formations and emissions are described by analyzing the main components: hydrocarbons, carbon dioxide, sulfur, nitrogen oxides, and particulate matter. Most of these studies also evaluated the influence of gaseous pollutants on human and environmental

health. The impact of commercial aviation emissions on air quality has been estimated to be responsible for approximately 16,000 premature deaths each year around the world [11]. In [12], important research questions on aviation-attributable air pollution were highlighted, such as global vs. local impacts, aviation impact in a changing atmosphere, and emission reduction strategies focused on technological changes such as alternative jet fuels [13-16]. In [17], the sources and contributions of submicron particles (PM) were identified at the UK's second-largest airport to provide information on whether and under what circumstances ultrafine particles (UFP) might be correlated with noise exposure and, therefore, might need to be taken into consideration in studies investigating associations between aircraft noise and health outcomes. In [18-19], pollutant gas emissions including NO_x , hydrocarbons (HC), and CO from aircraft during landing and take-off (LTO) cycles were estimated for 2010 at Kayseri Airport, Turkey. In [20],

the impact of aircraft on air quality was investigated, focusing on aviation-attributable PM_{2.5} on scales ranging from local (a few km) to continental (hundreds of km) using the Community Multiscale Air Quality-Advanced Plume Treatment (CMAQ-APT) model for US airports. In [21], ultrafine particles (UFP) were monitored at Heathrow Airport in the autumn of 2017, collecting high-resolution data from NO_x, PM, and black carbon analyzers on site. In [22-23] the impact of the airport on the environment was investigated, due to the proximity of the airport to the historic city of Venice and the fragile ecosystem of the lagoon surrounding the city. In [24], the NO_x emissions from commercial short-haul flights were assessed and quantified based on numerous actual flights, actual emissions, and actual meteorological data. In [25], the impact of Beirut Airport activities on local air quality emissions of NO₂ and VOCs was investigated, including emissions from aircraft LTO operations, ground support equipment, stationary sources, and airside and landside vehicles. This study, which was the first comprehensive emission inventory in the Middle East region, provided a method to assess airport emissions in a country without data. In [26], a systematic review of the impact of commercial aircraft activity on air quality near airports was presented. In [28], an airport-specific green rating framework was presented as a tool to assess the greenery of airport operations based on environmental indicators.

The current study investigated the formation and distribution of gaseous pollutants within the Henri Coanda Airport, Bucharest, focusing on the passenger embarkation area, which is closely related to the measures that are nowadays enforced in Europe called "decarbonizing airports". This study is the first of its kind at that airport, and investigates the causal relationship between meteorological parameters, especially wind speed and direction, and gaseous pollutant concentrations and aircraft movements.

II. MATERIALS AND METHODS

A. Henri Coanda International Airport Issues

The Henri Coanda International Airport is the only one in service for Romania's capital, Bucharest, located 15 km north of the city, as shown in Figure 1, and has an area of 605 hectares.



Fig. 1. Henri Coanda International Airport location. Image from Google Earth. © Airbus SNES/ Airbus, Maxar Technologies.

Figure 2 presents statistics related to the passenger numbers and aircraft movements within the airport [29].

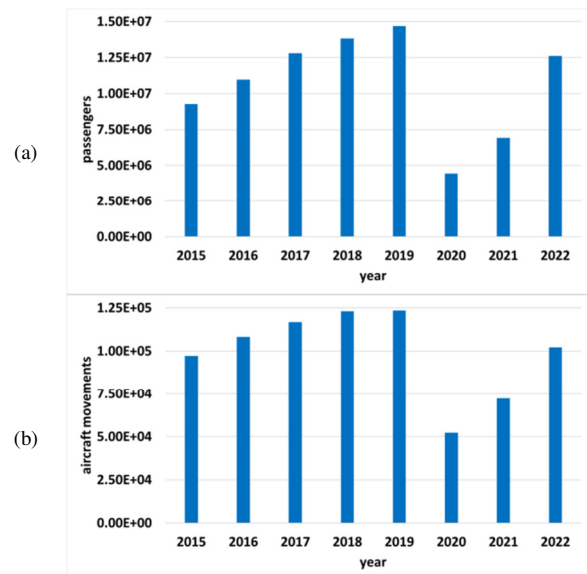


Fig. 2. Henri Coanda International Airport: (a) Passenger traffic and (b) aircraft movements.

Passenger and aircraft movements at Henri Coanda International Airport were constantly increasing until 2019, and now, after a period of low activity due to the SarsCov-2 pandemic, this trend is resuming at a higher rate, but not reaching the 2019 values. The increase in movements between 2016 and 2015 was 11.36% for aircraft and 18.38% for passengers, while the increase in movements between 2021 and 2022 was 41.5% for aircraft and 82.2% for passengers. The constant increase in airport aircraft movements may cause air quality problems. The national measurement and assessment stations are quite far from the airport, and thus their data do not show the reality within its premises. Therefore, no data are available on gaseous pollutants within the airport.

B. Experimental Campaign

Figure 3 shows the monitoring systems for air pollutants and weather for meteorological parameters placed in a mobile laboratory, belonging to the Romanian Research and Development Institute for Gas Turbines COMOTI, Bucharest. The mobile laboratory combined reference instruments for the major air pollutants (HORIBA AP360 series, CO, SO_x, NO_x, and O₃) and a meteorological station to measure wind speed and direction, air temperature, pressure, and relative humidity at 10 m above ground. The mobile testing laboratory was located about 240 m off the runway and Figure 4 shows its location in the airport area. Polluted air sampling was carried out at a height of 3.5 m from the ground. The pollutants were continuously measured, with 10 s intervals, throughout the entire measurement period with high-precision equipment:

- NO, NO₂, and NO_x were measured with a Horiba APNA 360 using chemoluminescence (reference method: SREN 14211:2012).
- SO₂ was measured with Horiba APSA 360, using UV fluorescence (reference method: SREN 14212:2012).

- O₃ was measured with Horiba APOA 360, using UV photometry (reference method: SREN 14625:2012).
- CO was measured with Horiba APMA 360, using nondispersive infrared (NDIR, reference method SREN 14626:2012).



Fig. 3. The monitoring system of air pollutants.



Fig. 4. Location of the mobile laboratory on the runway. Image from Google Earth. © Airbus SNES/ Airbus, Maxar Technologies.

III. RESULTS AND DISCUSSION

The data recorded by the mobile laboratory for 7 days were NO₂, CO, SO₂, and O₃, and their variation versus wind speed and direction was drawn to correlate with each other. The

aircraft types were A320, A319, A318, B737, ATR72, ATR42, and others, including helicopters, small airplanes, military airplanes, etc. "Others" represented 25% of the total aircraft LTOs during the 7-day monitoring period. Day 1 of movement monitoring was Tuesday. Day 7 had the most movements, so the other 6 days are represented as a percentage of it as follows: Day 1: 99.7%, Day 2: 99.7%, Day 3: 96.76%, Day 4: 96.3%, Day 5: 70.83%, and Day 6: 81.94%. Figures 5-11 show the evolution of gaseous pollutants for the 7 days of monitoring and the number of classified aircraft for an assessment of their contribution to overall pollution during landings and take-offs.

For Day 1, the mean measurements were NO₂ = 17.95 µg/m³, CO = 0.24 mg/m³, SO₂ = 1.58 µg/m³, O₃ = 36.30 µg/m³, WS = 5.17 m/s, and WD = 15.86°. As shown in Figure 5, some CO₂, SO₂, and CO-related peaks appear during the first hours of the day due to landing activity and wind speed and direction. Higher concentrations of NO₂, CO, and SO₂ appear between 17:00 and 18:00 due to increased LTOs within that interval. Within 01:00-06:00, there were no take-offs and only one landing, therefore, only one peak was registered.

For Day 2, the mean measurements were NO₂ = 16.30 µg/m³, CO = 0.25 mg/m³, SO₂ = 1 µg/m³, O₃ = 36.46 µg/m³, WS = 5.12 m/s, and WD = 25.54°. As shown in Figure 6, as the wind speed and direction changed, the registered values drastically decreased, even though between 21:00-22:00 there were many take-offs. Between 05:00 and 08:00, wind speed and direction changed, and although there were fewer movements, some peaks were registered.

For Day 3, the mean measurements were NO₂ = 23.43 µg/m³, CO = 0.27 mg/m³, SO₂ = 1.01 µg/m³, O₃ = 19.65 µg/m³, WS = 2.01 m/s, and WD = 143.29°. Figure 7 shows that in the first hours of monitoring, several peaks were registered and along with the change in wind speed and direction, the concentration tendency was increased. Around 08:00, the peaks increased due to the larger movements and settlement of the wind to almost atmospheric calm. Around 13:00, other peaks were registered due to LTOs, but larger peaks appeared during 16:00-17:00 due to the same activity but also the change in wind speed and direction. This day was one of the busiest on the airport in terms of LTOs.

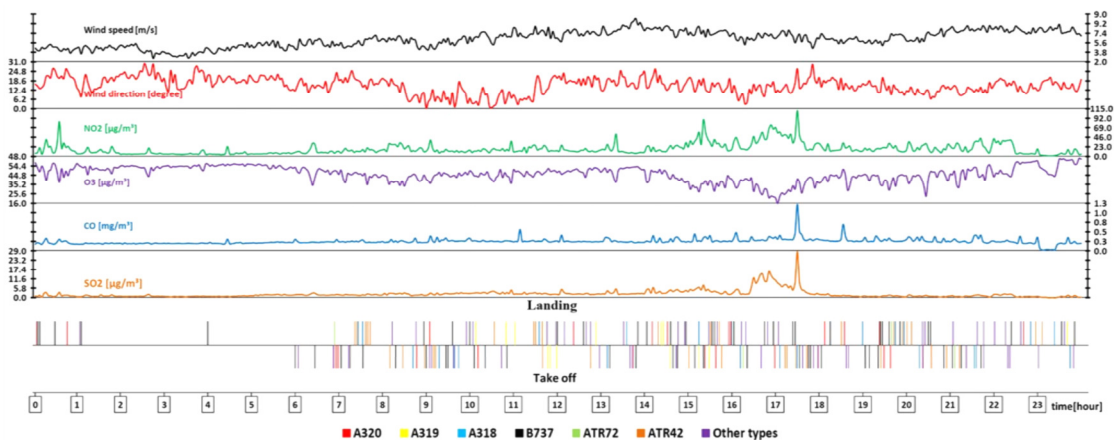


Fig. 5. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 1.

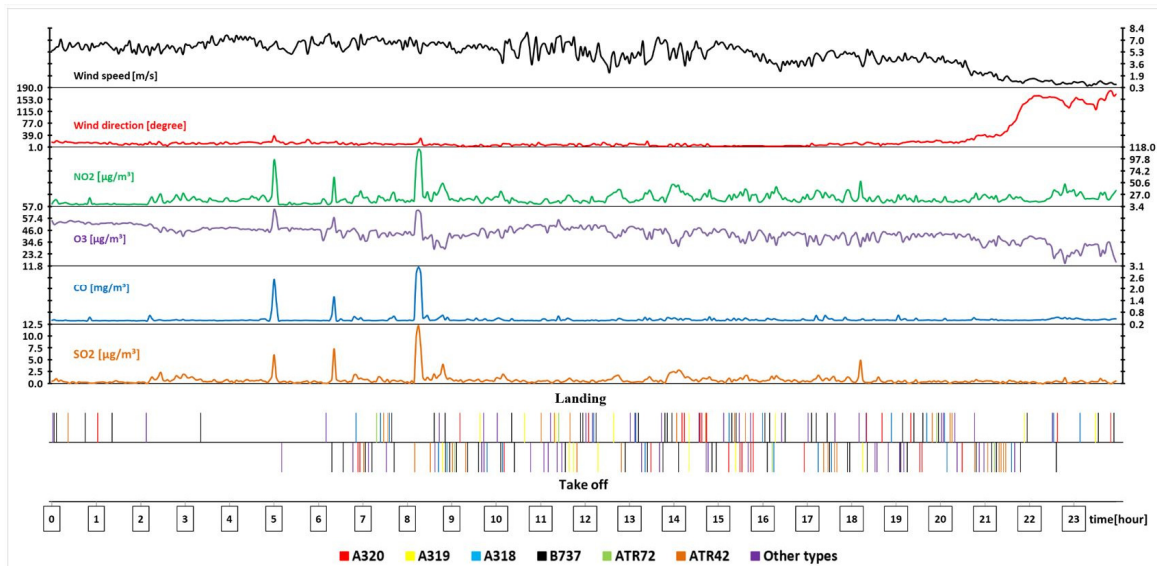


Fig. 6. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 2.

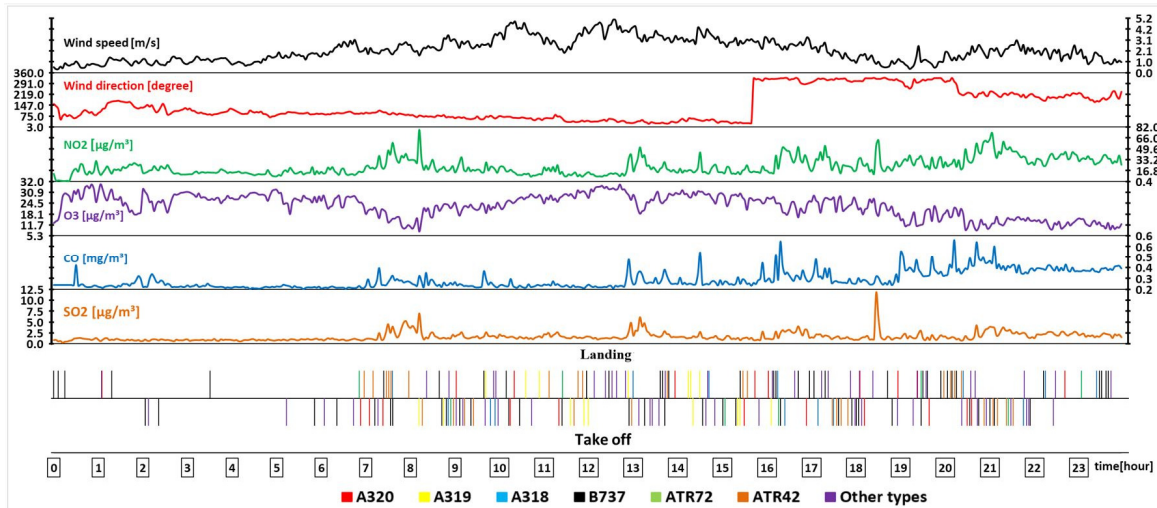


Fig. 7. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 3.

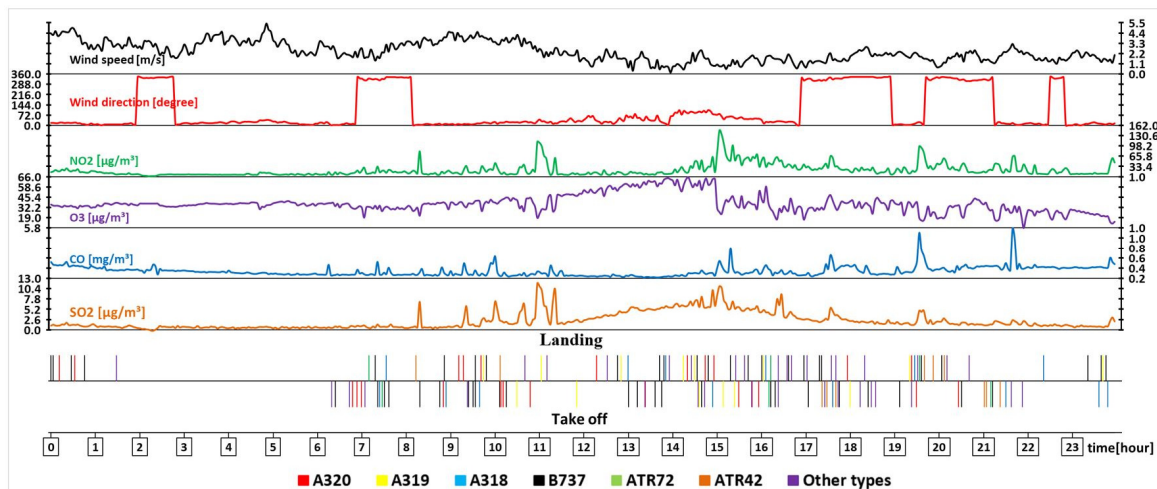


Fig. 8. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 4.

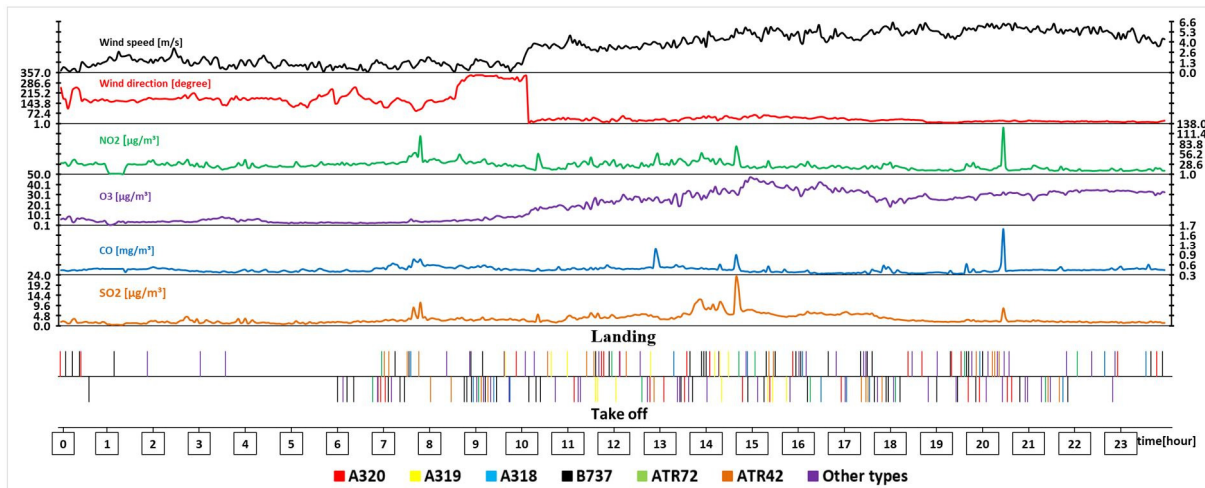


Fig. 9. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 5.

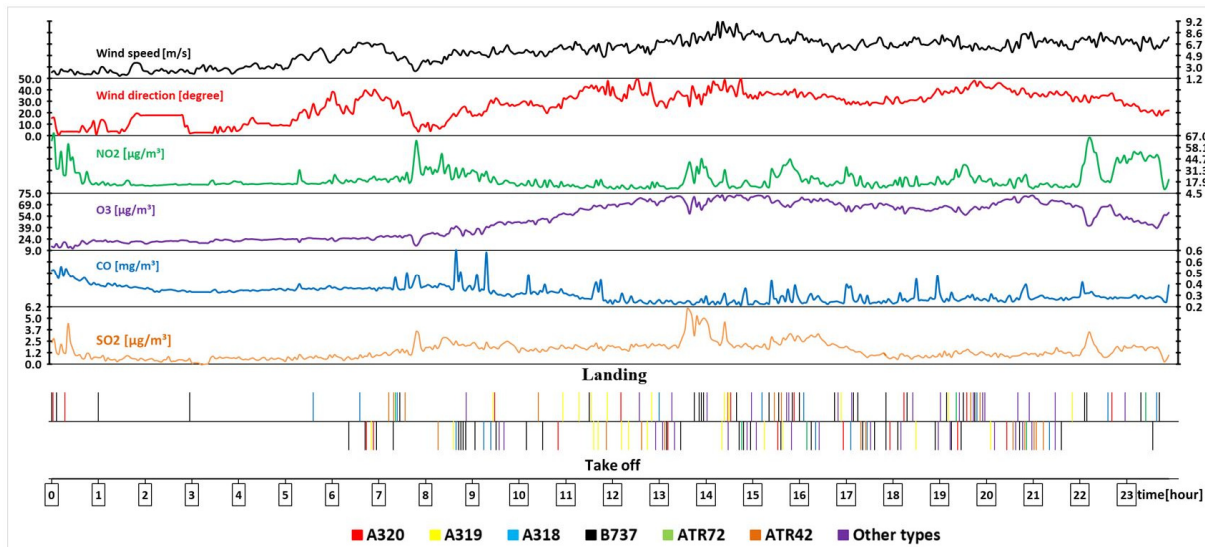


Fig. 10. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 6.

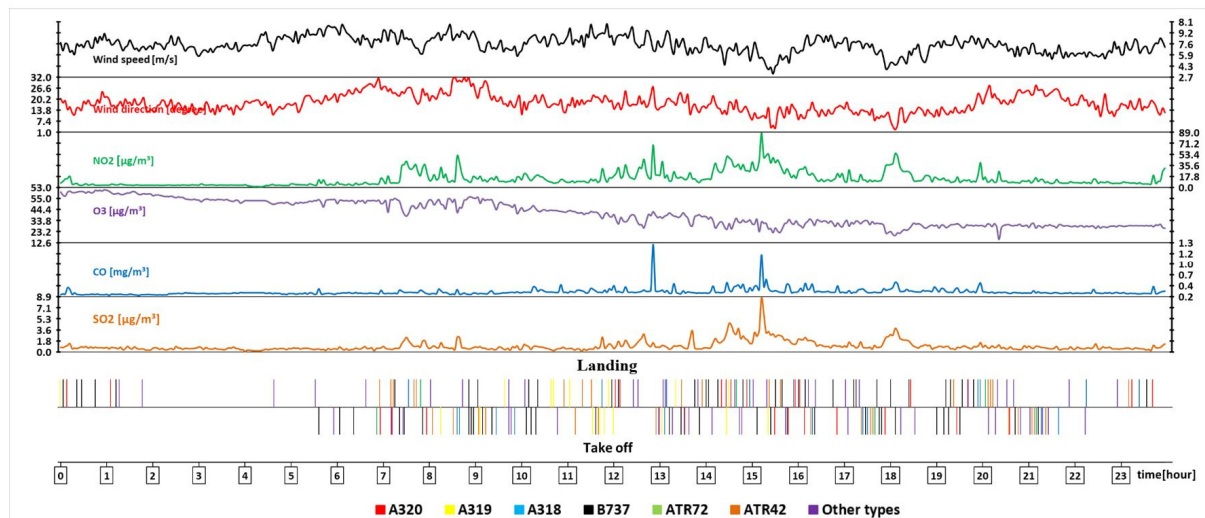


Fig. 11. Evolution of SO₂, CO, O₃, and NO₂ concentrations vs. wind speed for Day 7.

For Day 4, the mean values were $NO_2 = 25.63 \mu g/m^3$, $CO = 0.4 mg/m^3$, $SO_2 = 2.01 \mu g/m^3$, $O_3 = 19.81 \mu g/m^3$, $WS = 3.26 m/s$, and $WD = 97.08^\circ$. Day 4 had the lowest activity, so only a few small peaks were registered during the first hours, as shown in Figure 8. A bundle of peaks was recorded around 11:00 when the wind speed dropped, although the movements were low. Around 15:00, the number of movements increased and the wind speed was at its lowest, so the peaks are well represented.

For Day 5, the mean values were $NO_2 = 22.31 \mu g/m^3$, $CO = 0.28 mg/m^3$, $SO_2 = 1.82 \mu g/m^3$, $O_3 = 34.42 \mu g/m^3$, $WS = 2.55 m/s$, and $WD = 106.38^\circ$. Landings in the first hours had a minimal impact on the pollution values both because there were few and the wind speed and direction spread the pollutants. Around 09:00 a small peak appeared due to the large number of takeoffs but again wind speed and direction played a role in spreading the pollutants. After 10:00, the wind changed direction and its speed dropped. Therefore, peaks appeared and concentrations increased. Between 14:00 and 15:00, peaks appeared due to the constant large number of landing/takeoffs.

For Day 6, the mean measured values were $NO_2 = 15.27 \mu g/m^3$, $CO = 0.23 mg/m^3$, $SO_2 = 0.96 \mu g/m^3$, $O_3 = 44.21 \mu g/m^3$, $WS = 4.83 m/s$, and $WD = 26.73^\circ$. As in the previous days, some peaks appeared during LTOs at midnight, and then, until 07:00, the concentrations did not vary anymore. In the interval 08:00-09:00, due to the relatively many LTOs and changes in wind speed and direction, some peaks appeared. Additionally, high pollutant concentrations appeared after 14:00 and were kept relatively high until 22:00.

For Day 7, the mean values measured were: $NO_2 = 13.79 \mu g/m^3$, $CO = 0.23 mg/m^3$, $SO_2 = 0.4 \mu g/m^3$, $O_3 = 33.67 \mu g/m^3$, $WS = 5.79 m/s$, and $WD = 16.69^\circ$. This day is characterized by the most aircraft movements, but the overall trend was similar to the previous 6 days. Thus, some peaks appeared during LTOs at midnight, and then, until 07:00, the concentrations did not vary anymore. In the interval 08:00-09:00, some peaks appeared due to the relatively many LTOs and the changes in wind speed and direction. In addition, high pollutant concentrations appeared after 14:00 and remained relatively high until 22:00.

Pearson correlation was used to investigate the relationship between the pollutant concentrations and wind speed and direction. The Pearson correlation coefficient is used to measure the strength of a linear association between two variables, where the value $r = 1$ means a perfect positive correlation and the value $r = -1$ means a perfect negative correlation. Table I shows the Pearson correlations between NO_2 , CO , SO_2 , and O_3 concentrations, and wind speed and direction. Table I shows the strong positive correlation between the gaseous pollutant concentrations, except O_3 which shows a negative correlation, and wind speed and direction.

For Day 1, the correlation with wind speed is positive for NO_2 , CO , and SO_2 , but negative for O_3 , while the correlation with wind direction is almost null for NO_2 and SO_2 , positive for CO , and strongly positive for O_3 . For Day 2, the correlation with wind speed was negative for NO_2 , almost null for CO , and

positive for O_3 , while the correlation with wind direction was almost null for CO and SO_2 , positive for NO_2 , and strongly negative for O_3 . For Day 3, the correlation with wind speed is positive for SO_2 and O_3 and almost null for CO and NO_2 , while the correlation with wind direction is strongly positive for NO_2 and CO , strongly negative for O_3 , and almost null for SO_2 .

For Day 4, the correlation with wind speed is negative for NO_2 , almost null for CO , positive for SO_2 , and strongly positive (0.9) for O_3 , while the correlation with wind direction is almost null for CO , strongly positive for NO_2 , strongly negative for SO_2 , and very strongly negative for O_3 . For Day 5, the correlation of wind speed was strongly negative with NO_2 and SO_2 and almost null with CO , while the correlation of wind direction was almost null with NO_2 and CO and weakly negative for SO_2 and O_3 . For Day 6, the correlation of wind speed was almost null with NO_2 , strongly positive with SO_2 and O_3 , and strongly negative with CO , while the correlation of wind direction was almost null with NO_2 and O_3 , negative with SO_2 , and positive with CO . For Day 7, the correlation of wind speed was negative with NO_2 , SO_2 , and CO and strongly positive with O_3 , while the correlation of wind direction was strongly positive with O_3 and negative with NO_2 , CO , and SO_2 .

TABLE I. CORRELATIONS OF NO_2 , CO , SO_2 , AND O_3 WITH WIND SPEED AND WIND DIRECTION

	Day 1				Day 2			
	NO_2	CO	SO_2	O_3	NO_2	CO	SO_2	O_3
NO_2	1				1			
CO	0.63	1			0.78	1		
SO_2	0.76	0.60	1		0.83	0.84	1	
O_3	-0.75	-0.38	-0.59	1	-0.26	0.21	0.11	1
WS	0.26	0.15	0.22	-0.21	-0.15	0.03	0.12	0.66
WD	-0.10	-0.15	-0.07	0.27	0.13	-0.01	-0.05	-0.31
	Day 3				Day 4			
	NO_2	CO	SO_2	O_3	NO_2	CO	SO_2	O_3
NO_2	1				1			
CO	0.73	1			0.72	1		
SO_2	0.73	0.42	1		0.48	0.28	1	
O_3	-0.76	-0.58	-0.47	1	-0.32	-0.05	0.44	1
WS	-0.09	-0.04	0.18	0.27	-0.35	-0.08	0.31	0.90
WD	0.40	0.48	0.07	-0.42	0.22	-0.02	-0.29	-0.73
	Day 5				Day 6			
	NO_2	CO	SO_2	O_3	NO_2	CO	SO_2	O_3
NO_2	1				1			
CO	0.38	1			0.32	1		
SO_2	0.70	-0.03	1		0.45	-0.17	1	
O_3	-0.26	-0.41	0.36	1	-0.16	-0.44	0.14	1
WS	-0.32	0.02	-0.47	-0.14	0.02	-0.61	0.45	0.42
WD	0.03	0.05	-0.12	-0.16	-0.05	0.17	-0.21	0.09
	Day 7							
	NO_2	CO	SO_2	O_3				
NO_2	1							
CO	0.65	1						
SO_2	0.84	0.55	1					
O_3	-0.47	-0.30	-0.40	1				
WS	-0.31	-0.18	-0.36	0.43				
WD	-0.17	-0.15	-0.30	0.33				

Tables II and III show the percentages for each aircraft type for all days of monitoring for takeoffs and landings, respectively.

TABLE II. TAKEOFF AIRCRAFT TYPE PERCENTAGES

Day	Takeoff Aircraft types						
	A320	A319	A318	B737	ATR72	ATR42	Other
1	12.50	5.77	11.54	28.85	1.92	16.35	23.08
2	12.15	6.54	9.35	28.97	2.80	15.89	24.30
3	10.38	8.49	6.60	30.19	3.77	14.15	26.42
4	13.59	6.80	6.80	28.16	5.83	10.68	28.16
5	16.88	7.79	10.39	31.17	3.90	7.79	22.08
6	10.00	13.33	7.78	32.22	3.33	12.22	21.11
7	11.32	8.49	9.43	30.19	2.83	15.09	22.64

TABLE III. LANDING AIRCRAFT TYPE PERCENTAGES

Day	Landing Aircraft types						
	A320	A319	A318	B737	ATR72	ATR42	Other
1	10.91	6.36	10.00	28.18	1.82	17.27	25.45
2	13.08	7.48	11.21	28.97	2.80	12.15	24.30
3	9.71	6.80	6.80	32.04	3.88	15.53	25.24
4	14.29	6.67	6.67	26.67	5.71	13.33	28.16
5	14.47	10.53	7.89	32.89	3.95	6.58	23.68
6	10.34	12.64	10.34	31.03	3.45	10.34	21.84
7	12.73	7.27	8.18	29.09	2.73	15.45	24.55

IV. CONCLUSIONS

- The peaks for pollutant concentrations appeared during the period of a high number of LTOs, within a relatively short time, and with a direct correlation between the number of movements and concentration values.
- It is very difficult to determine a direct correlation between aircraft type and pollutant concentrations because of the number of different aircraft types that land or take off in a short time.
- Wind speed and direction directly influence pollutant concentration values since wind is the most important agent involved in pollutants' dispersion.
- Wind speed influences pollutant concentrations and wind direction influences their movement.
- Pearson's correlation is a very useful tool in assessing the direct correlation between meteorological parameters and gaseous pollutant concentrations.
- Lower pollutant concentration values were recorded on days with high wind speed (days, 1, 2, 6, and 7), while higher pollutant concentrations were recorded on days 3, 4, and 5 when the wind speed was lower.
- On days when the wind direction was toward the mobile lab, the pollutant concentrations were higher (Days 3, 4, and 5).
- On Days 1, 2, 6, and 7, when the wind direction was away from the mobile laboratory, the pollutant concentration values were lower.

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