Tucumán, Argentina, August 29, 2024.

CREATION OF THE FIRST AIR QUALITY MONITORING NETWORK IN THE PROVINCE OF TUCUMÁN

GRANT NUMBER: UC/FF/2023/005

FINAL REPORT

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1. INTRODUCTION

1.1 Future Fund

The Under2 Future Fund Coalition has existed since 2017 and was designed to empower and enable developing regions, members of the Under2 Coalition, to accelerate their transition towards low-carbon economies, in alignment with the Paris Agreement and the Under2 Memorandum of Understanding (MOU). The Future Fund allocates strategic funding once a year to support climate activities and to enhance participation in the global platforms of the Under2 Coalition (https://www.theclimategroup.org/future-fund).

The government of the Province of Tucumán joined the Under2 Coalition in 2018 and has since been involved in both individual and joint actions with the private agro-industrial sector to limit the emission of greenhouse gases and particulate matter, which are harmful to the health of living beings and the environment across the province and the region.

In this context, starting in 2021, the government began working on the Creation of the First Air Quality Monitoring Network in the Province of Tucumán, a project submitted to the Future Fund, which received Grant N°: UC/FF/2023/005. Below is the final report of the work carried out.

1.2 State of Air Pollution and its Monitoring

Air pollution is estimated to kill seven million people worldwide each year. Data from the World Health Organization (WHO) shows that 9 out of 10 people breathe polluted air, with developing countries being the most exposed. Sources of air pollution can be attributed to various factors, including industrial activity, the burning of fossil fuels associated with motor vehicles, and the open burning of biomass linked to agricultural activities (such as land preparation for agricultural use and the disposal of crop residues). These sources promote the formation and emission of a wide range of gases into the atmosphere, including carbon dioxide (CO_2), a greenhouse gas (GHG); nitrogen oxides (NO_x = NO + NO_2), precursors of photochemical smog; ozone (O_3); sulfide dioxide (SO_2), which causes acid rain; volatile organic compounds (VOCs); and ultrafine particulate matter (PM) (up to 10 micrometers in diameter). Particulate matter (PM) is strongly associated with an increase in the incidence of preterm births, low birth weight, cognitive problems in children and the elderly, and respiratory and cardiovascular diseases in the general population. It is estimated that more than 4.2 million deaths worldwide were caused by air pollution from

fine particles (PM2.5) in 2015, resulting in more premature deaths than malaria and HIV. Additionally, recent studies suggest a causal relationship between exposure to high concentrations of particulate matter in the air and an increased incidence of COVID-19 cases. Atmospheric pollution not only poses a threat to human health but also to the environment and the economy, as it reduces crop yields and affects precipitation and temperature patterns.

Although the sources of pollution and their contributions are diverse, biomass burning (whether accidental or intentional) is expected to contribute significantly not only in the region to be evaluated by this study but also in many other regions of the country. Despite strict laws to control and regulate the use of fire in most Latin American countries, more than one million hectares were burned in Argentina alone in 2022. Of these fires, 95% were caused by human activity, according to a recent report from the National Fire Management Service. The central and north-western regions of our country were the most affected, primarily due to intense agricultural activity and climatic factors such as lack of rainfall, high temperatures, and strong winds.

Within this region, the Province of Tucumán represents a perfect example: Tucumán is historically the most affected province each year by the open burning of biomass, related, among other things, to sugarcane cultivation. This situation can be easily observed using tools such as remote sensing, where it is evident that active fires during the sugarcane harvest season closely correlate with the cultivated area of sugarcane in Tucumán (**Figs. 1A and 1B**).

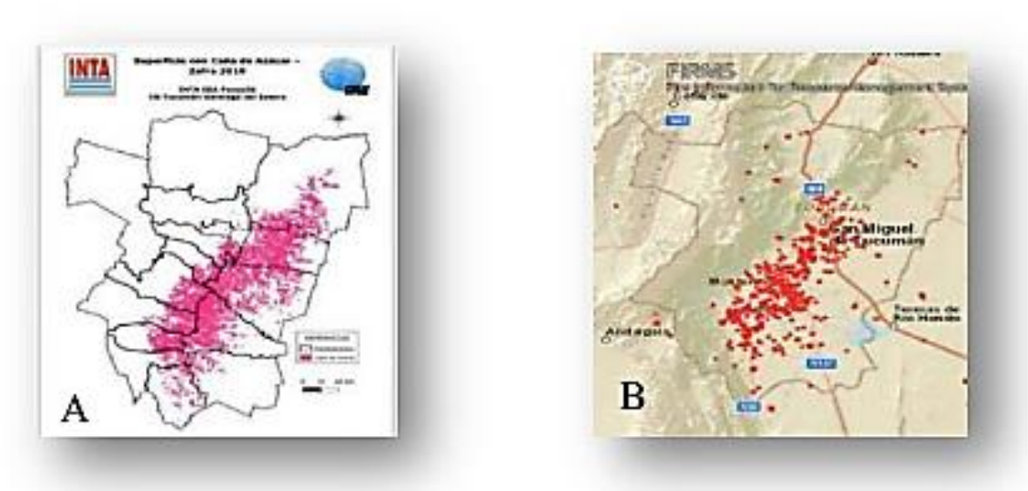

Fig. 1 A - Area with sugarcane crops in Tucumán in 2019; B - Active fires on July 19, 2020.

Although the damage to local fauna and flora is more evident, the effects on local air pollution and the regional transport of pollutants generated by these phenomena cannot be assessed without the use of ground-based monitoring systems.

Monitoring exposure to atmospheric pollution is a crucial component of the political debate. In this regard, over the past 40-50 years, more developed economies have established robust and costly air quality monitoring systems (**Fig. 2**).

Fig. 2 Distribution of air monitoring stations recorded worldwide as of March 2019.

However, this technology is not widely distributed, and many developing countries lack such monitoring stations. This results in a lack of information that could assist decision-makers in developing evidence-based policies to reduce exposure and mitigate the impact of air pollution on the environment and human health.

Therefore, in the Province of Tucumán, the importance of conducting a comprehensive and hybrid study of atmospheric pollutants affecting the region was proposed.

1.3 First Hybrid Air Monitoring Network in Tucumán

This project aims to create the first hybrid air quality monitoring network in the Province of Tucumán, which will initially allow for the evaluation of the current situation and, through data generation, the development of public policies based on scientific evidence to effectively control sources of air pollutant emissions.

Objectives:

A) Implement the first hybrid monitoring network in the Province of Tucumán, which includes the creation of the first Federal Reference Laboratory with US-EPA Monitors (NO_x, SO_2, and O_3) in Argentina, complemented by a network of thirty Integrated Environmental Sensor Modules - MISA (PM10, PM2.5, PM1, ambient temperature, relative humidity, and CO_2), installed throughout the entire Province of Tucumán.

B) Continuously and remotely monitor, through an open-access platform, the distribution of the parameters measured by the MISA modules.

C) Combined and assisted rationalization of air pollutant results obtained from the First Federal Reference Laboratory and the MISA modules, by integrating environmental and climatological variables through big data management and specific programming languages, in order to generate reports and publications, including future community outreach with high-quality processed data.

2. IMPLEMENTATION

2.1 Methodology and Approach

As part of the ***Breathe2Change Networking Initiative*** (breathe2change.org), the Subsecretariat of the Environment of Tucumán has been collaborating with the Atmospheric Studies Laboratory (LEA) of the Northwest Argentine Chemistry Institute

(INQUINOA)—a joint institute under the National Scientific and Technical Research Council (CONICET) and the National University of Tucumán—along with the Breathe2Change Foundation and Fundación León, which recently joined as a co-participant.

This interinstitutional team began working in 2021 on the implementation of the aforementioned air quality monitoring network in Tucumán. In the first stage, the team focused on designing the network, which included identifying twenty strategic locations within the province to install the MISA modules, and creating a geo-referenced map (**Fig. 3**).

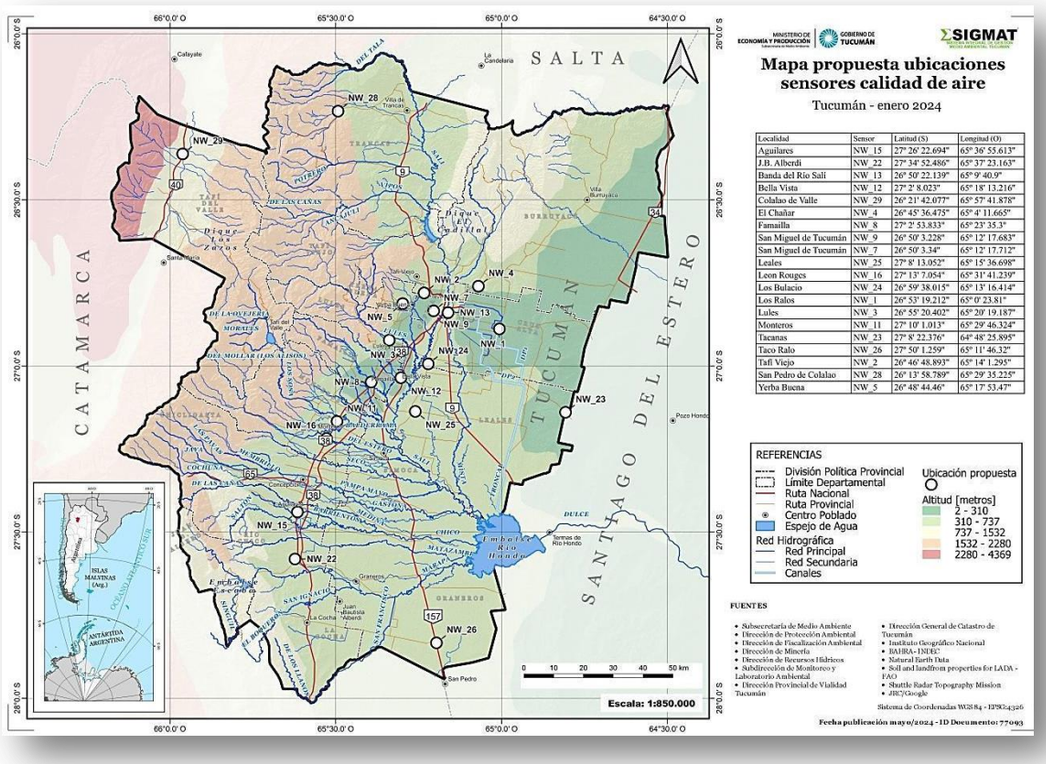

Fig. 3 Network of MISA sensor modules in the Province of Tucumán.

These sensors were initially installed at the LEA to verify their correct functioning under local climatic conditions during a trial period. Simultaneously, the project team conducted outreach to municipal and communal institutions, where the MISA modules were later installed after successfully passing the trial period (**Fig. 4**).

Fig. 4 Installation of MISA modules at various sites in the Province of Tucumán.

In a second stage, the implementation of the First Federal Reference Laboratory in Argentina was carried out with three US-EPA gas monitors and one particulate matter monitor (GRIMM) at the Atmospheric Studies Laboratory-INQUINOA (**Fig. 5**).

Fig. 5 First Federal Reference Laboratory with US-EPA monitors in Argentina at the Atmospheric Studies Laboratory of Tucumán (LEA - INQUINOA).

A comprehensive assessment of the MISA modules installed across the territory revealed several operational issues, caused by:

- Data transmission problems due to changes in Wi-Fi passwords.
- The need for firmware updates in the sensor modules.
- Anomalous data caused by sensor failures, issues with the circuit board, excess dust, insects, etc.

In the field, a general cleaning was performed on some sensors, the Wi-Fi password was checked, and the firmware was updated. Sensors that continued to produce anomalous data were removed from their locations and taken to the LEA for maintenance, repairs, and replacement of the optical sensor and/or circuit board (**Fig. 6**).

Fig. 6 Maintenance of the MISA modules at the LEA.

Before being relocated to the field, the MISA modules are calibrated and their correct functioning is verified against the GRIMM Particulate Matter Federal Reference equipment installed at the LEA (**Fig. 7**).

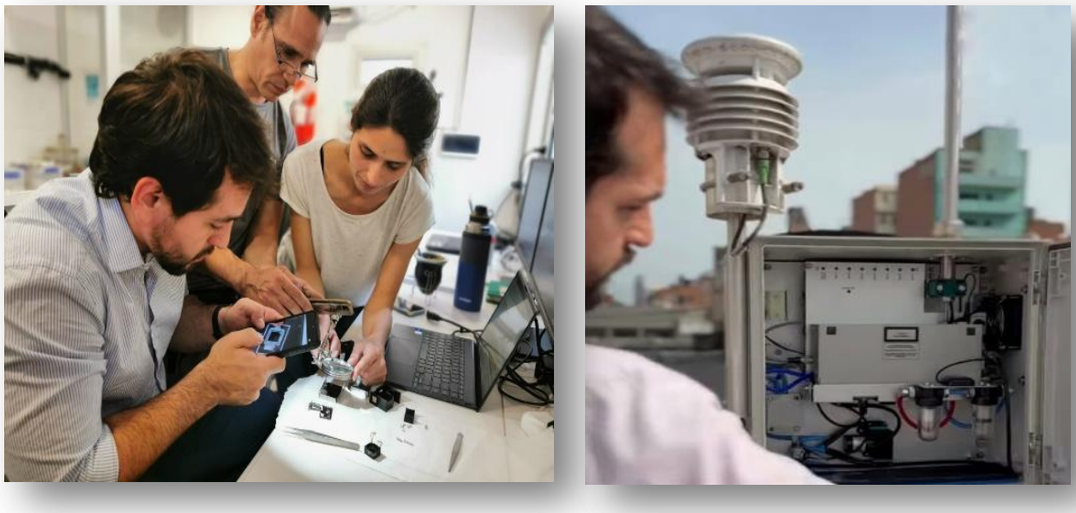

Fig. 7 Sensor adjustments (left) and the GRIMM equipment (right).

The research team is evaluating the results from the 2022-2023 period with the aim of selecting potential strategic sites to incorporate into the existing network, which is planned to include a total of 30 continuous emission sensors across the entire province. With the support of the **Future Fund**, Neuer weg Technologies (https://neuerweg.tech/), a company specialized in atmospheric chemistry was hired to help maintain the current sensor module network. The company also ensures the provision of new modules until the projected 30 MISA sensors are completed. Additionally, it guarantees their continuous operation, calibration, and real-time transmission of air quality data to an open-access digital platform. The company is also working on new developments in the digital platform to improve data reception from the field.

The US-EPA gas monitors (NO_x, SO_2, and O_3) installed at the LEA transmit data every thirty seconds to a computer, where they are stored in files by device, generating a baseline that enters big data programs through a datalogger based on a Linux server. The FTP (File Transfer Protocol) functionality was configured on the server to access the file structure where the data is stored. This setup allows files to be downloaded from anywhere in the world with internet access, using a specific user account and password. All of this facilitates the cross-platform analysis of information, speeding up data processing. The grant provided by the **Future Fund** will enable the purchase of calibration gas tubes, as well as essential supplies (filters, silica, lamps, etc.) to ensure the continuous operation of these devices.

2.2 Key Stakeholders in Project Management

The progress of this project was made possible by the formation of an interdisciplinary and interinstitutional team, involving representatives from various areas and sectors, including political, scientific, and community stakeholders. To achieve this, the Subsecretariat of the Environment of the Government of Tucumán coordinated efforts with the Atmospheric Studies Laboratory (LEA) of the Northwest Argentine Chemistry Institute (INQUINOA) — a joint institute under the National Scientific and Technical Research Council (CONICET) and the National University of Tucumán (UNT) — along with the Breathe2Change Foundation and Fundación León, to carry out this challenging project.

2.3 Challenges

The results obtained thus far, and those expected in the future, are anticipated to serve as tools for establishing a baseline for research into the main causes of air pollution in Tucumán. These findings will also support the development of laws and public policies aimed at mitigating the effects of pollution on environmental quality and improving the quality of life for the community.

2.4 Achievements

Thanks to the creation of the first Air Quality Monitoring Network in Tucumán, several lines of research have been initiated. Some of them are listed below:

- Analysis of various air quality indicators for the first time in the Province of Tucumán.
- Study of the spatial-temporal dispersion of pollutants based on point measurements at different monitoring stations.
- Calibration of satellite products using measurements from the GRIMM Federal Reference Particulate Matter Monitor as a reference.
- Impact of air quality on ocular and respiratory diseases in children aged 7 to 11 years.
- Comparison of PM2.5 measurements from MISA modules with a reference technique, such as gravimetric methods, using low and high-flow pumps in the provincial capital.
- Chemical and morphological characterization of particulate matter.
- Biological effect tests of particulate matter on rats.
- Air quality and clear sky conditions: Study of atmospheric pollution associated with astronomical observations.
- Study on the advantages of MISA modules for the development of an early fire detection sensor network.

3. CONCLUSIONS

3.1 Results

This section includes preliminary results. A greater amount of data, analysis, and research is still required to obtain a clear understanding of the situation in the province. Up to this point, and based on some of the results obtained, processed, and analysed from 2023, undergraduate and graduate students, as well as researchers from our team, are working on theses and publications. This report includes images and conclusions that reflect their findings.

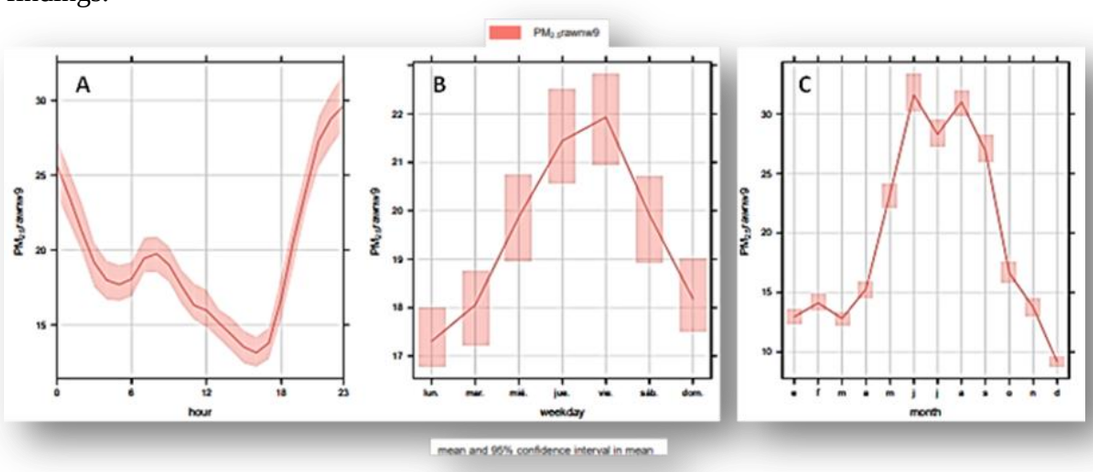

Fig. 8 Temporal variability of PM2.5 concentration in San Miguel de Tucumán (capital of the province). A: Daily. B: Weekly. C: Monthly.

The graphs in **Figs. 8A-C**, provided by LEA thesis student Kathrin Huber (a member of the research team and an Environmental Engineering student, in her thesis "Analysis of Air Quality Indicators in the Province of Tucumán"), were developed using the R program, based on the 2023 PM2.5 level readings measured at the MISA, installed in the city of San Miguel de Tucumán, the capital of the Province of Tucumán. **Figs. 8A-C** show the daily, weekly, and monthly variability, respectively, of PM2.5 concentration. In the daily variation graph (**Fig. 8A**) the peaks of high particulate matter concentration coincide with the apparent increase in vehicular movement, which occurs in the morning and late afternoon/evening. In the case of weekly variation (**Fig. 8B**), the highest concentrations throughout the year occur on Thursdays and Fridays. The causes for these results have not yet been identified, and this is one of the lines of research to be pursued. Meanwhile, on a monthly basis (**Fig. 8C**), there is a notable increase in PM2.5 concentration during the driest months (May to September), which coincides with the period of peak industrial activity in the province. The measured levels even exceeded the WHO's recommended annual average concentrations (10 µg/m³).

The images in **Fig. 9**, provided by Mag. Facundo Reynoso Posse (a member of the research team and PhD in Geomatics and Spatial Systems), were generated through spatial distribution predictions of PM2.5 using the krigging method, taking quarterly averages for eleven fixed monitoring points. In the first quarter (**Fig. 9A**), low PM2.5 concentrations are observed, coinciding with the humid months, low industrial activity, and few fire outbreaks in the province.

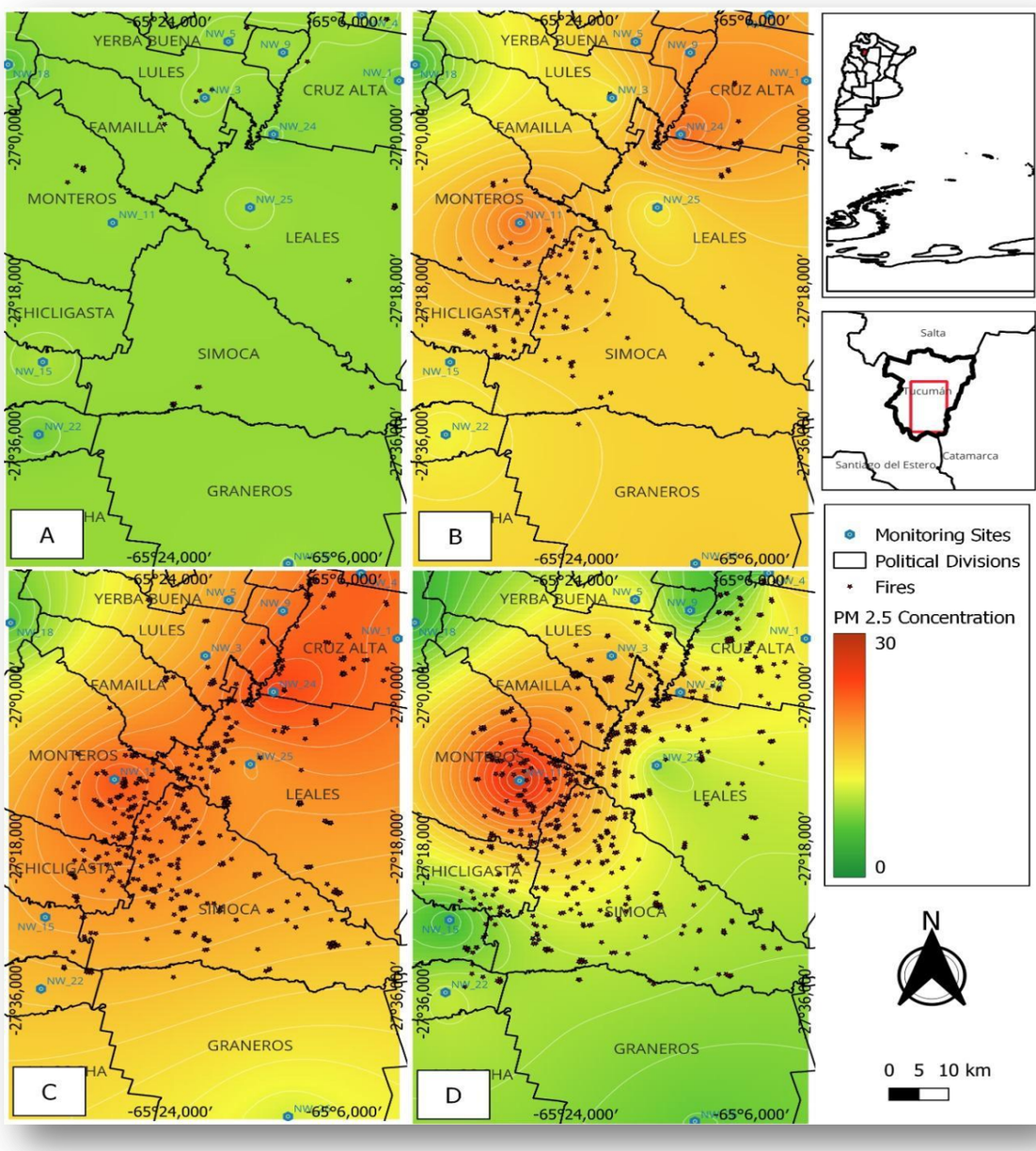

Fig. 9 Spatial distribution predictions of PM2.5. A: January to March. B: April to June. C: July to September. D: October to December. The locations of the MISA stations (light blue circles) and fire hotspots (black dots) are indicated.

For the second quarter of the year (**Fig. 9B**), as the sugar-alcohol and citrus industries begin their activities, drought intensifies, and fire hotspots increase, there is a notable rise in PM2.5 concentration in the air across the entire province, except in the Tafí del Valle area (northwest sector), where industrial activity is nonexistent, and the geomorphological/climatic conditions differ from the rest of the province. In our research, this area is considered the "zero" for PM2.5 concentration. In the third quarter of the year (**Fig. 9C**), there is a significant increase in particulate matter, similar to shown in **Fig. 8C**, which could be associated with industrial activity reaching its peak between July and September, while dry conditions still prevail, accompanied by occasional Zonda winds (strong, warm, and dry winds), which in turn exacerbate the fire hotspots. In contrast, in the "zero" zone of Tafí del Valle, even when conditions are dry, PM2.5 concentrations remain low. For the last quarter of the year (**Fig. 9D**), with the decrease in industrial activity (end of the harvest season), the wet hydrological period begins, bringing rains that significantly lower PM2.5 concentrations across most of the province, except in the central zone, where

it is evident that the precipitation is still insufficient to mitigate the consequences of the remaining active fires.

The preliminary processing and analysis of the measurements from the US-EPA monitors, installed at LEA, yielded interesting results. The graphs in **Fig. 10** reflect the temporal variability of ozone, carbon monoxide, and nitrogen dioxide concentrations, expressed in ppb, starting from May.

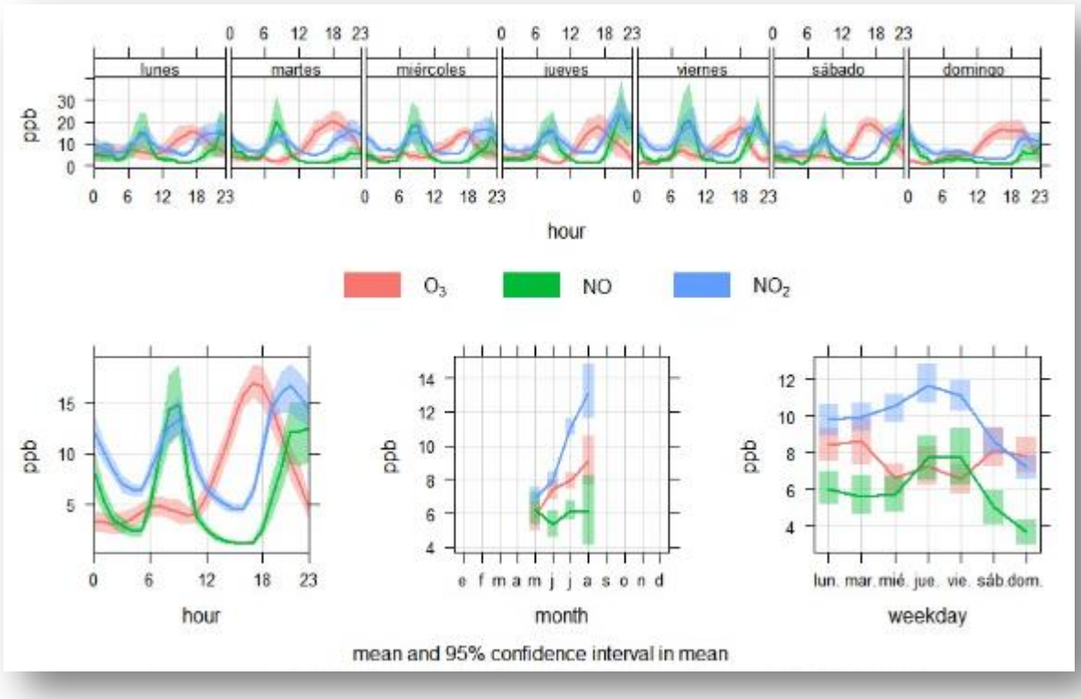

Fig. 10 Temporal variability of NO_2, NO, and O_3 concentrations.

The concentrations of NO, NO_2, and ozone exhibit expected variation patterns within an urban area with a significant contribution from vehicular traffic (**Fig. 10**). During daylight hours, peaks are observed in the morning and late afternoon/evening, coinciding with the PM2.5 peaks (**Fig. 8A**), suggesting that the main source of these air pollutants was vehicular traffic. As expected, ozone reaches its peak concentration in the afternoon due to the effect of solar radiation. To date, there has been an increase in the monthly average of each gas from May to August, likely due to the lack of rain, increased industrial activity, and biomass burning. Weekly, an increase in NO_x is seen on Thursdays and Fridays, while O_3 decreases on those days (**Fig. 10**). This behaviour will continue to be investigated.

3.2 Final considerations and next steps

In the Province of Tucumán, air quality is significantly compromised due to the emission of gaseous pollutants and fine particles during the dry season and during the period of higher incidence of fires, both controlled and accidental. This phenomenon has been identified as one of the main causes of pollution in the region, representing a considerable risk to public health.

Data collected during the air quality monitoring project show that the peaks in pollutant concentrations coincide with the winter season, a period in which meteorological conditions, such as the low altitude of the mixing layer and thermal inversion, favour the accumulation of pollutants in the atmosphere. This not only increases the population's exposure to dangerous levels of particulate matter and other pollutants, but also exacerbates pre-existing respiratory symptoms, such as asthma, chronic bronchitis and other acute and chronic respiratory diseases.

Given these findings, it is imperative to address the problem in a comprehensive manner, connecting the areas of public health and environment to better understand the magnitude of respiratory conditions and other pathologies related to air pollution in Tucumán. A logical next step would be to conduct an epidemiological analysis correlating exposure to high levels of air pollutants during winter peaks with increased morbidity and mortality rates due to respiratory diseases in the local population. It is also essential to extend this analysis to a regional level, to determine whether the effects observed in Tucumán are representative of a broader phenomenon affecting other areas with similar climatic and environmental conditions. This multidisciplinary approach will allow not only a better understanding of the problem, but also the identification of vulnerable populations and the planning of more effective intervention strategies.

The growing evidence that the number of fires globally is increasing, with serious consequences for both public health and climate change, underscores the urgent need to implement mitigation strategies. Open burning of biomass, including forest and agricultural fires, has become the main source of global air pollution and is responsible for the emission of large amounts of greenhouse gases (GHGs), which further aggravate the problem of climate change. To address this crisis, it is essential to develop and implement programs to raise public awareness of the risks of fires and biomass burning, both for public health and the environment. In addition, early fire warning systems should be established that use advanced monitoring and forecasting technologies to rapidly detect fire outbreaks and prevent their spread. Institutional strengthening of fire and civil defense agencies is equally crucial, ensuring that they have the necessary resources to respond effectively to fires and minimize their impacts. This combination of public awareness, institutional preparedness and advanced technology will be key to mitigating the risks associated with fires and protecting public health and the environment at the local, regional and global levels.

In view of the above, the following lines of work will be considered:

A- Development of an Integrated Health and Environment Program: Create a program that combines air quality studies with epidemiological analyses to assess the impact of fire pollution on public health, with a focus on protecting vulnerable populations during winter peaks.

B- Implementation of Early Warning Systems and Institutional Strengthening: Establish advanced early warning systems to detect and respond quickly to fires, along with strengthening local agencies such as fire-fighters and civil defense to improve their response capacity.

C- Continuous Environmental Awareness and Education: Develop environmental awareness and education campaigns aimed at the population, focusing on the risks of biomass burning and fires, highlighting the importance of prevention to protect health and the environment.

The success of these recommendations depends to a large extent on continuing interdisciplinary work and inter-institutional linkages, such as the one fostered by the ***Breathe2Change Networking Initiative*** since 2021, between academic, governmental and civil society entities in the Province of Tucumán. In addition, it is essential to continue to rely on the ongoing support of international programs, such as The Climate Group's Under2 and the Bentley Foundation, which can provide the resources, expertise and visibility needed to implement these strategies effectively and sustainably.

4. APPENDIX

The real-time air quality data platform that is operational today can be accessed through:

https://breathe2change.org/