SPATIAL-TEMPORAL ANALYSIS OF NO_2 IN THE METROPOLITAN REGION OF SÃO PAULO

ANÁLISE ESPAÇO-TEMPORAL DE NO_2 NA REGIÃO METROPOLITANA DE SÃO PAULO

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Abstract: Nowadays, several methods of monitoring air pollutants exist, however few still allow a large spatial and temporal coverage. Sentinel-5P is a satellite dedicated to atmospheric monitoring with high spatial and temporal resolutions, offering a large data of miscellaneous chemical species. Nitrogen oxides (NO and NO_2), emitted by anthropogenic activities into the atmosphere - in large urban centers their main emitting source is vehicles - need particular attention, in addition to being primary pollutants, they are precursors for formation of other chemical species due to photochemical reactions, mainly tropospheric ozone. These photochemical interactions of NO_x stimulate to reduce its lifetime in the atmosphere. Furthermore, these pollutants are used as air quality indexes. The Metropolitan Region of São Paulo (MRSP) has more than 30 cities, being an important economic center for the state of São Paulo, Brazil. The MRSP has a vehicular circulation mesh with a high presence of light and heavy vehicles, besides industries and bears a high population density. Such factors make this region a favorable area for a satellite study given its complexity. Thus, the present work uses Sentinel-5P NO_2 L2 data in order to analyze the evolution of concentrations throughout the year of 2019.

Keywords: Remote sensing. Nitrogen dioxide. Air pollution.

Resumo: Atualmente, existem vários métodos de monitoramento de poluentes atmosféricos, porém poucos permitem uma grande cobertura espacial e temporal. O Sentinel-5P é um satélite dedicado ao monitoramento atmosférico com alta resolução espacial-temporal, oferecendo um grande volume de dados de diversas espécies químicas. Os óxidos de nitrogênio (NO e NO_2), emitidos por atividades antrópicas na atmosfera - nos grandes centros urbanos sua principal fonte emissora são os veículos - merecem atenção especial, além de serem poluentes primários, são precursores da formação de outras espécies químicas devido à reações fotoquímicas, principalmente o ozônio troposférico. Essas interações fotoquímicas de NO_x estimulam a redução de seu tempo de vida na atmosfera. Além disso, esses poluentes são usados como índices de qualidade do ar. A Região Metropolitana de São Paulo (RMSP) possui mais de 30 cidades, sendo um importante polo econômico do estado de São Paulo. A RMSP possui rodovias com grande circulação de veículos leves e pesados, indústrias e também alta densidade populacional. Tais fatores tornam esta região uma área favorável para um estudo de satélite. Assim, o presente trabalho utiliza dados do Sentinel-5P NO_2 L2 para analisar a evolução das concentrações ao longo de 2019.

Palavras-chave: Sensoriamento remoto. Dióxido de nitrogênio. Poluição do ar.

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1 INTRODUCTION

The advent of industrialization and urbanization, the presence of undesirable chemical species in the atmosphere has become common,due to anthropic emissions, such species are called pollutants. The increase in concentrations of these in the atmosphere has brought several consequences for the planet, such as: the degradation of air quality and health problems for the population (WALLACE; HOBBS, 2006).

The consequences of the problem of excessive air pollution have been one of the most discussed topics over the last decade. Taking into account aspects that have directly influenced the daily life of the world population, such as: heat waves, changes in the hydrological cycle among others.

As well as the large metropolises around the world, the Metropolitan Region of São Paulo (MRSP) suffers from air quality problems. The biggest polluting sources in this metropolitan region are the vehicles and the industries, however, it is emphasized that the majority emitter are the vehicles (CETESB, 2020a; CETESB, 2021a).

NO_x is emitted through combustion processes, so both industrial processes and combustion of fossil fuels in vehicles provides the emission of this primary pollutant (EPA, 2021).

In addition, NO_x are precursors of other pollutants, mainly Ozone (O_3), making it essential to monitor these nitrogen compounds (CETESB, 2021a).

The agency responsible for monitoring the air quality of the state of São Paulo, Companhia Ambiental Estadual (CETESB), in its latest report points out that the MRSP is responsible for 48% of the state's vehicle fleet. In this report are presented the relative emissions by type of source in the MRSP, and when it comes to NO_x the greatest source is heavy vehicles which represents 48%, followed by 35.1% of industrial processes, 15.9% from light vehicles and 1% from motorcycles (CETESB, 2021a).

Despite being a complete surface monitoring, there is still a lack of monitoring stations in some cities. Remote sensing data can improve the monitoring of some pollutants, once when it concerns remote sensing and more specific data from satellites, it is possible to obtain data with a high temporal and also spatial resolution. Sentinel-5P provides both, not only for NO_x but for other chemical species. Thus, the observations carried out by satellites over the MRSP provided a better understanding of the spatial and temporal distribution of NO_2 concentrations.

2 MATERIAL AND METHOD

2.2 Metropolitan Region of São Paulo

The Metropolitan Region of São Paulo (MRSP) is located in the state of São Paulo in Brazil. MRSP is constituted by 39 cities (CETESB, 2021b). Together all of this city occupies an area of 7.946,96 km². As related in the PDUI (2021) website this region has been classified since 2014 by ONU as the sixth urban agglomeration, being the biggest in South America.

Furthermore the MRSP population was estimated at 21 million inhabitants in 2015, and it is responsible for 56% of the state's PIB and 18% of Brazil's PIB (PDUI, 2021). As expected for a region with a huge number of inhabitants, the MRSP has a great vehicle fleet, which considers in these estimates all kinds of vehicles, which accounts for around 7 million vehicles. Besides this fleet being huge, the mean age of it is estimated at 10.1 years (CETESB, 2021c).

One of the factors that make the atmosphere of the region very heterogeneous are the industrial poles, which present 30.9% of the value of industrial transformation (VIT) of São Paulo state (SEADE, 2019), and only the capital has 6.7%.

It is the most complex and diversified metropolitan region in the country in social, economic and demographic terms, making it a special case for studies of daily displacement, especially of vehicular fleets. In terms of population, the region ranks among the largest human agglomerations in the world, equalling the metropolitan regions of Tokyo, New York and Mexico City. One in every ten Brazilians lives in the RMSP. Every hour the Region gains 31 new inhabitants (IPEA, 2013; PDUI, 2021).

2.3 Sentinel - 5P

Sentinel-5P (Sentinel 5 Precursor satellite) was successfully launched in 2017, on board a TROPOMI (Tropospheric Monitoring Instrument). It is responsible for the acquisition of data on chemical species which are air pollutants (ESA, 2021). The Sentinel-5P has a bandwidth, which allows daily global coverage. Sentinel-5P has three types of processing stream data: NRTI (near-real time), OFFL (offline) e RPRO (reprocessing) (ESKES *et al.*, 2021).

To accomplish the objective, collected the data for the whole year of 2019. The data used was NO_2 L2 offline, obtained in the S5P Pre-Operations Data Hub (https://s5phub.copernicus.eu/dhus/).

For the analyses, the data were standardized spatially in a grid of 0.01 x 0.01 arc degree, besides being performed the filtering of the data through the *qa_value* using only those that have a value higher than 0.75. The temporal analysis, boxplot type graphics, was performed using the algorithm developed and available by OMRANI *et al.* (2020).

3 RESULTS

To evaluate this preliminary study a total of 436 files of NO_2 were acquired by TROPOMI sensor. Each file represents one time that the satellite passed by the interested area. Which means that are some days that we have more than one overpass of Sentinel-5P over the area. This was expected due to Sentinel's large swath.

The first step taken to perform the preliminary Sentinel-5P NO_2 analysis on the MRSP was to regrid the data, which provides that all the data become uniformized, so in each data all pixels had the same size, since differences in them may occur due to the angulation of the sun (OMRANI *et al.*, 2020). After such processing, a resample of all data was performed in days, so the data set analyzed was composed of 365 days.

Figure 1 shows the arrangement of the mean concentration of NO_2 over the months from January to April, it is emphasized that the study region is indicated by the contour including the division with the cities belonging to MRSP.

Figure 1 - Mean concentration of NO_2 from January to April

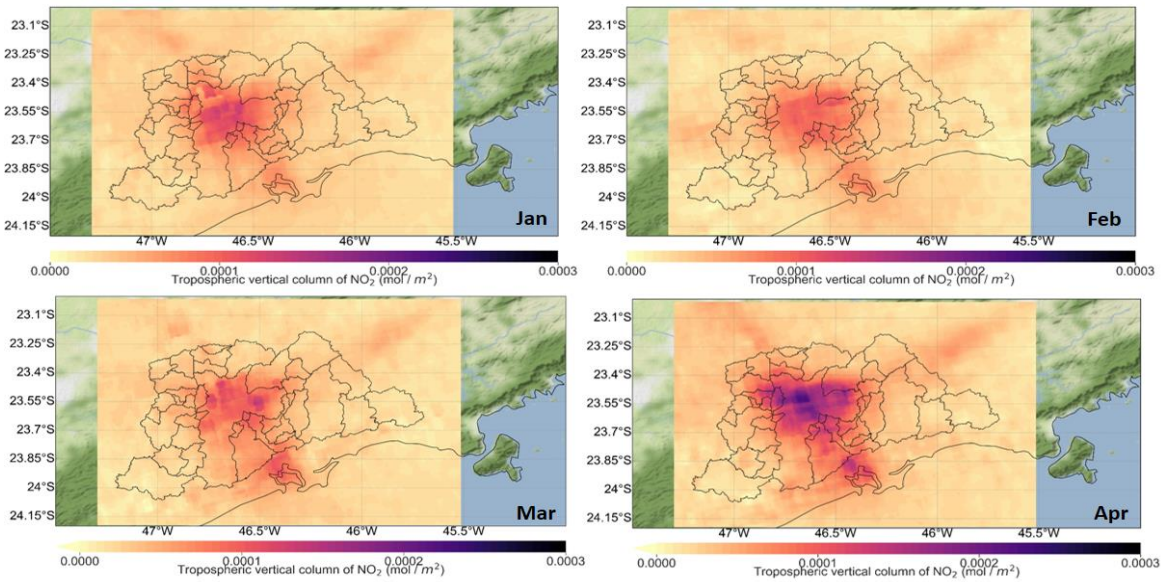


Figure 2 shows the mean concentration of NO_2 from May to August and figure 3 presents the mean concentration from September to December. The area of interest is delimited by the shapefile, from IVS-IPEA (2021), of the MRSP as the figure 1.

Figure 2 - Mean concentration of NO2 from May to August

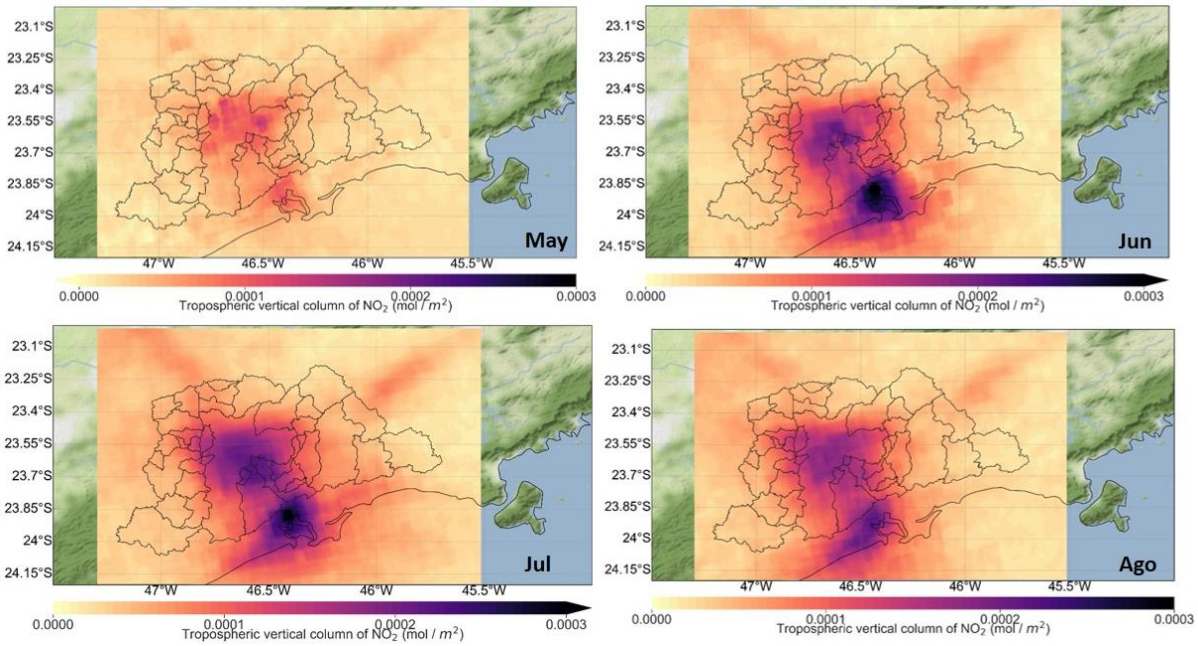
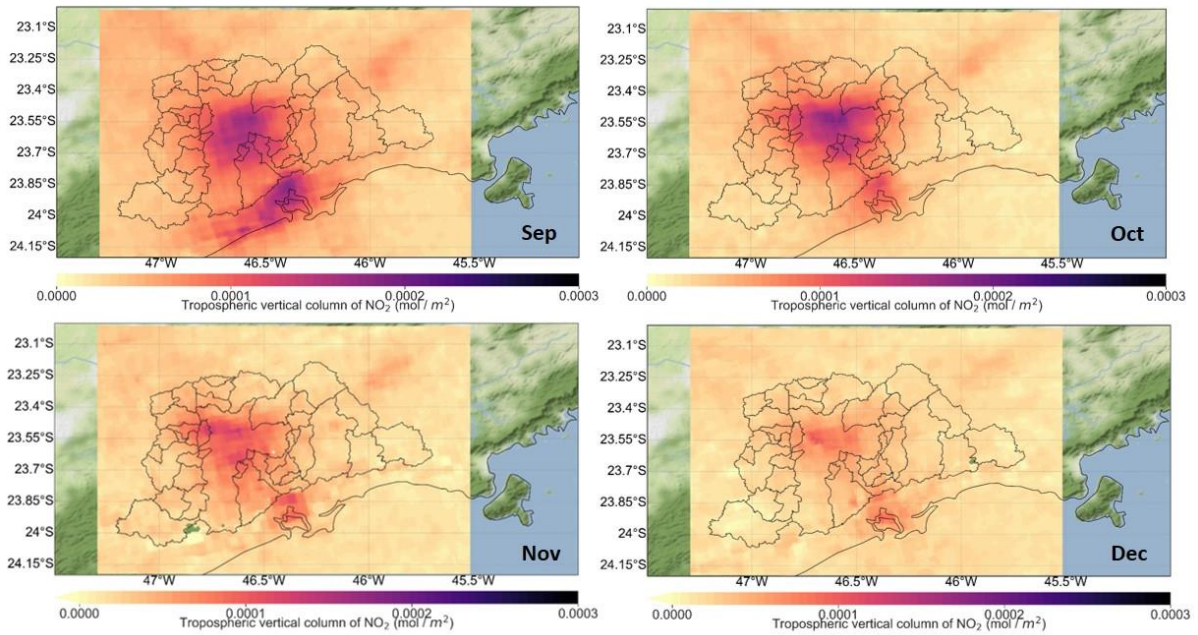


Figure 3 - Mean concentration of NO2 from September to December

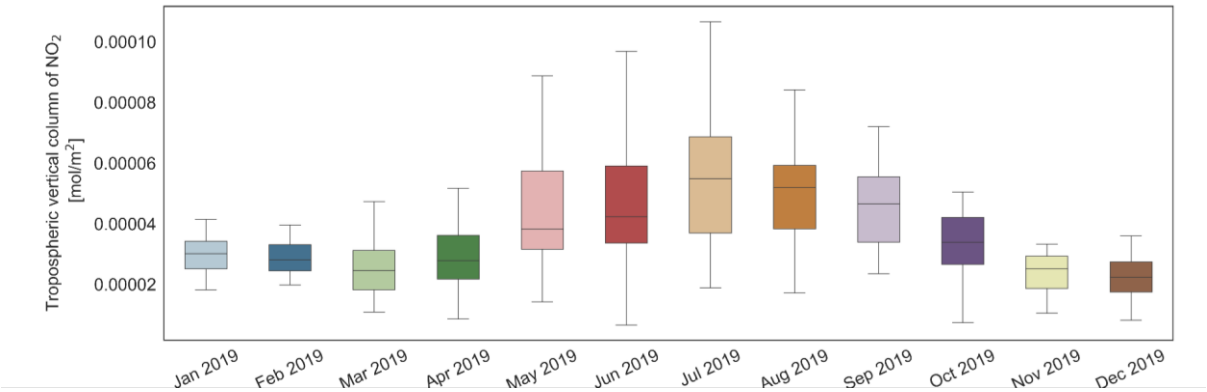


As we observe the evolution of the tropospheric column of NO_2 during the year 2019 (figures 1, 2 and 3) it is possible to observe that the city that always has a higher intensity is the city of São Paulo. This result was expected since the city of São Paulo is one of the largest metropolis on the planet, and has the largest vehicular fleet in the state of São Paulo

(IBGE, 2021; SARAIVA, 2020). Another aspect that is noticeable is the enhancement during the months of May to July.

Figure 4 shows the tropospheric vertical column of NO_2 over the months. It is possible to observe that the highest median is in the month of June, winter months.

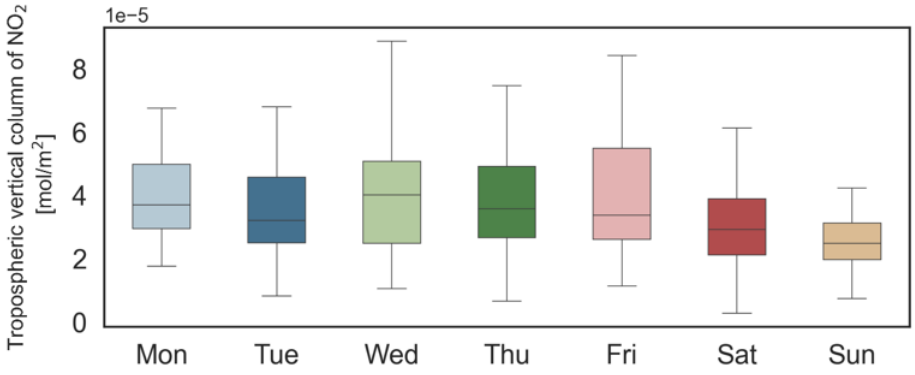
Figure 4 - Distribution of NO2 during the months of 2019



And by comparing figures 1, 2, 3 and 4 it is possible to observe the same behavior, there is an increase of NO_2 in the winter months. The months from May to September require special attention, the agency responsible for monitoring air quality in the state of São Paulo, the Companhia Ambiental do Estado de São Paulo (CETESB), elaborate a report referring to the months from May to September, called winter operation (CETESB, 2020b).

In Figure 5, we have arranged the NO_2 variation throughout the year 2019, however classified in days of the week. It is possible to identify that there is a reduction in weekend values.

Figure 5 - Distribution of NO2 on weekdays



As the city of São Paulo is one of the cities most affected by the presence of NO_2, it somehow controls the trends of the average values for the region. This is clear when we

observe Figure 5 the presence of the weekend effect, where the reduction in NO_x emissions occurs, due to the reduction in vehicle traffic. This effect has already been reported in other urban areas, and the municipality of São Paulo is also affected by it (ANDRADE *et al.*, 2017; ALVIM *et al.*, 2018).

4 CONCLUSION

This study aimed to obtain preliminary results on the temporal and spatial layout of Tropomi NO_2 data on MRSP during 2019. The study obtained expressive results that show that, even if some inferences are needed in the future, the results obtained in the spatial analysis showed characteristics already expected, such as how the city of São Paulo had more intensity than the other cities during most of the year.

Another factor that has been shown to be relevant is the results from May to August, which is a period that usually requires greater monitoring of air pollutants, since some of the months in question are in the winter period, that is, period where there is a lower incidence of rainfall. Such a factor provides an unfavorable dispersion of pollutants.

As well as the spatial data the temporal data pointed out a common denominator that is the higher presence of NO_2 during the months of May to August, figure 4 explains this. The data regarding the time distribution during the days of the week, also go against what is expected, a reduction of NO_x emissions at the weekends. Nevertheless, some adjusts are needed to obtain a valuable analysis, statistical analysis and improvements in the algorithm used.

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