Estimating AOD and its comparison with satellite data and $PM_{10}$ measured in Monterrey, Mexico

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**Abstract**

La profundidad óptica de aerosol a 550nm (AOD550nm) es una medida empleada para conocer la cantidad de partículas suspendidas en la atmósfera, desde una dada altura hasta la superficie terrestre. El material particulado de tamaño menor o igual a 10 micrómetros se denomina $PM_{10}$ y su concentración es medida a nivel del suelo. Estas partículas interactúan con la radiación solar causando efectos de dispersión, scattering y absorción provocando así una disminución de intensidad con respecto a la original. Con la ayuda del modelo SMARTS (Simple Model of the Atmospheric Radiative Transfer of Sunshine) y mediciones de irradiancia solar VIS+NIR (285-2800nm) del Sistema Integral de Monitoreo Ambiental (SIMA) del Estado de Nuevo León, se estimaron los valores del $AOD_{550nm}$ para días de cielo despejado en el periodo 2016-2020. Estos resultados fueron comparados con mediciones de $AOD_{550nm}$ (Collection 6.1) realizadas con el instrumento satelital MODIS-NASA para las mismas fechas, sobre el Área Metropolitana de Monterrey. Los valores del $AOD_{550nm}$ derivado del modelo tienen mínimos en invierno y máximos en verano, en un rango entre 0.1 y 0.6 respectivamente. Mientras que en el caso satelital tiene el mismo comportamiento con máximos alcanzando el valor de 0.8. Además estos valores fueron correlacionados con mediciones de $PM_{10}$ realizadas por las mismas estaciones meteorológicas del SIMA. Se discute el origen de las fuentes de aerosol y la correlación entre ambos resultados.

# 1. Introduction

Particulate matter (PM), or aerosol, is the set of suspended liquid or solid particles found in the atmosphere. The most relevant to human health are the ones with a diameter smaller than 10 $\mu$m ($PM_{10}$) and smaller than 2.5 $\mu$m ($PM_{2.5}$). With these sizes PM is capable of entering our respiratory and circulatory system, causing cardiovascular, respiratory and pregnancy problems, and even can increase the risk of pulmonary cancer and mortality [1]. PM can also affect visibility, cloud formation and produce damage to ecosystems and cultural sites [2].

The Monterrey Metropolitan Area (MMA) has a severe air pollution problem, with an average annual concentration of PM higher than the Official Mexican Standard (NOM) in all stations since 2000 [3]. The "Sistema de Monitoreo Ambiental" (SIMA) is the institute that since 1992 reports and shares data on air pollution over the MMA from its current 13 monitoring stations. According to its 2019 air quality report, more than half of the year the $PM_{10}$ standard is exceeded, so it can be concluded that it is the main pollutant in the area. The same conclusion that can be reached with the results of Benítez-García [4] and the National Institute of Ecology and Climate Change [5, 6]. Meanwhile, $PM_{2.5}$ has data recording problems in most of the monitoring stations, even though it is known it involves higher health risks. Some of the consequences of high PM levels are already beginning to be noticed, such as the loss of visibility in the city at certain times of the day and premature deaths from PM have an average cost of 1 % of the country's gross domestic product [7].

Several temporal analyses of PM have been done and also studies trying to pinpoint the sources of this pollutant, either by chemical characterization and emissions inventories analysis. However, little research has been done taking into account the Aerosol Optical Depth, that has the advantage of measuring the whole vertical area of the atmosphere, and not only near the Earth surface. That's why the aim of this study is to examine PM trends by comparing PM data measured on ground by SIMA, Aerosol Optical Depth (AOD) estimated by solar irradiance measurements and AOD data from NASA's MODIS satellite. We hope to contribute to the better understanding of the behavior of the pollutant in the complex physiographic zone of the MMA, since it is limited by the Northern Gulf Coastal Plain in the northeast and the Sierra Madre Oriental in the southwest.

## 1.1. Study Area

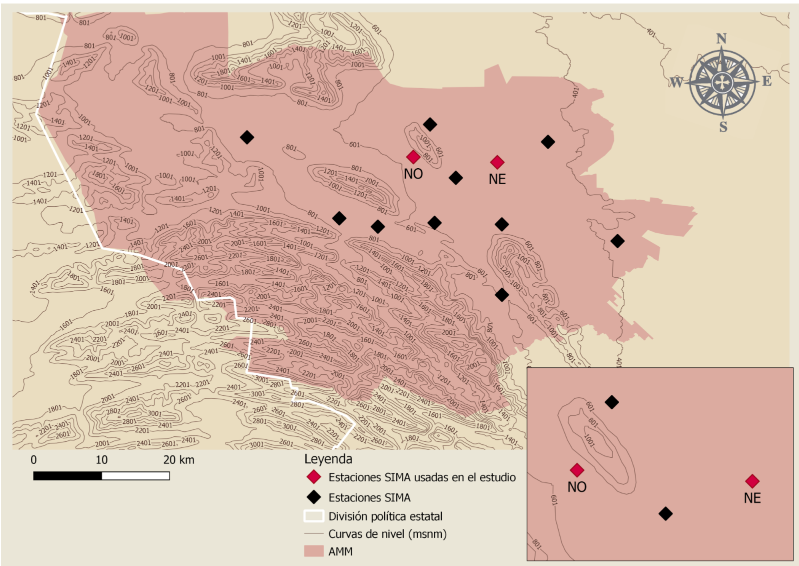


Figura 1: Incluir locación de MMA en México (climas), distribución, estaciones y alturas

The MMA is an industrial power in Northeast Mexico and the third largest urban area in the country. Given this and the way the urban area developed, the distribution of the PM sources is not homogeneous. The MMA includes the municipalities of Apodaca, Cadereyta, Escobedo, García, Guadalupe, Juárez, Monterrey, San Nicolás de los Garza, San Pedro, Santa Catarina and begins to extend towards Santiago with an area of 7,657 km$^2$ in 2015 [8]. They all are limited by the Northern Gulf Coastal Plain in the northeast and the Sierra Madre Oriental in the southwest, which causes a downward flow of air from the mountains at night and in the early morning [9]. However, the predominant direction of the wind is from east to west and this transports the PM to the mountains, which acts as a barrier by accumulating the particles [10]. A combination of the increase in wind speeds, high temperatures and humidity, is what makes PM concentrations drop in summer [10, 11].

# 2. Methodology

## 2.1. Groud-level PM concentrations

We collected SIMA's data from all 13 stations for the period of 2015-2020, where three of them started operating in 2017. Data includes hourly measures of $PM_{10}$, $PM_{2.5}$, solar irradiance, humidity, wind and other pollutants. The measuring instruments that are located at SIMA's meteorological station are required to adapt to the mexican guidelines for obtaining and communicating the air quality index and health risks that can be found as NOM-172-SEMARNAT-2019.

| Stations | 2015 | | 2016 | | 2017 | | 2018 | | 2019 | | 2020 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| name | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ |
| Centro | 7.07 | 3.78 | 7.85 | - | 7.26 | 5.12 | 5.08 | 3.31 | 4.16 | 3.5 | 4.16 | 3.38 |
| Noreste | 7.01 | 4.83 | 7.96 | 0.33 | 7.39 | - | 5.21 | 2.18 | 4.31 | 3.89 | 4.18 | 4.09 |
| Noreste2 | 6.72 | 5.8 | 7.58 | 5.72 | 7.23 | 2.49 | 5.14 | 3.2 | 4.13 | 3.79 | 4.2 | 2.9 |
| Noroeste | 7.12 | 6.48 | 7.94 | 2.96 | 7.39 | - | 5.08 | 2.15 | 3.97 | 3.1 | 4.44 | 4.44 |
| Noroeste2 | 6.26 | - | 6.82 | - | 7.18 | - | 5.17 | 1.88 | 4.19 | 3.86 | 4.41 | 3.99 |
| Norte | 5.73 | - | 7.94 | - | 6.98 | - | 5.04 | 1.86 | 4.21 | 3.26 | 3.16 | 2.87 |
| Norte2 | - | - | - | - | 1.56 | 1.41 | 5.05 | 4.35 | 4.13 | 3.44 | 4.19 | 2.94 |
| Sur | - | - | - | - | 1.71 | 0.95 | 4.97 | 1.55 | 4.23 | 2.4 | 4.39 | 2.57 |
| Sureste | 6.93 | 3.57 | 7.87 | 3.76 | 7.38 | 5.75 | 5.05 | 3.91 | 4.16 | 3.86 | 4.33 | 4.1 |
| Sureste2 | 7.16 | - | 8.03 | - | 7.18 | - | 4.95 | 2.08 | 4.19 | 3.0 | 4.11 | 2.74 |
| Sureste3 | - | - | - | - | 2.78 | 2.44 | 5.09 | 3.82 | 4.3 | 3.38 | - | - |
| Suroeste | 6.89 | 4.68 | 7.84 | 5.23 | 7.34 | 3.46 | 4.96 | 2.02 | 4.28 | 4.2 | 4.45 | 4.25 |
| Suroeste2 | 6.6 | 3.36 | 7.84 | 4.31 | 7.02 | - | 5.09 | 1.81 | 4.23 | 3.81 | 4.04 | 3.54 |

## 2.2. SMARTS AOD Model

Only solar radiation measurements under clear skies were selected. The source code of the SMARTS model was modified to enter the values of Table 1 and perform iterations with the AOD550nm, until the relative difference between the measured and modeled irradiance reaches 10 % at solar noon.

## 2.3. MODIS-NASA Data

We automated the download of data of Aerosol Optical Depth at 550 nm ($AOD_{550nm}$) from NASA's satellite MODIS (`https://ladsweb.modaps.eosdis.nasa.gov/`). The data is taken daily and with a spatial resolution of 1 Deg. We used the product MODIS-Aqua Aerosol Cloud Water Vapor Ozone Daily L3 Global 1Deg CMG (MYD08_D3) and looked at two data sets: Deep Blue Combined Mean and Land and Ocean Mean.

### 2.4. Wind

### 2.5. Data processing

We developed a code in Python to analyze the distinct data sets. For PM data, we analyzed availability, trends, and selected the data that coincided with the time the satellite passed over the coordinates of the stations. The AOD data were compared with the PM data to find the correlation. For the linear regression the module sklearn.linear_model was used.

## 3. Results

The efficiency of data availability in the four years was very different for $PM_{10}$ and $PM_{2.5}$; with 96.9 % and 27.3 % respectively. $PM_{2.5}$ wasn't measured for more than two years in the middle of the time period that was taken for the study, and that is why $PM_{10}$ is used to compare it with AOD.

The behavior of $PM_{10}$ and $PM_{2.5}$ was observed both during the year and the day. We found there is an annual trend (Fig. 2),in the driest months (December to February) the PM levels are the highest, whereas in the month where maximum precipitation is reached (September) PM is at its minimum. This can also be seen in Figure 3, where we can see the behaviour during an average day of each season. It is in winter when the average day for the four years far exceeds the Mexican norm standard of $PM_{10}$ in the peak hours of activity. It should also be noted that the peaks in July of both 2015 and 2018 are due to sandstorms that came from the Sahara desert.

The analysis of the average behavior during a day allows us to observe the effect that human activity has on pollution. In Figure 3 and 4, the maximums of the curves correspond with the automobile traffic activity and work hours in the city. When making the distinction by weekday (Fig. 4) it can be noted that Sunday has the least concentration of PM, Thursday has the mornings maximum and Saturday is the afternoons. This accurately reflects the weekly anthropogenic activity in the AMM.

## 4. Conclusion

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