

Estimating AOD and its comparison with satellite data and PM₁₀ measured in
Monterrey, Mexico

A. Ipiña¹, G. López-Padilla², C. Zúñiga²

1. Instituto de Física Rosario (IFIR) – Universidad Nacional Rosario – Consejo Nacional de Investigaciones Científicas y Técnicas, 27 de Febrero 210BIS – (S2000EKF) Rosario – Argentina.
2. Facultad de Ciencias Físico Matemáticas – Universidad Autónoma de Nuevo León, Pedro de Alba S/N - Ciudad Universitaria San Nicolás de los Garza (66451) – México.

Abstract

La profundidad óptica de aerosol a 550nm (AOD_{550nm}) 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 PM₁₀ 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 PM₁₀ 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 μm (PM₁₀) and smaller than 2.5 μm (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

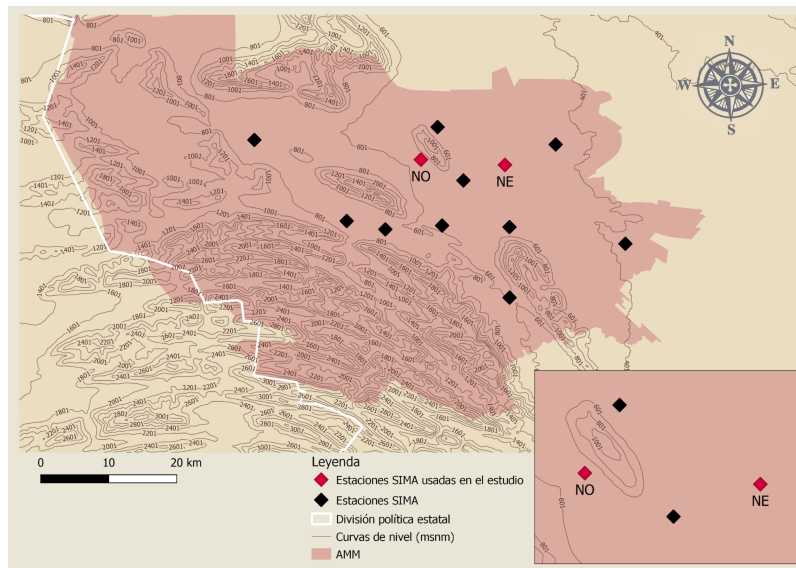


Figura 1: Incluir locación de MMA en México (climas), distribución, estaciones y alturas

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 distribu-

tion 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 km² 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].

Nombre	Code	Elevacion (msnm)	Lat	Long	Operando desde
Obispado	CE	560	25.67	-100.338	20-09-1992
Escobedo	N	528	25.8	-100.344	22-12-2009
Universidad	N2	520	25.7295	-100.3099	04-10-2017
San Nicolás	NE	476	25.75	-100.255	20-09-1992
Apodaca	NE2	432	25.777	-100.188	01-06-2011
San Bernabé	NW	571	25.757	-100.366	20-09-1992
García	NW2	716	25.783	-100.586	24-07-2009
Serena	S	630	25.5749	-100.2489	04-10-2017
Pastora	SE	492	25.668	-100.249	20-09-1992
Juárez	SE2	387	25.646	-100.096	01-10-2012
Cadereyta	SE3	340	25.36	-99.9955	21-08-2017
Santa Catarina	SW	694	25.676	-100.464	20-09-1992
San Pedro	SW2	636	25.665	-100.413	26-02-2014

Tabla 1

2. Methodology

2.1. measurements analysis

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 (CHECAR) of PM₁₀, 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. De las estaciones San Nicolas y San Bernabé se realizó un filtro de días de cielo despejado haciendo uso de las mediciones de irradiancia solar en el rango 285nm a 2800nm. En la tabla 2 se muestra el porcentaje de mediciones anuales en cada estación de la red del SIMA, se relleno en rojo las estaciones que tienen un porcentaje menor a 75 %, ya que con esto se considera que las mediciones no son representativas [9].

Station Name	Code	2015		2016		2017		2018		2019		2020	
		PM ₁₀	SR	PM ₁₀	SR	PM ₁₀	SR	PM ₁₀	SR	PM ₁₀	SR	PM ₁₀	SR
Obispado	CE	94.6	95.8	97.0	97.7	96.8	98.18	94.8	99.1	95.1	94.5	92.8	96.5
Escobedo	N	76.8	98.8	98.1	97.9	93.0	96.55	94.1	97.6	96.3	99.9	73.7	84.3
Universidad	N2	-	-	-	-	20.9	25.14	94.3	98.5	94.4	98.8	92.3	99.1
San Nicolas	NE	93.9	83.9	98.3	96.9	98.1	99.19	97.4	99.8	98.5	99.5	92.8	89.2
Apodaca	NE2	89.9	98.3	93.7	99.8	96.3	99.79	96.1	99.4	94.5	99.1	91.1	98.1
San Bernabé	NW	95.3	99.3	98.1	94.9	98.5	99.73	94.9	99.5	90.9	94.4	96.5	98.7
García	NW2	83.8	97.7	84.3	88.5	95.7	99.02	96.6	99.5	95.8	98.2	96.4	99.4
Pueblo Serena	S	-	-	-	-	22.8	23.69	92.9	99.4	96.7	99.6	94.8	99.9
La Pastora	SE	92.8	98.6	97.2	99.0	98.4	99.1	94.3	98.5	95.9	98.4	94.1	99.1
Juarez	SE2	95.9	99.7	99.1	100.0	95.7	97.36	92.4	99.6	95.8	64.2	90.3	99.7
Cadereyta	SE3	-	-	-	-	37.1	38.95	95.1	99.1	98.3	99.8	94.1	99.7
Santa Catarina	SW	92.3	97.2	96.9	98.7	97.9	99.58	92.6	99.2	97.9	99.6	97.0	99.6
San Pedro	SW2	88.4	96.5	96.8	98.9	93.6	98.09	95.1	99.5	96.66	99.7	90.8	99.9

Tabla 2: Porcentaje anual de las mediciones de PM₁₀ e irradiancia solar de cada estacion del SIMA en el periodo 2015-2020.

2.2. Satellite data

2.2.1. OMI-NASA Data

Descargamos los datos de las columnas de Ozono (O₃) en Dobson Units del satélite OMI de la NASA (<https://aura.gsfc.nasa.gov/omi.html>). Los datos fueron tomados diariamente con una resolución espacial de 0.25°. Tomamos el producto OMI/Aura Ozone DOAS Total Column L3 1 day V3 (OMDOAO3e), con un código escrito en *Python* obtuvimos los promedios mensuales para cada año para así dar un valor a los días en que no se tuvo una medición en la zona metropolitana de Monterrey.

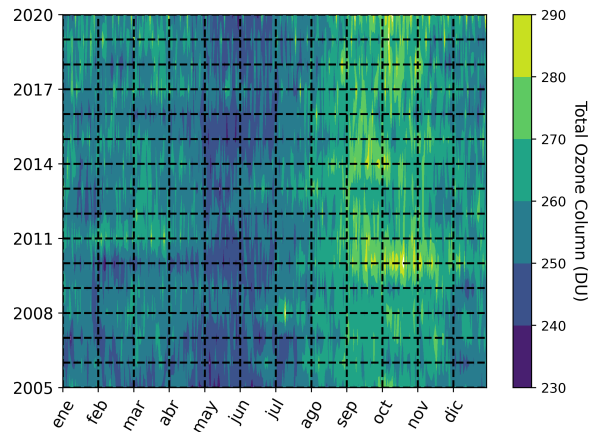


Figura 2

2.2.2. MODIS-NASA Data

We downloaded the 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.

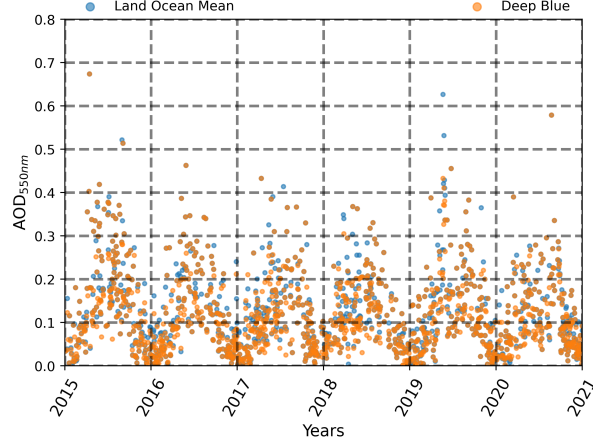


Figura 3

2.3. SMARTS Model

El *Simple Model of the Atmosphere Radiative Transfer of Sunshine* (SMARTS) es un modelo espectral escrito en el lenguaje *Fortran*, el cual realiza la predicción de los rayos de luz directos, difusos y la irradiancia global sobre cualquier geometría en la superficie de la Tierra. En base a esto se creó un código en *Python* que realizó la lectura de los parámetros de la tabla 3 y va escribiendo el archivo de entrada con el formato del modelo SMARTS.

State	Col Ozone (DU)	Wavelength (nm)	α_1	α_2	SSA ₅₀₀	g ₅₀₀
Pristine	OMI - NASA	285-2800	0.8565	1.2037	0.6536	0.6783
Moderate						
Pristine			1	1	0.8	0.68
Moderate						

Tabla 3: α_1 : Ångström for $\lambda < 500nm$, α_2 : Ångström for $\lambda > 500nm$, SSA₅₀₀: Single Scattering Albedo at 500 nm, g₅₀₀: asymmetry factor at 500 nm.

State	CH ₂ O	CH ₄	CO	HNO ₂	HNO ₃	NO	NO ₂	NO ₃	O ₃	SO ₂
Pristine	-0.003	0	-0.1	-9.9x10 ⁻⁴	0	0	0	-4.9x10 ⁻⁴	-0.007	0
Moderate	0.007	0.3	0.35	0.002	0.005	0.2	0.02	5x10 ⁻⁵	0.053	0.05

Tabla 4

Only solar radiation measurements under clear skies were selected.

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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