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Effects of Saharan Dust over the Air Quality of Southern and Central Europe

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Geophysical Laboratory I

Joydeep Sarkar
Registration Number - 437956

Supervised by
Fatima Mirza

Abstract

In this Geophysics Laboratory, we aim to calculate the Aerosol Optical Depth (AOD) of the aerosol particles from the Sahara dust event that occured in the year 2021. The laboratory work involves working with data collected from 12th of February to 11th of March using the two instruments - Aethalometer and Nephelometer located at the site of the event in Granada, Spain. We finally make a comparison of the AOD and Angstrom Exponent(AE) of the in-situ data with that of the data obtained from AERONET, an international project of Remote Sensing instrument for calculating and analysing Aerosols in the atmosphere. Comparison of in-situ data with that of AERONET would help us in understanding the variation(if any) of these methods of collecting and analysing data of the same event, at the same time most importantly making a critical review of the difference in air quality over the region.

Contents

1 Introduction

1.1 Aerosols

While walking on a street or strolling across the road, we often come across small and light flying particles. Pollen, pollution and dust are some of the most commonly experienced particles. Some of these can be seen within naked eyes, while others can only be visualized with the help of a microscope. Our atmosphere consists of so many of these type of particles. These are called aerosols[1] and play a significant role in many different types of phenomena on earth. With growing effects of climate change[2] and corresponding factors it has therefore become important to assess and understand the impact of these aerosol particles on our health and daily activities [3].

1.2 Interaction of Light with Aerosols

Understanding the interaction of aerosols with light is very important since their interaction with solar radiation and produces some interesting results, most of which has a major influence on the climate. Their interaction with light occurs in the following[4] ways.

- By scattering of light - Certain types of aerosols scatter the light they interact with. Thereby, it increases reflection in the atmosphere[3]. Furthermore, on a large scale, the aerosols by reflecting light, causes reduction in the amount of radiant heat reaching the Earth's surface. So, therefore their interaction creates a kind of cooling effect on our planet.
- By absorption of light - Most aerosols however absorb light. The aerosols of specific type due to absorption of incoming light energy results in some considerable warming in its surrounding regions. Amongst all particulate matter, black carbon[3] has the highest capacity to absorb light.

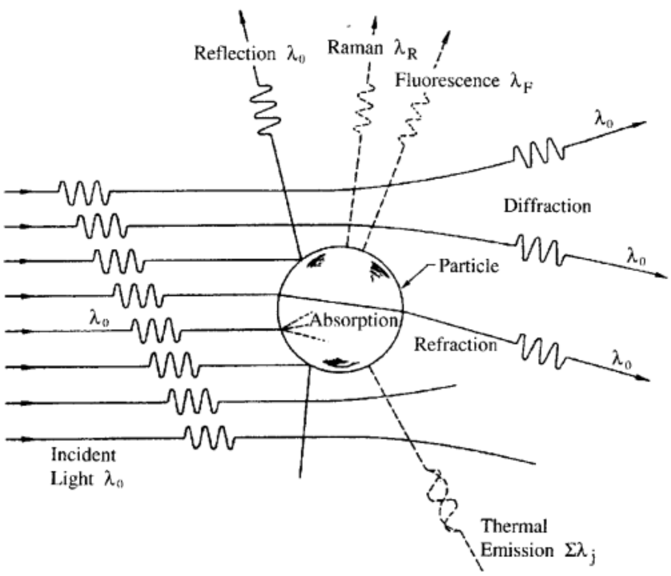

Figure 1: Interaction of light with a particle[5]

In figure 1, we can understand how a particle on interaction with light undergoes various processes. The radiation of light is denoted by λ_0. The interaction highly depends upon the wavelength of the incident light/radiation and the size of the particle, given by the following dimensionless equation[5], where λ is the wavelength of light, D_p the diameter of the particle undergoing interaction with light.

$$\alpha = \frac{\pi D_p}{\lambda} \tag{1}$$

In 20th century, the physicist Gustav Mie, provided a mathematical explanation of the particle-light interaction. This kind of particle-light interaction is known as the Mie scattering as a dedication to his work.

1.3 Beer's Law

The intensity of light undergoes attenuation as it passes through different medium. This is described by the Beer's law. Consider a situation, where light of wavelength λ passes through a layer dx perpendicular to intensity $F(\lambda)$. Therefore, the radiation undergoes attenuation in as decribed by the following equation[5]

$$F(x + dx, \lambda) - F(x, \lambda) = -b(x, \lambda)F(x, \lambda)dx \tag{2}$$

$b(x, \lambda)$ denotes the extinction coefficient and where, $b(x, \lambda)$[5] is the extinction coefficient which is the sum of absorption and scattering, given by $b = b_a + b_s$. Also, considering $dx \to 0$, we obtain the mathematical form[5] of the Beer's law.

$$\frac{dF(x, \lambda)}{dx} = -b(x, \lambda)F(x, \lambda)dx \tag{3}$$

1.4 Optical Depth

The amount of light passing through a material is described by the term Optical Depth. Mathematically, it is a dimensionless quantity and for a particular wavelength λ the optical depth between two points x_1 and x_2 is given by[5]

$$\tau(x_1, x_2; \lambda) = \int_{x_2}^{x_1} b(x, \lambda)\, dx \tag{4}$$

1.5 Aerosol Optical Depth

Optical Depth when applied to the atmosphere, is called the AOD[6][7], which explains the effect of aerosols on the movement of solar radiation of particular wavelengths through the atmosphere. The mathematics of AOD is a bit different and is obtained with the extended version of the Beer's law as we would see further.

The Beer's law as described mathematically by equation 3 was further used and extended to explain the movement of solar[6] radiation through the atmosphere and how it undergoes attenuation during its transmission. Based on the work by the respective researchers, it is now also known as the Beer-Lambert-Bouguer[6] law, which states that, for a wavelength λ the solar radiation $E(W/m^2)$ is given by the equation[8]

$$E(\lambda) = E_0(\lambda)R^2 \exp\left[-m(\theta)\tau_{aerosol}(\lambda)\right] \tag{5}$$

In the above equation, $E_0(\lambda)$ denotes the solar irradiance at wavelength λ, R is the earth–sun distance correction factor corresponding to the measurement time, $m(\theta)$ denotes the relative air mass and $\tau(\lambda)$ is the total vertical optical depth of the atmosphere. Using equation 4, the total vertical depth $\tau(\lambda)$ now becomes[8]

$$\tau(\lambda) = -\frac{1}{m(\theta)} \log \frac{E(\lambda)}{R^2 E_0(\lambda)} \tag{6}$$

The total optical depth τ can be written in given form[8]by neglecting the absorption and scattering terms and so, we only have the total optical depth as the summation of aerosol optical depth and the rayleigh scattrering.

$$\tau = \tau_a + \tau_r \tag{7}$$

When P denotes the surface pressure, and P_0 is the atmospheric pressure. The scattering for molecules can be calculated using the following equation[8]

$$\tau_r = 0.0088 \left(\frac{P}{P_0}\right) \lambda^{-4.05} \tag{8}$$

Equation 8 can be used to calculate the Aerosol optical depth τ_a. Therefore, the final equation[8]to calculate AOD becomes

$$\tau_a = \tau - \tau_r \tag{9}$$

$$\tau_a = -\frac{1}{m(\theta)} \log\left[\frac{E(\lambda)}{R^2 E_0(\lambda)}\right] - 0.0088 \left(\frac{P}{P_0}\right) \lambda^{-4.05} \tag{10}$$

1.6 Angstrom Exponent

The optical depth of an aerosol is dependent on the wavelength of light. This is explained by the Angstrom Exponent[7][9] given by the following equation[7],

$$AE = -\frac{\log \frac{\tau_{\lambda_1}}{\tau_{\lambda_2}}}{\log \frac{\lambda_1}{\lambda_2}} \tag{11}$$

The Angstrom Exponent provides us with the benefit of calculating values of AOD for other wavelength if the values at one wavelength are already known. For calculating the values, the general form of the above equation can be written in the following[5] way

$$AOD_{\lambda_2} = AOD_{\lambda_1} \left(\frac{\lambda_2}{\lambda_1}\right)^{-AE} \tag{12}$$

2 Instruments

2.1 Nephelometer

The light scattered by the aerosols could be measured with a nephelometer[10]. By considering the amount of light scattered by the gas, the walls and noise of the detector, the nephelometer analyses the scattering properties of the aerosol. In the dataset for this experiment, the nephelometer data consists of scatter and backscatter data from 3 different wavelengths, 450 nm, 550 nm and 700 nm.

2.2 Aethalometer

In the atmosphere it is possible to find a large number of particulate matter [11] in the form of smoke or black carbon. The particle concentration of such particulate matter is measured by the aethalometer[11]. Out dataset consists of values of black carbon concentration.

2.3 Sun Sky Photometer

Sun sky photometer[9][12] is a device that measures AOD of the upto the height of the atmosphere. The mechanism by which the photometer calculates the AOD can be seen from equation 6 and 11. The values of the data collected by the instrument is maintained at the AERONET[12] database, which comprises an international project of instruments(including sun sky photometer and other devices) based on remote sensing mechanism for calculating and analysing Aerosols in the atmosphere.

3 Methodology

The objective of this work is to compare AOD and AE obtained with remote sensing instrument - Sun-Sky Photometer with absorption, scattering measurements and AE obtained from in-situ instruments for the same dust event, at the same date and place.

3.1 Data

The data collected for this laboratory has been obtained with from 3 different instruments, Nephelometer, Aethaelometer and Sun Sky Photometer. The dataset consists of values in categories of Date time, temperature, pressure, scattering(450 nm 550 nm and 700nm), backscattering(450 nm, 550 nm, 700 nm) and black carbon particle concentration at different wavelengths.

3.2 Data Analysis

To analyse the data, one can use any programming language or software. For my convenience, I have used python and visualized the code in pandas dataframe.

DateTimeUTC	Dates	Sca450	Sca550	Sca700	Bsca450	Bsca550	Bsca700
2021-02-12 00:04:00	2021-02-12	35.13	25.57	15.45	4.54	3.78	1.92
2021-02-12 00:05:00	2021-02-12	36.27	25.66	14.51	4.83	3.52	3.15
2021-02-12 00:06:00	2021-02-12	35.96	25.94	16.02	5.24	3.89	2.73
2021-02-12 00:07:00	2021-02-12	36.37	25.95	15.96	5.05	3.67	2.69
2021-02-12 00:08:00	2021-02-12	36.94	26.35	15.32	5.58	4.23	3.66
2021-02-12 00:09:00	2021-02-12	37.61	26.95	17.62	5.01	4.12	2.90
2021-02-12 00:10:00	2021-02-12	37.37	27.08	16.12	5.17	3.88	1.89
2021-02-12 00:11:00	2021-02-12	38.04	27.37	17.15	5.58	4.09	2.43
2021-02-12 00:12:00	2021-02-12	39.85	28.18	15.72	5.23	4.11	2.72
2021-02-12 00:13:00	2021-02-12	39.09	28.57	16.80	5.65	4.27	2.96

Figure 2: In-situ data of the Saharan dust event

- Based on the values as shown in figure 2, we calculate AE values for in-situ data by using the formula from equation 12, but since we don't have values of AOD, we use scattering values by substituting in the formula.
- We plot the variation of AE vs the Dates from the dataset and observe their variation.
- We then obtain the values of AE for the AERONET dataset(figure 4) at the wavelengths at which in-situ measurements collect scattering values.
- We compared the values of the AE(in-situ) vs AE(AERONET).
- We now obtain the values of AOD from AERONET data based on the wavelengths of the in-situ data.

DateTimeUTC	Dates	Sca450	Sca550	Sca700	Bsca450	Bsca550	Bsca700	AE_450-700	AE_450-550	AE_550-700
2021-02-12 00:04:00	2021-02-12	35.13	25.57	15.45	4.54	3.78	1.92	1.859180	1.582870	2.089096
2021-02-12 00:05:00	2021-02-12	36.27	25.66	14.51	4.83	3.52	3.15	2.073529	1.724505	2.363951
2021-02-12 00:06:00	2021-02-12	35.96	25.94	16.02	5.24	3.89	2.73	1.830035	1.627647	1.998441
2021-02-12 00:07:00	2021-02-12	36.37	25.95	15.96	5.05	3.67	2.69	1.864187	1.682222	2.015599
2021-02-12 00:08:00	2021-02-12	36.94	26.35	15.32	5.58	4.23	3.66	1.992011	1.683488	2.248733
2021-02-12 00:09:00	2021-02-12	37.61	26.95	17.62	5.01	4.12	2.90	1.716114	1.660864	1.762088
2021-02-12 00:10:00	2021-02-12	37.37	27.08	16.12	5.17	3.88	1.89	1.902999	1.604982	2.150980
2021-02-12 00:11:00	2021-02-12	38.04	27.37	17.15	5.58	4.09	2.43	1.803035	1.640452	1.938320
2021-02-12 00:12:00	2021-02-12	39.85	28.18	15.72	5.23	4.11	2.72	2.105296	1.726759	2.420276

Figure 3: Values of AE after calculation from the in-situ data

Date	AOD_440nm	AOD_500nm	AOD_675nm	AE_380-500	AE_440-675	AE_500-870
2021-02-12	0.038184	0.032826	0.026612	0.570716	0.817774	0.443302
2021-02-12	0.938344	0.980857	0.990770	-0.225942	-0.110329	-0.098936
2021-02-12	0.443479	0.448338	0.462060	0.011519	-0.096699	-0.191341
2021-02-12	0.446034	0.454489	0.455580	-0.456964	-0.042072	-0.171260
2021-02-12	0.314906	0.306905	0.346168	0.021302	-0.253214	-0.333690
2021-02-12	0.299534	0.287613	0.275186	0.104091	0.188975	0.070536
2021-02-12	0.268334	0.261399	0.252441	0.179923	0.137910	0.021028
2021-02-12	0.169361	0.161073	0.165726	0.406575	0.024725	-0.127413
2021-02-12	0.286292	0.287075	0.306372	-0.159086	-0.168770	-0.241486
2021-02-12	0.205451	0.204220	0.196554	0.384302	0.107703	0.006478

Figure 4: Values of AERONET dataset from the Sun Sky Photometer

- Using figure 4, we can obtain columnar properties and AOD for the entire atmospheric column.
- Figure 3 shows the scattering, backscattering values(optical properties) obtained with in-situ instruments for aerosol at ground level.
- We would now see how the values of both these vary in terms of AE and AOD.

4 Figures and Discussion

4.1 Angstrom Exponent from In-Situ Data

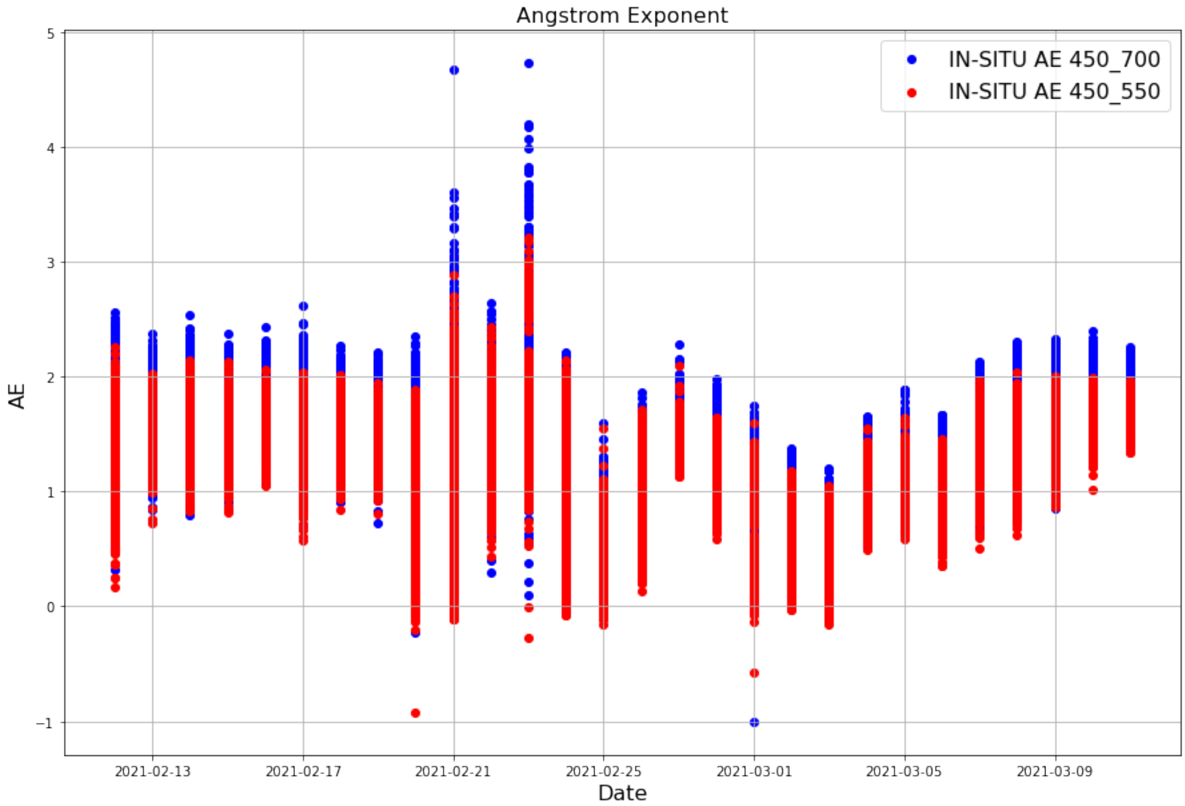

Figure 5: AE Variation for In-Situ Data

- Unlike AOD, AE cannot be obtained for a fixed wavelength. It's value is obtained by using two different wavelengths. Therefore, one cannot have AE for 450, 550 or 700 nm. We calculate the AE obtained from 450 and 550 nm or 450 and 700 nm. Therefore, one calculates the AE based on the intervals available or required.
- The values of AE is the highest at around 21st - 24th of February, followed by that there is a fall in its magnitude and finally around the 1st week of March, the AE starts rising again.

4.2 Angstrom Exponent from AERONET Data

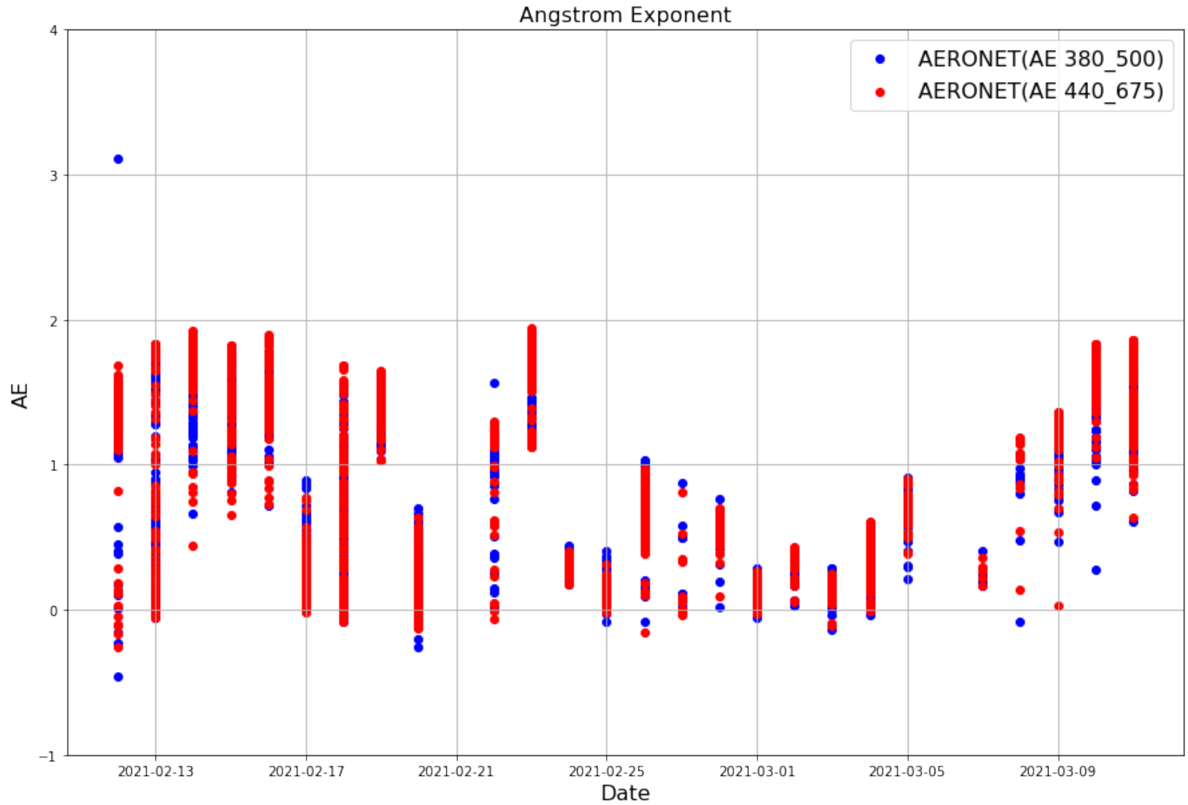

Figure 6: AE Variation for the AERONET Data

- The values of AE lies strictly within a magnitude of 2, unlike the variation of AE for in-situ data.
- The AE falls below 2 at around the last week of February and rises again after the 1st week of March.

4.3 AE In-Situ vs AE AERONET

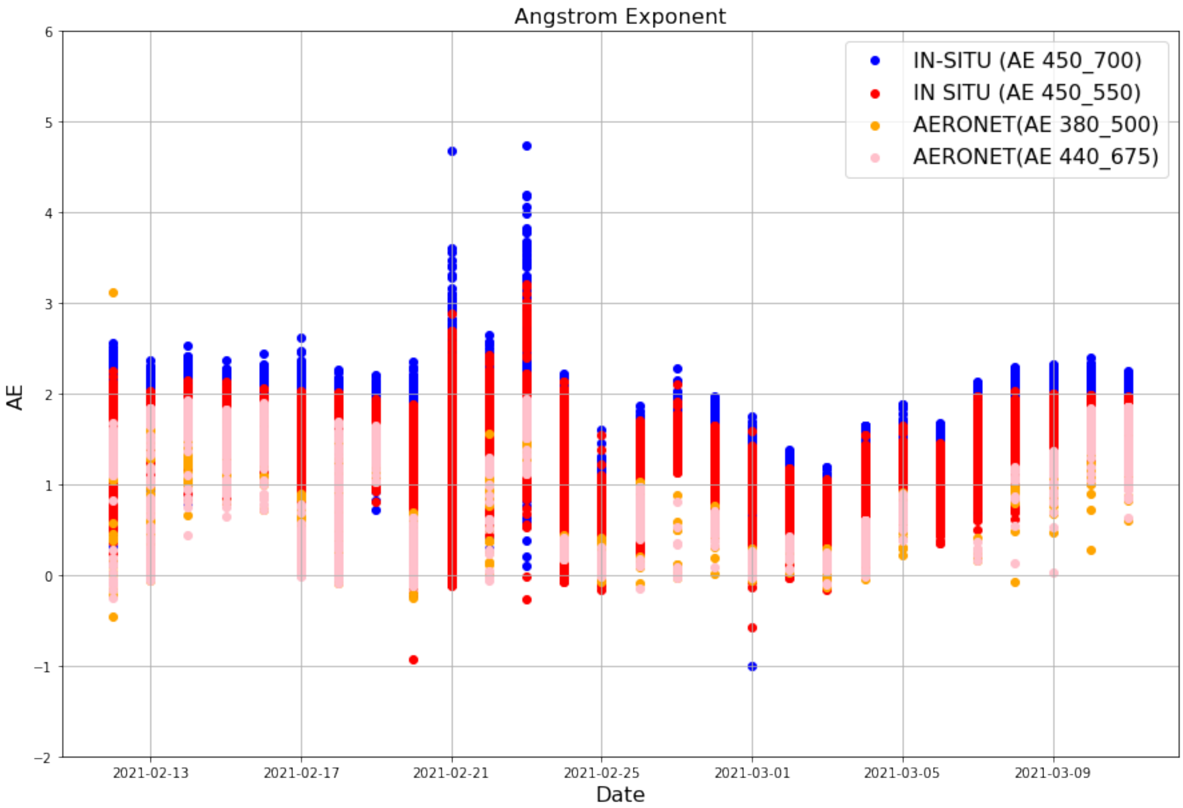

Figure 7: AE Comparison for in-situ and AERONET data

- Here we can clearly visualize how the AE varies for both AERONET and in-situ data. It's particularly interesting to note that AE values lies higher for the in-situ instruments.
- Also, it might be that since we don't have exact values of AE for AERONET dataset, therefore, the values might not be as prominent for visualizing those values.
- Nevertheless, the range of values are within the interval as same as for in-situ, hence the comparisons made are valid enough.

4.4 AOD from AERONET data

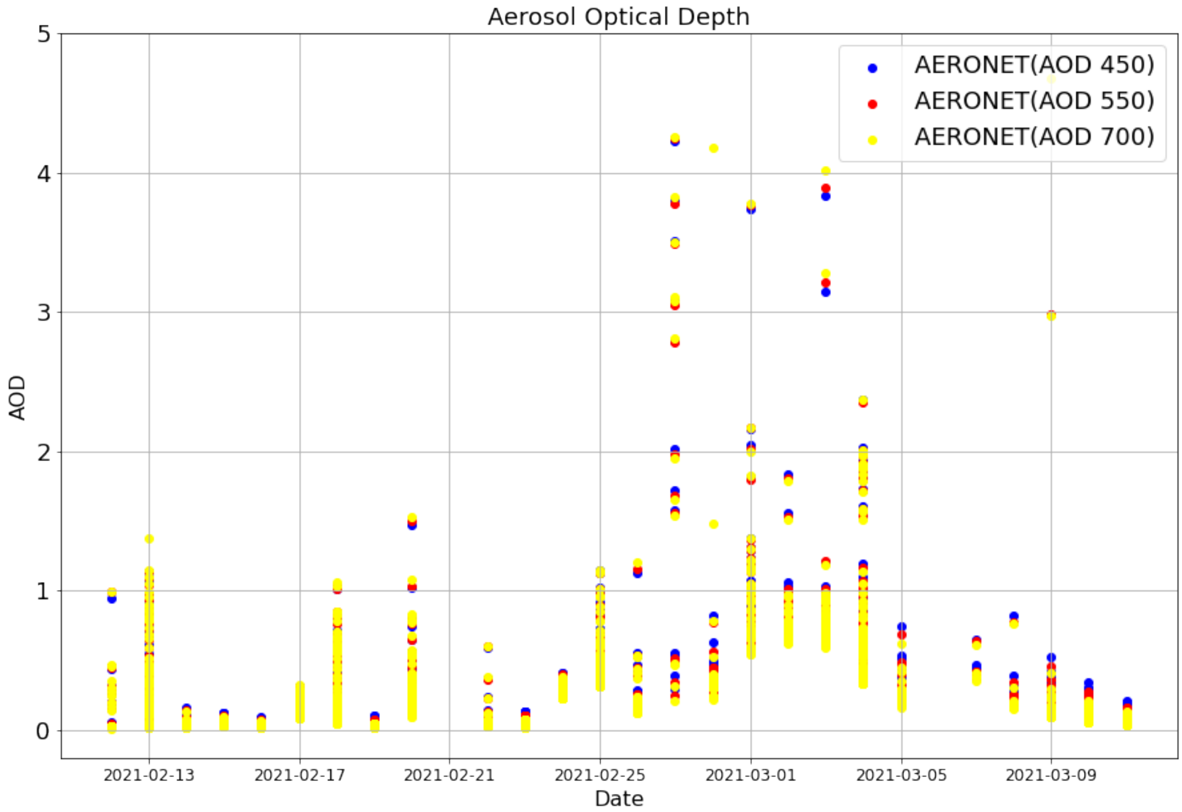

Figure 8: AOD Variation at the in-situ wavelengths

- The AOD for the AERONET data stays low within a range of around 1 till the last week of February and then undergoes a rise in magnitude of 4 from around the last days of February to the 1st week of March.
- The values fall back sharply to previous values towards the 2nd week of March.
- AOD values for wavelength of 700 nm occupies lower magnitude as compared to AOD for 450 nm.

4.5 AOD from AERONET vs In-Situ Scattering

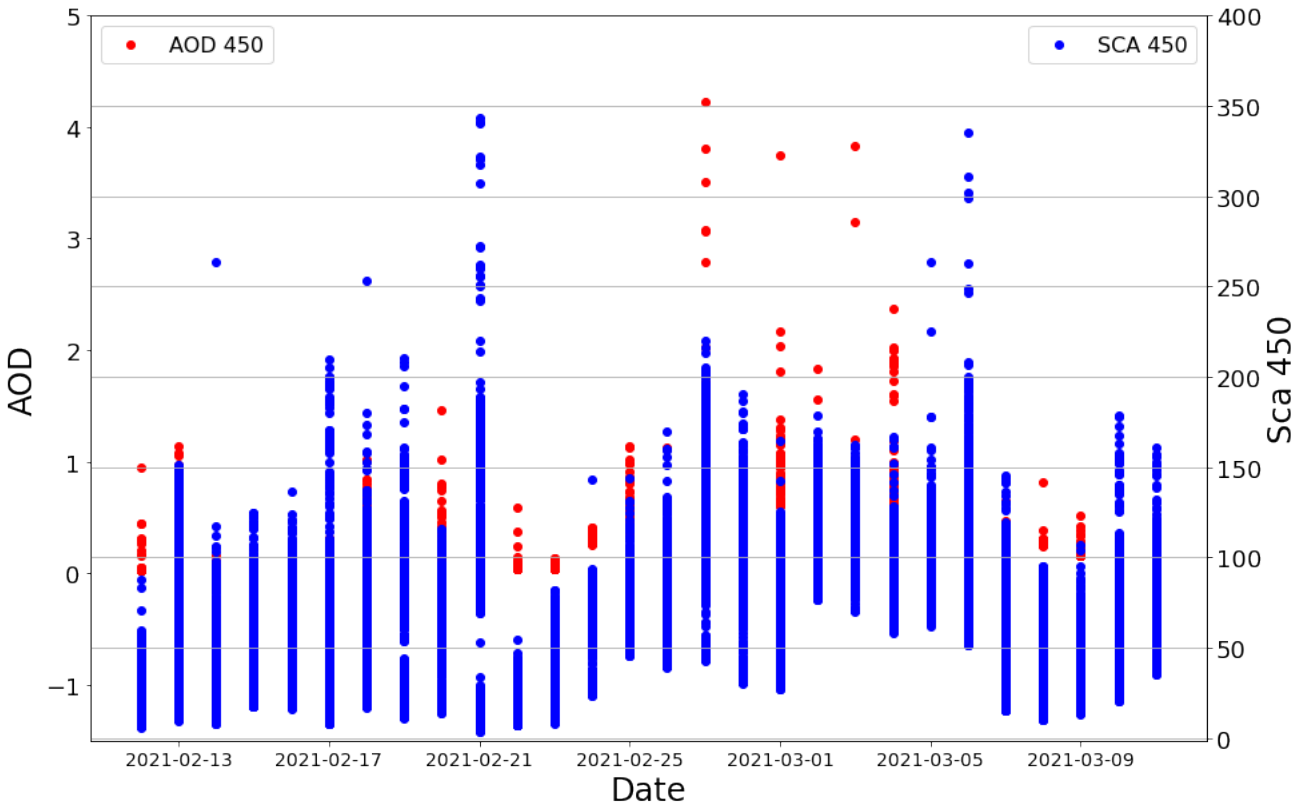

Figure 9: AOD vs Scattering at λ of 450 nm from in-situ wavelengths

- The comparison between AOD from AERONET and Scattering from in-situ data gives a proper info about large scattering at a wavelength of 450 nm.
- The scattering seems to be higher for 21st February and lowest, the very next day. The AOD similarly is highest for around a particular day in the last week of February.

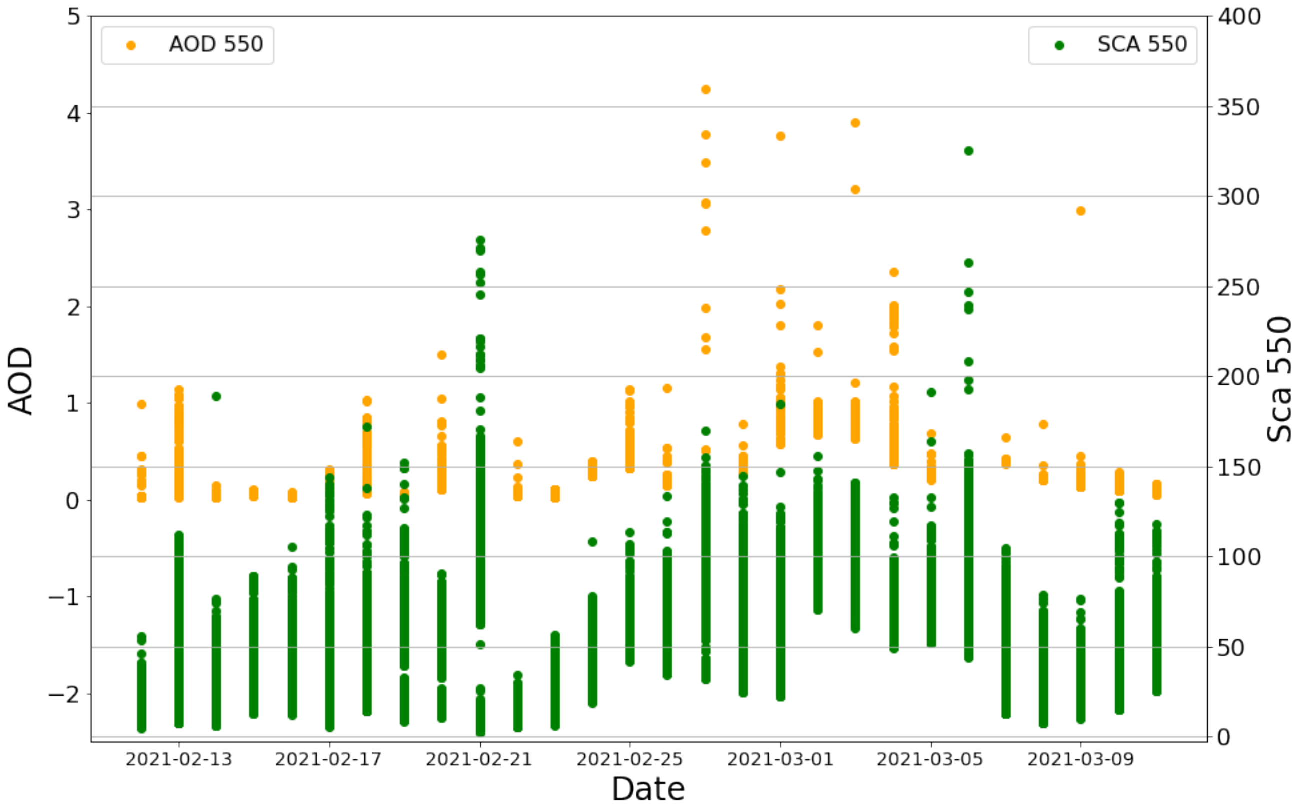

Figure 10: AOD vs Scattering at λ of 550 nm from in-situ wavelengths

- The scattering shown by in-situ data at a wavelength of 550 nm is much lesser as compared to that of 450 nm in the previous figure.
- There is a major discontinuity between the AOD values and the scattering from in-situ data as the scattering values seems to lie more in the negative scale.

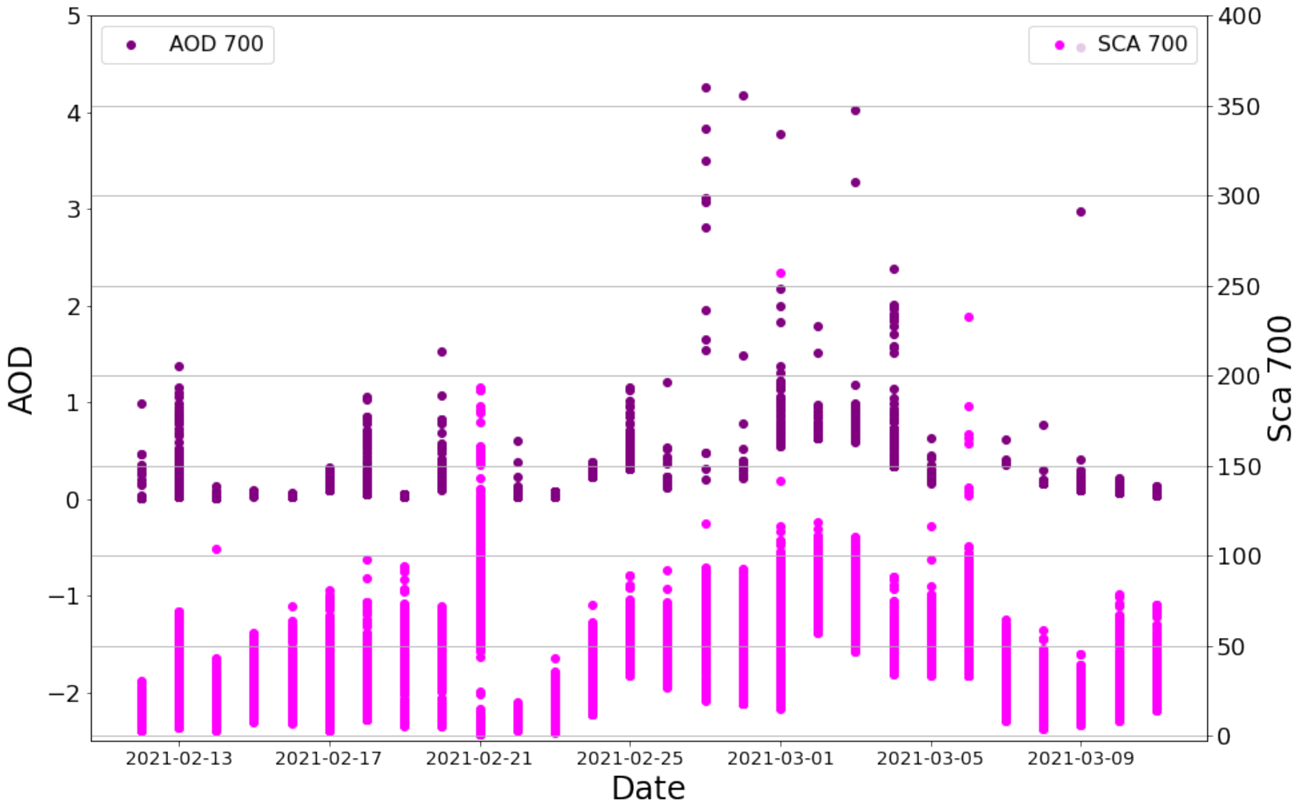

Figure 11: AOD vs Scattering at λ of 700 nm from in-situ wavelengths

- The scattering decreases more for the wavelength of 700 nm. The values are more negative at this range.
- In fact the AOD values too as well lies around 1 and 2 unlike the previous wavelengths.
- However, similar to previous wavlengths, there is noticeable rise of AOD around the last week of February.

5 Discussion

- The difference in variation of AE for AERONET in comparison to in-situ data could be because of difference of sensitivity of data collection in terms of location of the instruments.
- There are various languages and softwares for visualizing xls files, python might not be a better choice for this. Visualization and working in MATLAB could produce more better plots.
- Also, because of the in-situ measurements there is more depthness in the range of AE unlike AERONET data collected from the Sun Sky Photometer, which collects measurements from far away.

6 Conclusion

- The values of AE obtained from in-situ data is higher in magnitude as compared to the AE from AERONET dataset.
- AOD obtained from AERONET dataset for in-situ wavelengths lies mostly within a magnitude of 1, but has higher peaks around the last week of February and 1st week of March.
- Scattering values for in-situ data becomes more negative for higher wavelengths as compared to the AOD for the same wavelengths obtained from AERONET data. There is also less continuity between the two as the wavelengths increases.

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