Classification of aerosols using multiple clustering techniques over Zanjan, Iran, during 2010-2014

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Abstract. A more detailed study and identification of aerosol types can help to better understand the sources and effects of aerosols. In the present study, a number of optical properties of aerosols have been investigated seasonal for discrimination of aerosol types during 2010-2014 over Zanjan, Iran. Also using AERosol RObotic NETwork (AERONET) data, aerosol was classified by multiple clustering techniques. Both fine and coarse modes particles were seen in seasonal averaged of Aerosol Volume Size Distribution (AVSD). Single Scattering Albedo (SSA) variations indicate the presence of scattering aerosol like dust in the spring, summer and fall, and dominance of absorbing type aerosols in the winter. The maximum value of the phase function was observed in the summer and in small scattering angle which can be due to presence of coarse mode dust particles. The scatter plot of Aerosol Optical Depth (AOD) versus Angstrom Exponent (AE) is one of the most effective methods to find aerosol types. Extinction Angstrom exponent (EAE) versus SSA and EAE versus absorption Angstrom exponent (AAE) are other ways to classification of aerosol types. Graphs show abundance of dust in the spring, summer and fall in Zanjan's atmosphere. Also presence of urban/industrial aerosols is in all seasons, especially in the fall and winter. In addition mixed aerosols exist in all seasons. On the other hand, no biomass burning aerosols found in Zanjan's atmosphere.

1 Introduction

Aerosols are Liquid or solid particles suspended in the air [1]. Human health hazards and air pollution are some of the effects of aerosols, As well as reducing the horizontal visibility [2, 3]. Aerosol can change the amount of radiation reaching the earth's surface by absorbing and scattering the radiation, also it is causing climate changes [4].

Aerosols classified according to their size, distribution, composition and how they are formed [2, 5]. Fine mode particles with a radius less than 0.6 μm often are produced through condensation of precursor gases [2, 6]. Coarse mode particles with a radius larger than 0.6 μm, produced by mechanical action of wind [6]. Vegetation debris, desert dust and sea salt are examples of coarse mode particles [2].

In the Middle East and Iran, many problems due to high concentration of atmospheric aerosols are happening. So, accurate and extensive studies are needed in the area. Few researches have been conducted to inquire optical properties of aerosols by means of remote sensing techniques [7-9] and radiative effect of aerosols [10] over Iran. Different clustering techniques have been used to detect various types of aerosols in different locations in the word [11-13].

In the present study, first the optical properties such as Aerosol Volume Size Distribution (AVSD), Single Scattering Albedo (SSA) and Phase function, were investigated using AErosol RObotic NETwork (AERONET) data. Then different aerosol types were classified using multiple clustering techniques over Zanjan, Iran during 2010-2014. Different optical properties of aerosols are plotted such as Aerosol Optical Depth (AOD) versus Angstrom Exponent (AE), Extinction Angstrom Exponent (EAE) versus SSA and EAE versus absorption Angstrom Exponent (AAE) to classified aerosols. Variation in types of aerosols in the atmosphere of Zanjan has been studied in different seasons.

2 Data and methodology

2.1 Site description

Zanjan is a city in the northwest part of Iran plateau (36.70 N, 48.50 E). Zanjan is located 1638 m above sea level and has semi-arid climate. Zanjan has dry and hot summers, cold and snowy winters and wet springs. The annual mean temperature over a period of 33 years is 10.7 C [14].

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Dust particles are abundant in May to July which is dry months and anthropogenic aerosols are permanent. Being in the neighbourhood of the active and important sources of dust like Tigris-Euphrates basin and Arabian Peninsula as well as local dust sources are the main cause of dust [7, 10].

2.2 AERONET data

AERONET is a network of ground-based remote sensing measurements. A research institute IASBS (Institute for Advanced Studies in Basic Sciences) in Zanjan equipped to a CIMEL CE318-2 sun photometer since 2006. It is linked to AERONET network from 2009 and provides an important database of aerosol physical, optical, and radiative properties.

3 Results and discussion

3.1 Aerosol optical properties

3.1.1 Aerosol volume size distribution

Aerosol distributions are classified in fine and coarse categories. AVSD is showed by Eq. (1):

$$\frac{dv(r)}{dln(r)} = \sum_{i=1}^{2} \frac{c_{v,i}}{\sqrt{2\pi}\sigma_i} exp\left[-\frac{(lnr-lnr_{v,i})^2}{2\sigma_i^2}\right] \qquad (1)$$

where, σ_i is the standard deviation, $r_{v,i}$ is the volume median radius and $c_{v,i}$ is the volume concentration for fine and coarse modes [15]. Fig. 1 shows the seasonal averaged of AVSD for Zanjan during 2010-2014. Despite the existence of both fine and coarse modes, considerable variations can be found in the coarse mode. About radii of 0.11 and 2.24 μm, the maximum values of AVSD for the fine and coarse mode were observed. In the summer and spring the high values of AVSD could be due to presence of dust particles [16-18].

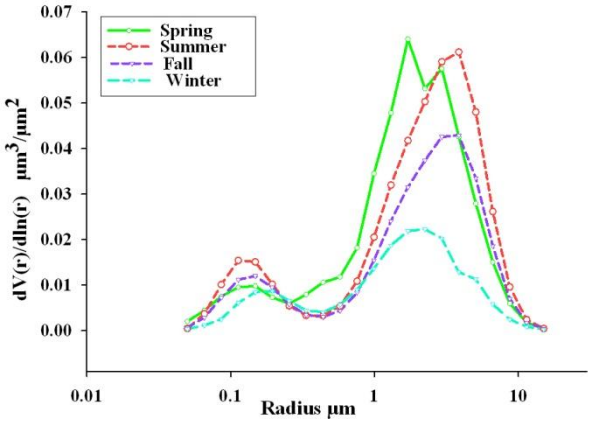

Fig. 1. Seasonal averaged of AERONET retrieved AVSD over Zanjan during 2010-2014.

3.1.2 Single scattering albedo

The ratio of scattering efficiency to total extinction efficiency is introduced as SSA [1]. It can vary from 0 for purely absorbing aerosols to 1 for purely scattering one. Fig.2 shows the seasonal averaged of SSA at 440, 675, 870 and 1020 nm. Composition and chemical characteristics of particles can determine the spectral behaviour of SSA [18]. The high values of SSA denote the dominance of scattering type aerosols in the summer, spring and fall [19] . SSA increases with increasing the wavelength in the summer because of the dominance of desert dust [20]. Due to presence of absorbing aerosols in the winter the value of SSA is low [19]. SSA is lower in the spring than fall; despite there are a large amount of dust aerosol. It could be due to the high error in SSA calculation using AERONET algorithm. Standard deviation of 0.05 for calculation of SSA has been reported by Dubovik [6].

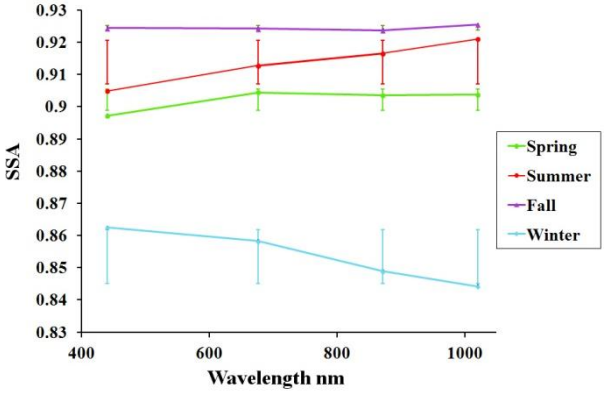

Fig. 2. Seasonal averaged of AERONET retrieved SSA over Zanjan during 2010-2014.

3.1.3 Phase function

Phase function illustrates how much light is scattered in each direction. It is the angular distribution of light intensity scattered by a particle at a given wavelength [1]. The variation of seasonal average phase function versus the scattering angle during 2010-2014 is shown in Fig. 3. The highest amount of the phase function was observed in the summer. Coarse mode particles can cause a high phase function in small scattering angle. Phase function reduced uniformly in angles between 0-10 degrees. Furthermore at angles bigger than 10 low values of phase function were due to presence of fine mode particles [21].

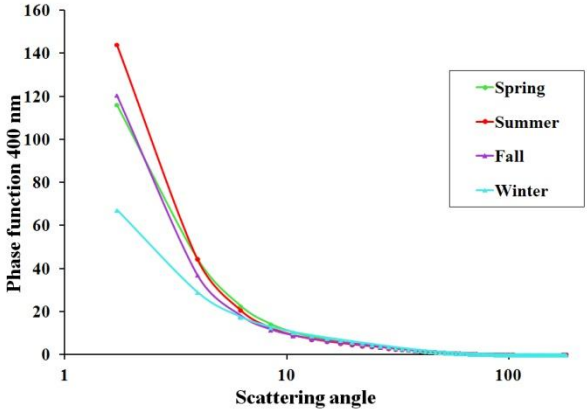

Fig. 3. Seasonal averaged of AERONET retrieved phase function versus the scattering angle over Zanjan during 2010-2014.

3.2 Multiple clustering techniques

3.2.1 Aerosol optical depth versus angstrom exponent

To find aerosol types in the atmosphere, several methods have been used to classify them. One of the most effective methods is drawing AOD versus AE [21-23]. AOD measures the reduction of solar radiation due to scattering and absorption of sunlight caused by aerosol. AE is used to determine the dependency of the aerosol optical depth on wavelength according to the Angstrom equation. This scatter plot can use to distinguish the different types of aerosol through determination of physically interpretable cluster regions [23]. The four-dimensional cluster analysis rather than pairs of clusters (this study) is very effective for more accuracy in classification of aerosols [24]. Spending more time to use Mahalanobis classification will provide a useful way of combining several dimensions of multi wavelength optical information to assign aerosols to classes [25].

Fig. 4 demonstrates the seasonal scatter plot of AOD_{500} versus $AE_{(440-870)}$ over Zanjan during 2010-2014. Variations in the relationship between the AOD and AE are useful tool to classify and assess the effects of different sources on the seasonal aerosol concentration and size of aerosol particles [21, 26]. A number of researchers categorized different aerosol types using the AOD-AE clustering technique over different regions [23, 27]. A threshold values were used to determine types of aerosols: AOD > 0.25 and AE < 0.7 signify coarse mode particles like dust [13]. Dust was abundant in spring and summer in the atmosphere of Zanjan. AOD < 0.3 and AE < 0.7 were indicative of mixed aerosols [28]. Mixed aerosol was existing in all seasons. 0.01 <AOD< 0.7 and 0.7 <AE< 1.7 was used to distinguish urban/industrial aerosols [21]. Urban/industrial aerosols were available in all seasons over study site, especially in fall and winter. However, AOD>0.5 and AE > 1.0 represent biomass burning [28] that did not exist in the atmosphere of Zanjan. AOD< 0.2 and high values of AE represented the clean atmosphere condition [28] in falls and winters. This result was consistent with our other findings over Zanjan [9,10].

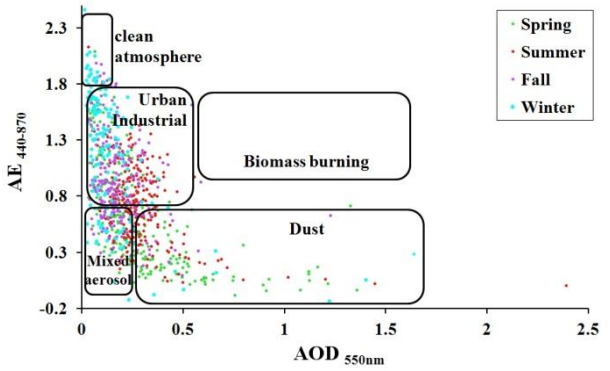

Fig. 4. Seasonal scattered plot of AOD_{500} versus $AE_{(440-870)}$ over Zanjan during 2010-2014.

3.2.2 Extinction angstrom exponent versus Single scattering albedo

Another way to categorize aerosol types is plotting SSA versus EAE. SSA is a good factor showing the type of aerosols and determining the scattering or absorbing type of aerosols. EAE is a factor to indicate the size of particles [21]. Fig. 5 shows the seasonal scattered plot of SSA versus EAE over Zanjan during 2010-2014.

The cluster analysis characterizes three important types of aerosol which were discriminated as: dust (high SSA and low EAE), Mixed (high SSA and moderate EAE), and urban/industrial aerosol (high SSA and high EAE) [21, 30, 31]. This clustering technique revealed that dust is most abundant in spring, summer and fall. As found in many research, in different regions [21, 29, 31]. Urban/industrial aerosols in all seasons especially in winter were accessible. Mixed aerosol can be observed in all seasons. On the other side the absence of biomass burning is also noted in the atmosphere of Zanjan.

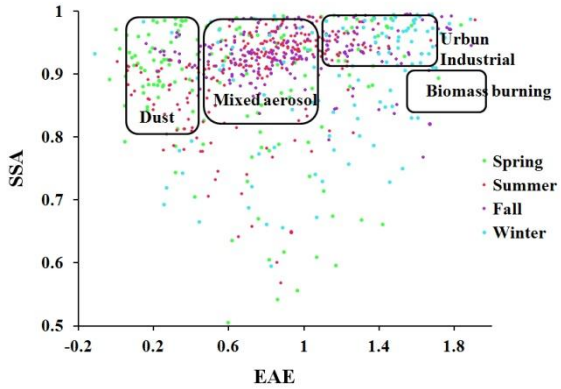

Fig. 5. Seasonal scattered plot of EAE versus SSA over Zanjan during 2010-2014.

3.2.3 Extinction angstrom exponent versus Absorption angstrom exponent

Fig. 6 shows the clustering of aerosol type during different seasons over Zanjan using scattered plot of EAE versus AAE. Clustering of aerosol types in the figure revealed the occurrence of dust aerosols based on the categorization of Mishra et al, [30] and Russell et al. [31] during the spring, summer and fall seasons were more than winter. This graph strengthened the results of previous graphs and it also confirms that there is no biomass burning aerosols.

Urban/industrial aerosols have been categorized according to Mishra et al. [30] and Zhu et al. [32]. As it can be seen, urban/industrial aerosols were present in all seasons especially winter. This result was very well matched with the findings of other researchers [30-32]. Almost all seasons experience mixed aerosols [13, 29]. These results were in good agreement with our other findings [9,10].

The most trustable way for classification of particles is to use several different techniques simultaneously and find a result in combination of these methods.

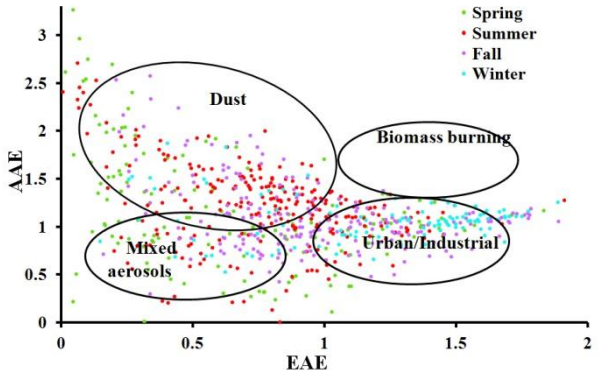

Fig. 6. Seasonal scattered plot of EAE versus AAE over Zanjan during 2010-2014.

3 Conclusions

A detailed study on the optical properties of aerosols using AERONET data was accomplished over Zanjan, Iran during 2010-2014. Then the different aerosol types were classified using multiple clustering techniques.

The seasonal averaged of AVSD over Zanjan shows the existence of both fine and coarse modes particles. The higher values of coarse mode in the spring and summer could be due to presence of dust particles in these seasons.

The high values of SSA in the summer, spring and fall show the dominance of scattering type aerosols. Due to dominance of desert dust in the summer, SSA increases with increasing the wavelength. The value of SSA is low in the winter Due to presence of absorbing aerosols.

The maximum value of the phase function occurred in the scattering angle of zero. The maximum value of the phase function was observed in the summer. A high phase function in small scattering angle can be due to presence of coarse mode particles. In addition low values of phase function at angles bigger than 10 were due to presence of fine mode particles.

One of the most effective methods to find aerosol types is drawing AOD versus AE. This scatter plot showed the presence of dust in spring and summer in the atmosphere of Zanjan. Furthermore, Industrial aerosols were present in all seasons over study site especially in fall and winter. On the other hand, there was no biomass burning in the atmosphere.

Another way to classify aerosol types is plotting EAE versus SSA. The plot showed that the total value of dust and mixed aerosols were low in winter and high in summer. Urban/industrial aerosols were present in all seasons particularly in fall and winter.

Scatter plot of EAE versus AAE showed the presence of dust aerosols during the spring, summer and fall. Biomass burning aerosols was not observed in this graph. Urban/industrial aerosols prevailed in all seasons especially in fall and winter. Mixed aerosols existed in all seasons.

The authors would like to thank NASA and IASBS for providing the data at AERONET site in Zanjan, IASBS (Institute for Advanced Studies in Basic Sciences).

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