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Estimation of Dust Downfall Time in Dusty Days using the Correlation between PM_{10} and Sunphotometer Data

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Abstract. Urban air pollution has become a serious challenge in all societies. Nowadays, pollutants are measured by various tools and devices, including local particulate measurement instruments and ground-based remote sensing devices. This paper aims to estimate dust downfall time in dusty days of Zanjan city using the data obtained from ground-based aerosol sampling device and sunphotometer. The particulates with the size of less than 10 micrometers (PM_{10}) were measured by ground-based measurement device in the height of 3 meters above the ground, while aerosol optical depth (AOD), which represents the amount of aerosols in vertical column of atmosphere, was measured by sunphotometer. According to correlation coefficient diagram, PM_{10} and AOD reached a maximum of 2, 6, 3 and 3 hours in dusty days of 9, 10, 24 and 25 June 2010. In other words, dust downfall took 2, 6, 3 and 3 hours respectively in the aforementioned days.

Keywords: Downfall, dust, sunphotometer, correlation

1 Introduction

Aerosols are solid and liquid particles in the air. These particles may be produced by natural sources (e.g. dust particles, sea salt and volcanic activities) and artificial sources (e.g. industrial activities, transportation and fuel) (Seinfeld and Pandis, 1998).

Nowadays, particle pollution has become a serious challenge in the Middle Eastern countries such as Saudi Arabia, Iraq and Syria. In Iran, likewise, people are facing particulate matter for many days of a year (even tens of days in certain areas). Generally, the Middle East is one of the most susceptible regions to dust storms due to the circulating structure of atmosphere combined with surface coverage and fine-grain alluviums (Mofidi and Jaafari, 2011). Iran is situated in dust belt embracing northern Africa, Middle East and central and southern Asia (Prospero., et al, 2002). This fact, combined with western direction of atmospheric circulation, has caused the western regions of Iran, including Zanjan Province (where there is no source of local dust) to be engaged with dust problem. When there is a relative atmospheric stability, the dust settles on the ground and reduces the visibility, develops respiratory diseases, and gives rise to many other problems. In situ instruments are often too sporadic, so air quality estimates in the areas lacking these stations have no acceptable accuracy. To remove this problem, other sources must be used to investigate air pollution and air quality. Among these sources is remote sensing data. Sunphotometer stations are used to precisely monitor the particulate matter and air pollution. Aerosol optical depth (AOD) obtained from sunphotometer may be correlated with the concentration of pollutants, so it may be used to obtain the required data on the concentration of pollutants and air pollution. Luminita et al. (2011) conducted a study on the relationship between particulate density and AOD in two suburban areas in Romania and an urban area in England during 2007-2009. The results of linear regression analysis indicated a significant correlation coefficient of 0.7 between AOD and particulate density. They found that sunphotometer was an efficient alternative for improving air quality supervision and extending spatial coverage. Moreover, they extracted AOD data from AERONET network (Luminita and Sabina, 2011).

1.1 Deposition and Accumulation of Dust

Dust is transmitted in three steps: loading from the ground, carrying through the atmosphere, and deposition on the ground.

The distance traveled by dust depends on various factors including speed, turbulence, wind, dust properties and deposition speed. Deposition speed is determined by the mass and the shape of each particle. Dust deposition occurs in two forms: gravitational deposition (dry deposition) and rainfall deposition (wet deposition). Wet deposition may occur below the clouds, where raindrops or snowdrops wash out the dust or where dust particles inside the clouds are trapped by water drops. Sometimes deposition occurs in dust rain phenomenon.

The relative importance of dry and wet depositions may vary depending on the season, rainfall and location. Wet deposition can be measured directly, while dry deposition is normally estimated by measuring aerosol concentration and deposition speed (Prospero, 1996). Nevertheless, there exist various methods which may produce different results (Torres-Padron, 2002).

In Mediterranean region, dry deposition is the dominant type of deposition, particularly in summer season when dust concentration is in maximum level and the rainfall is in low level. On the other hand, the North Pacific Ocean is dominated by wet deposition (up to ten times dry deposition) (Zhao et al., 2003). China is dominated by dry deposition, while Korea, Taiwan and the eastern sea are dominated by wet deposition. As we move towards the south, wet deposition gains the relative dominance in a belt which is under the influence of tropical convergence and rainfall (Sarthou et al., 2003).

Dust deposition in land areas often occur in dry form, particularly when particles pass through rough areas. Plantation is an efficient method for trapping the dust. Rocks do the same job, but rocky lands maintain only 20% of the deposited dust (Goossens, 1995).

Generally, the bigger the dust particles, the sooner they fall down on the ground. According to common theories on deposition speed, a large part of the particles which travel more than 100 kilometers away from the source have a diameter of less than 20 micrometers (Gillette, 1979). Nevertheless, many researchers have found particles in the size of sand (bigger than 62.5 micrometers) in a noticeable distance from the source. Such particles, also called giant particles, have been found in different regions, including Cape Verde Islands (Glassium and Peraspro, 1980), Canary Islands and South of Britain (Madilton et al., 2001). Giant particles have also been recorded in farther distances from their sources. Such particles have been witnessed in the

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northeast of Africa on the Pacific Ocean (Betzer et al., 1988). The presence of big particles in such a large distance from their source is unexpected because they have a high deposition speed (Betzer et al., 1988; Midelton et al, 2001). Such transportation distance cannot be explained by today's knowledge on atmospheric transmission mechanisms.

Dust deposition should be distinguished from dust accumulation. According to Gosnes (2005), deposition refers to the amount of settlement which affects the surface unit during a specific time, while dust accumulation refers to the amount of deposition which remains on the surface at the end of a time interval.

The available data suggests that a large amount of deposition may occur in certain areas. For example, deposition was estimated to be $10^7 \times 15$ tons the northern Africa dust rain in 1901. In the dust rain of England in 1903, this figure was estimated to be 10^7 tons.

1.2 Study Area, Data and Methodology

Dust sources are distributed on the earth on an irregular basis. The majority of dust sources are located in the northern hemisphere, between the northern Africa, Middle East, and central and southern Asia. Iran is located in this area, known as dust belt.

Powerful convection flows near the ground cause particles to enter the atmosphere. In mountainous areas, evaporation develops a cold air front. As the result of contact between the compressed cold air and warm air, a powerful convection flow lifts the particles from the ground (Knippertz, 2007). Dust storms emit a noticeable amount of dust into the atmosphere. Dust density sometimes reaches 200 microgram/cubic meter (http://www.archive.worldpressphoto.org.).

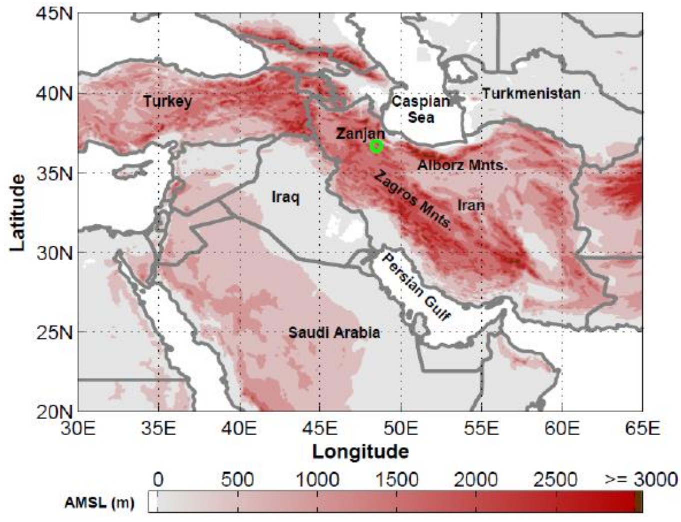

Fig 1: Elevation map of the Middle East. Zanjan is highlighted by green circle [17].

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The size of aerosols may vary from a couple of nanometers to 100 micrometers. The properties of aerosols highly depend on their size. Distribution of particle size is an important parameter for determining particle dynamics, displacement, deposition, and aerosol stay duration in atmosphere. PM_{10} is deposited within a couple of hours, while $PM_{2.5}$ remains in the air for many days or weeks and travels long distances.

Big particles tend to settle on the ground quickly due to gravity, so they are often close to emission sources. On the other hand, small particles tend to stay in the atmosphere for a longer time and consequently settle away from their sources.

To investigate the correlation between aerosol optical depth and particulate density, we used the following correlation formula:

$$corr(x,y)=\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

In this equation, x_i is AOD data, y_i is the density of particulates with the size of less than 10 microns (PM_{10}).

For this purpose, we obtained AOD data in the wavelength of 870 nanometers from the sunphotometer located at the faculty of physics of Zanjan basic sciences post-graduation university and obtained PM_{10} data from Zanjan Environment Department.

2 Results and Analysis

Aerosols are deposited in two ways: dry deposition and wet deposition. Dry deposition occurs when the particle falls down on the ground as the result of gravity. Web deposition occurs when the particle is deposited by raindrops.

The simplest motion of aerosols in the atmosphere is straight and steady movement. In this type of movement, aerosol has a constant speed based on an external force, which is called final speed of aerosol. Here, the external force is the gravity. Therefore, aerosols tend to come down and settle on the ground. Using Stokes law, we obtained the final speed of aerosols as follows:

$$u_t=\frac{g(\rho_p-\rho)D_p^{\ 2}}{18\mu} \quad (2)$$

In this equation, g is gravitational acceleration which equals 9.8 m/s/s, ρ_p is particulate density, ρ is air density, D_p is particle diameter, and μ is air viscosity. Deposition speed of PM10 has been estimated to be 30 mm/s.

2.1 Linear Regression Diagram of PM10 and AOD

Figure 2 illustrates the linear regression diagram of PM10 and AOD and the corresponding time change for summer season during 2010-2012. The correlation coefficient of 0.83 for summer season indicates that a good correlation exists between AOD and PM10 in summer season. Time change diagram and linear regression diagram indicate that AOD and PM10 have a similar time change. The lack of 100% relationship between these two variables may be explained by the increased PM10 due to surface

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wind on the ground, resulting in the reduced AOD. On the other hand, a great deal of aerosols may exist above the ground and in troposphere and might not settle on the ground, resulting in the reduced correlation. There is also a good relationship between the data in time change diagram, in which PM10 and AOD have been depicted simultaneously.

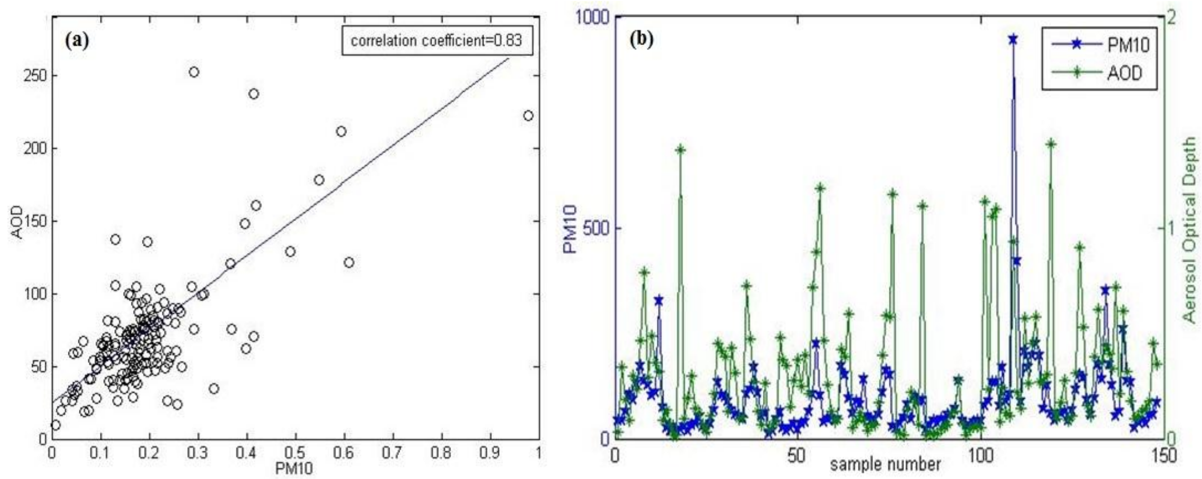

Fig 2: Linear regression diagram for AOD and PM10 in Zanjan atmosphere during 2010-2012 for (a) summer season and (b) time changes of AOD compared to PM10 in this season

Given that Zanjan has no important local source and the previous studies indicate that surface winds do not play a significant role in dust movement in Zanjan city (Masoumi, 2012), it is concluded that dust pollution in Zanjan city has a non-local origin. This pollution is transmitted from external sources to Zanjan atmosphere by upper swift winds or jet flows.

2.2 Correlation of AOD and PM10 with Visibility

Figure 3 (parts (a) and (b)) illustrates the average visibility in Zanjan city during the period under study in terms of PM10 and AOD in the wavelength of 870 nanometers. As shown in the diagram, there is a negative correlation between AOD and PM10, which indicates that the increased PM10 has resulted in the reduced visibility in Zanjan City. Moreover, there is a weaker relationship between AOD and visibility (part b). This means that the entire dust has not settled on the ground, with a portion remaining in the air.

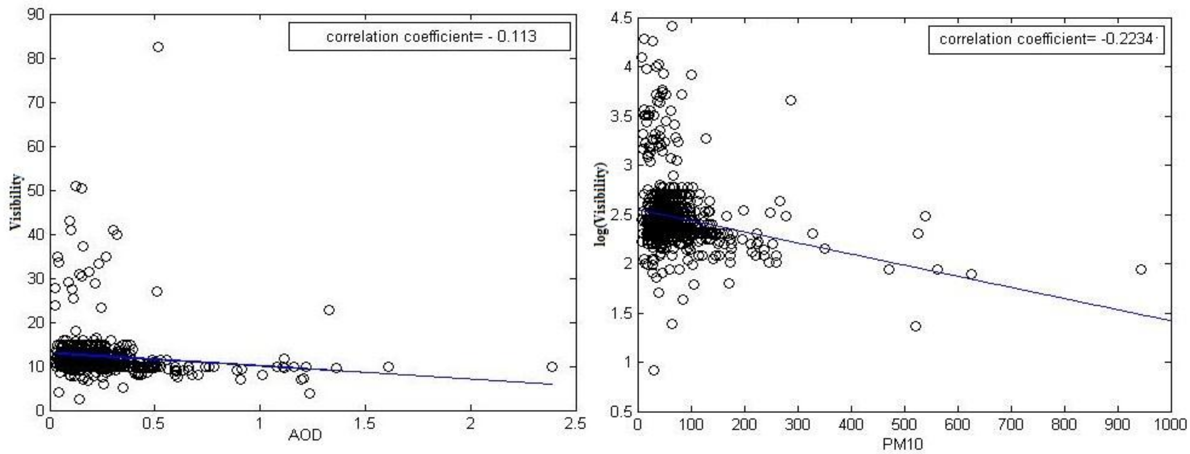

Fig 3: The average daily visibility of Zanjan city during 2010-2012 in terms of (a) the average daily PM10 and (b) the average daily AOD in the wavelength of 870 nanometers

The big correlation between PM10 and AOD in Zanjan atmosphere indicates that the majority of aerosols in upper layers of atmosphere have settled on the ground.

2.3 Estimate of dust downfall time

Aerosols may remain in atmosphere from several days to several weeks. If aerosols enter the upper layers of atmosphere (above troposphere), they may travel very long distances, even between the continents. This explains the global impact of aerosols.

Dust particles are normally coarse particles. If not moved to the height of 15000ft and more by severe dust storms, dust particles settle on the ground (Ginoux, 2001). Though having a relatively short lifetime, aerosols may travel long distances. For example, particles which move with an average speed of 5 m/s remain in the atmosphere for one week and travel a distance of 3000 kilometers (Chin, 2009). Aerosols are dispersed by horizontal movement of air. The best example of transmitted aerosols is dust aerosols which are transmitted from Africa and Asia to other continents (Duce et al., 1980; Prospero, 2005). The majority of dust sources are close to the surface. Aerosols have the highest concentration in boundary layer and remain in troposphere. Coarse particles rarely go up to upper layers due to gravitational deposition, but volcanos are able to move aerosols and gases directly into stratosphere.

Figure 4 illustrates the correlation coefficient between AOD and PM10 for four dusty days in summer season (9, 10, 24 and 25 June 2010) with time step of one hour.

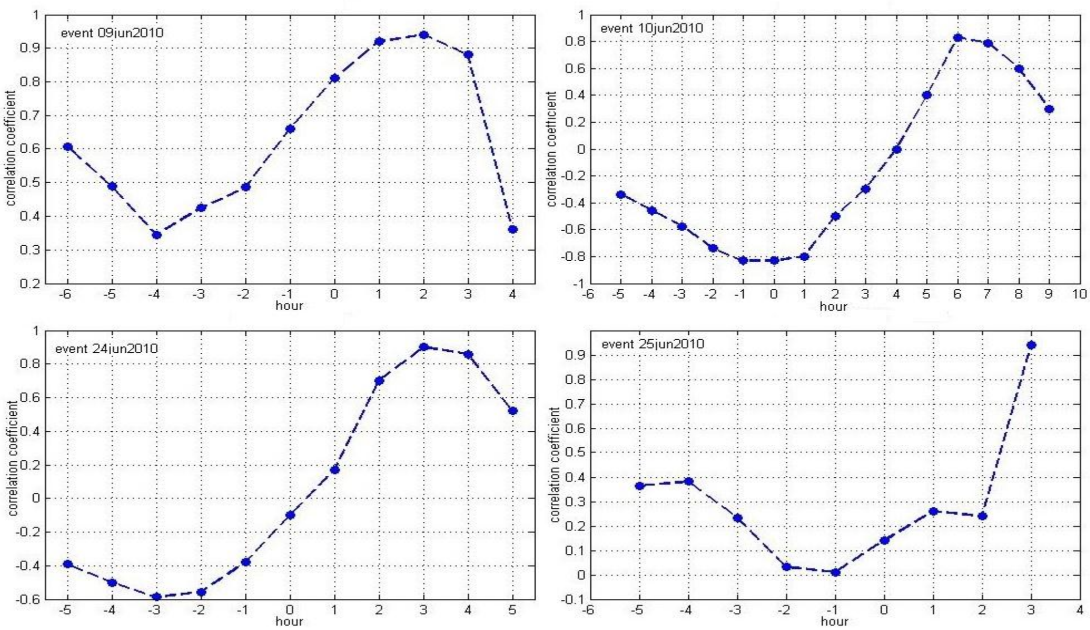

Fig 4- correlation coefficient between AOD and PM10 with time step of one hour for 9, 10, 24 and 25 June 2010

Zero hour indicates the correlation between these two variables. The diagrams show the correlation coefficient between AOD and PM10. For example, a maximum correlation coefficient is seen in 2 hours prior to the event in dusty day of 9 June 2010. This means that dust layer downfall has taken 2 hours. On 10, 24 and 25 June, dust downfall has taken 6, 3 and 3 hours respectively (positive times mean time delay from zero time).

3. Conclusion

In this study, we estimated dust downfall time for four dusty days (9, 10, 24 and 25 June 2010) using the coefficient of correlation between PM10 and AOD with time step of one hour. We found dust downfall in the vertical column of atmosphere took about 3 hours. Given that no rainfall has occurred in the said days, dust deposition type has been dry deposition or gravitational deposition. We also studied the correlation between PM10 and AOD during 2010-2012 and found that a good correlation (0.83) existed between them. therefore, sunphotometer can be used in the areas which lack ground station.

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