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Analyzing Black Cloud Dynamics over Cairo, Nile Delta Region and Alexandria using Aerosols and Water Vapor Data

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1. Introduction

Cairo is the largest city of Africa and one of the world's megacities, with a population of more than 20 million people and containing more than one third of the national industry. It is a rapidly expanding city which leads to many associated environmental problems. As a result, it is also one of the most air polluted megacities in the world (Molina and Molina, 2004). It suffers from high ambient concentrations of atmospheric pollutants including particulates (PM), carbon monoxide, nitrogen oxides, ozone and sulfur dioxide (Abu-Allaban et al., 2007, Abu-Allaban et al., 2002, El-Metwally et al., 2008). The pollution phenomenon locally known as "Black cloud" over Cairo has been attributed to many reasons among which are biomass burning, local emission and long range transport during the fall season. Several studies have been conducted to address and discuss the forth mentioned reasons for the increased pollution levels over Cairo and the greater Delta region using ground-based and satellite air quality data as compared to other megacities (Abu-Allaban et al., 2002, 2007, 2009; Alfaro and Wahab, 2006; El-Askary and Kafatos, 2008; El-Metwally et al., 2008; Favez et al., 2008; Kanakidou et al., 2011; Mahmoud et al., 2008; and Marey et al., 2010; Prasad et al., 2010 and Zakey et al., 2004). Marey et al. (2010) utilized a multi sensor approach using the Moderate Resolution Imaging Spectrometer (MODIS) and the Multi-angle Imaging SpectroRadiometer (MISR) with meteorological data and trajectory analyses to determine the cause of these events and to examine reasons for the black cloud formation over Cairo. MODIS fire counts identify the aerosol source as the burning of agricultural waste after harvest season in the Nile Delta region. MISR data show that these fires create low altitude (<500 m) plumes of smoke that flow over Cairo in a few hours, as confirmed by Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) forward trajectory analyses. However, Prasad et al. (2010) suggest that the long range transport of dust at high altitude (2.5-6 km) from the Western Sahara and its deposition over the Nile Delta region is one of the major contributors to air pollution episodes during this season.

Cairo experiences different seasonal climate systems impacted by the western desert through sand and dust storms, as well as local, increasing anthropogenic activities. As a result, it is characterized by a complicated meteorology, varying with the time of the year and resultant pollution which is worst during the black cloud episodes reported in this paper and in turn affecting the local climate (Zakey et al., 2004) During winter the climate is generally cold, humid and rainy; while during the summer season the predominant weather is hot and dry (Zakey et al., 2008). Hence, the city witnesses significant impacts on the public health (Hossny et al., 2001). On the other hand, Alexandria as a Mediterranean city has better climate conditions, yet being the largest industrial city, with ~55% of total Egyptian industry, suffers from pollution episodes, which are, however, still not as intense as the ones usually observed over Cairo. El-Metwally et al., (2008) and El-Askary et al., (2009) revealed that Cairo's and Alexandria's aerosol includes; "background pollution'', ''pollution-like'', and ''dust-like'' components. Generally speaking, Egypt is influenced by the regional scale trade wind system that is enhanced during the warm period of the year resulting in winds over Egypt are from North supporting the sea-breezes along the Mediterranean coastline (Kallos et al., 1998, 2007; El-Askary et al. 2009). It has been thought that pollution episodes occur only over Cairo and are due to local emissions; however, we will show that there are large emissions from the surrounding cities that are likely contributing to Cairo pollution. On the other hand, it is noteworthy that the low topography of Cairo bounded by Giza (western highlands) and Mokatam (eastern highlands) contributes as well to the onset of these pollution events, compared to the surrounding region previously reported (El-Askary, 2006). During the autumn season, aerosols originating from the biomass burning from different cities within the Nile Delta, add to the region's anthropogenic aerosols, and hence contribute to bigger pollution events. Here, we propose a wider contribution from other anthropogenic sources in surrounding cities among the major contributors to this problem. Cairo, Alexandria, together with other cities within the greater Nile Delta region extending from ~ 29° to 31° N, are the sites of the present study. Five locations within the Delta together with Alexandria, a coastal city, have been selected for this analysis based on their locations with respect to Cairo and the reported polluting events. Cairo together with the other relevant cities is located in the Northern Delta Region, which is a heavily populated area. However, Alexandria is located along the Mediterranean Sea and is the only coastal city involved in this analysis (Figure 1).

This work presents an attempt to study the wide spatial distribution of pollution over Northern Egypt. (Table 1) shows the locations of the cities under investigation and their main sources of air pollution, namely heavy traffic / industrial / residential / commercial / mixed emissions or biomass burning.

Fig. 1. Base Map for cities under consideration

City	Latitude	Longitude	Activity or pollution source
Alexandria	31.213 N	29.944 E	Industrial/Residential and traffic sectors
Tanta	30.779 N	30.996 E	Burn harvest byproducts Industrial/Residential
Damanhur	31.040 N	30.469 E	Burn harvest byproducts/Residential
El Mahala	30.975 N	31.163 E	Industrial/Excessive emissions from brick factories
El Mansoura	31.039 N	31.379 E	Burn harvest byproducts Industrial/Residential
Cairo	30.064 N	31.249 E	Excessive pollution from industrial/Dump sites burning and traffic sectors

Table 1.Cities locations for AOD and WV analysis and their possible pollution source

2. Aerosol Optical Depth (AOD) and Water Vapor Column (WVC) data used

Over the last decade aerosols have been studied quantitatively regionally and globally using satellite remote sensing. Such studies are very useful in climate studies (Kaufman et al., 2002; King et al., 1999). The Mediterranean basin aerosols belong to a variety of sources, either being natural (sea salts, desert dust) or anthropogenic (local sources) due to the increasing urbanization and industrialization, as well as long range transport from Europe (Astitha et al., 2008; Kallos et al., 1998, 2007). As such, AOD obtained from the MODIS data was used to study urban air quality (Engel-Cox et al., 2004). Diversity in the aerosol origin influences to a great extent their optical properties (Pace et al., 2006). The data set used in this study involves six years of monthly average observations of AOD over the Delta region derived from MODIS level-2 AOT atmospheric daily products data at a 10 km resolution. The WVC data are obtained at the 1-km MODIS spatial resolution. The Level 2 data are generated at the 1-km spatial resolution level using the near-infrared algorithm during the day and at 5×5 1-km pixel resolution for both day and night. The AOD parameter obtained from the MODIS data is used as an indicator for the black cloud impacts on the optical properties of the aerosols forming in the vertical column of the atmosphere. It is well known that Northern Egypt suffers from variability of atmospheric pollutant sources and hence the mixing processes scenario in the atmosphere is most likely a mixed aerosol type. Since we are studying the impact of anthropogenic pollutants on aerosol optical properties during the fall season, characterized by the well known black cloud pollution episodes, a seasonal component is expected to affect the AOD values. Therefore, AOD obtained from the MODIS sensor over the period February 2000 to August 2009 is detrended using climatological values to remove any seasonal contribution to observed main anomalies (Gautam et al., 2007). De-seasonalizing is performed for the time series at each grid location by calculating the deviations from the climatological mean annual cycle. Hence, the anomalies in the annual cycle can more easily be inferred.

The high AOD values over Cairo are a result of the unregulated continuous emissions, coupled with the stable meteorological conditions by weak wind currents as well as almost neutral stratification (El-Askary, and Kafatos, 2008). High AOD values associated with slowly moving air masses are generally accompanied by higher precipitable water vapor (Xia et al., 2007). We anticipate that high WVC will be observed regionally over locations where high AOD is also observed. The MODIS precipitable water product consisting of the water-vapor column is essential in understanding the aerosol properties, and aerosol-cloud interactions (Jin et al., 2005).

2.1 Aerosol data analysis

Monthly average Aerosol Optical Depth (AOD) and Water Vapor Clear Column (WVC) over Cairo, Alexandria and the Delta cities of Damanhur, Tanta, El Mahala and El Mansoura were analyzed for 2000-2009. High AOD values are observed during the September, October and November (SON) season, over all locations at different levels showing the regional extent of such pollution events. Figures 2a and 2b show monthly average values of AOD and monthly AOD anomaly during the period from February 2000 to August 2009 over the six cities.

Figure 2a shows a strong variability and similarity in the aerosol patterns over the entire region associated with the presence of a clear annual component for the locations under investigation. It also shows the presence of two main peaks corresponding to dust and anthropogenic episodes superimposed on the annual variability over the six locations within the entire time period (Figure 4) (El-Askary, and M. Kafatos, 2008). This result favours the idea of treating the overall pollution phenomenon as a regional one, rather than just being a local phenomenon over Cairo. However, for better visualizing the high AOD concentrations without the annual variability component, the climatology has been extracted out and only the anomaly is presented here (Figure 2b). Moreover, it is clear that the AOD variability over Cairo, El Mahala and Tanta are slightly higher than El Mansoura and definitely higher than those over Alexandria and Damanhur (Figure 2b).

This is attributed to the fact that Alexandria and Damanhur are located in the vicinity of the Mediterranean and are subject to a component of sea and land breeze as well as wet deposition which contribute to a speedy cleaning up of the atmosphere. Alexandria is the biggest industrial city of Egypt, since it accommodates >65 % of the petroleum related industries and >55 % of the entire industrial sector, yet as we said above, it doesn't suffer as intense pollution episodes as Cairo, raising a question about the overall sink of these pollutants.

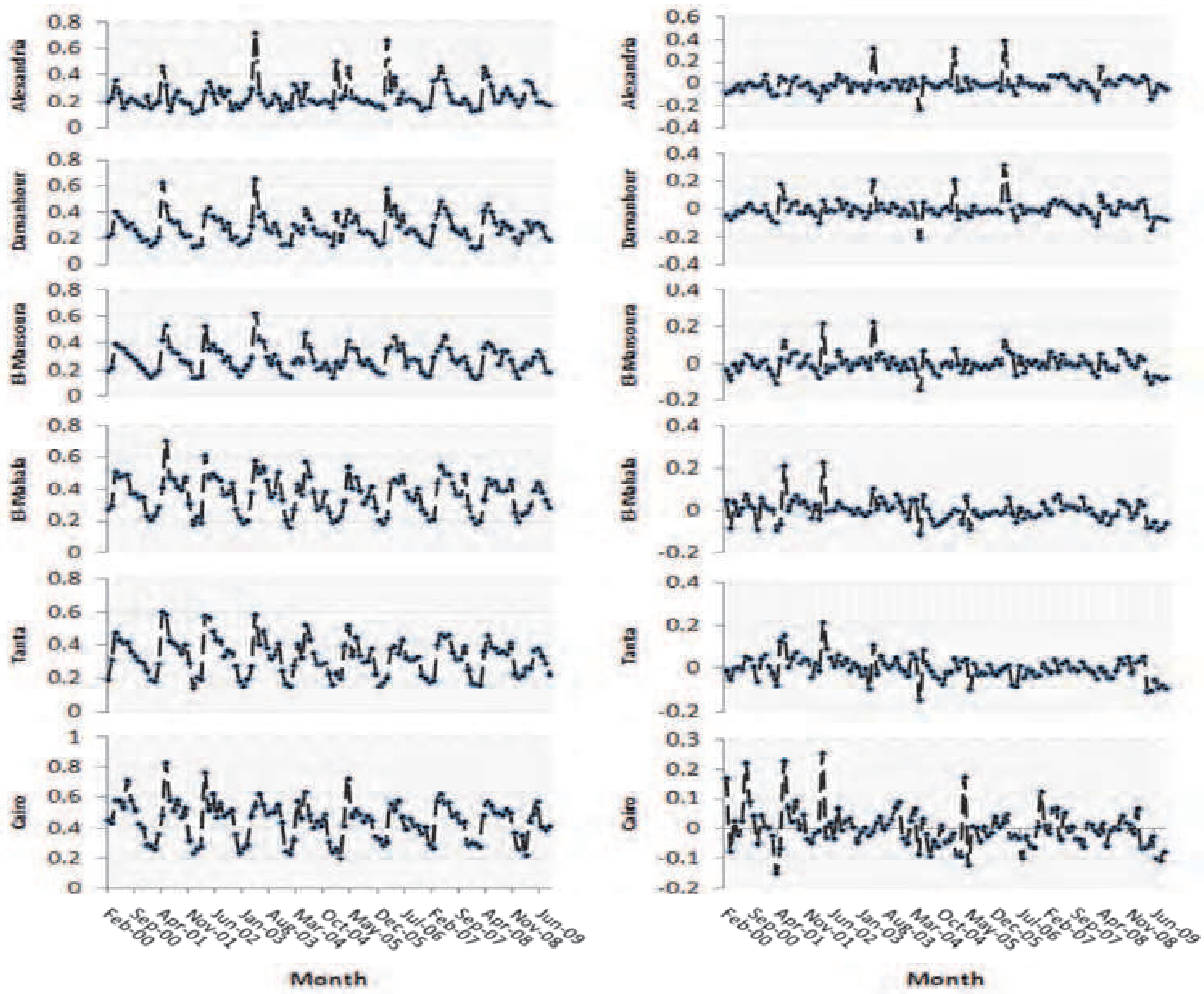

Fig. 2. Aerosol Optical Depth (unitless) Over Delta Region Cities from February 2000 to August 2009 a) Original data B) De-seasonalized data

As emphasized here, the aerosols over the Northern coast of Egypt and the Delta region can have origins other than just local ones. These seasonal aerosols may be either from natural causes, for instance desert dust particles directly transported from the Western desert regions; or anthropogenic aerosols from the industrialized areas, maritime particles produced over the Mediterranean and smoke particles from seasonal biomass fires (Barnaba and Gobbi, 2004). Luria et al. (1996), Millan et al. (1997), Kallos et al. (1998, 2007), Prasad el al. (2010) found that this geographical region is exposed to long range transport of anthropogenic pollutants as well as dust particles. According to their findings, long range transported (mainly from Europe) anthropogenic aerosol concentrations are very high during the warm period of the year due to the prevailing trade wind patterns, photochemical activity and absence of precipitation. During the transient seasons, and mainly spring, the desert dust transport is a major contributor. Sea-salt particles contribute to aerosol concentrations over the coastal areas, mainly during weather conditions with strong winds (synoptic scale component). It becomes more important during winter due to the passage of synoptic systems and during summer due to trade winds (from N) and the wave breaking activity along the coast. Here we also show long range transport of desert dust from Western Sahara that passes over the eastern Sahara during September-October (Figure 3).

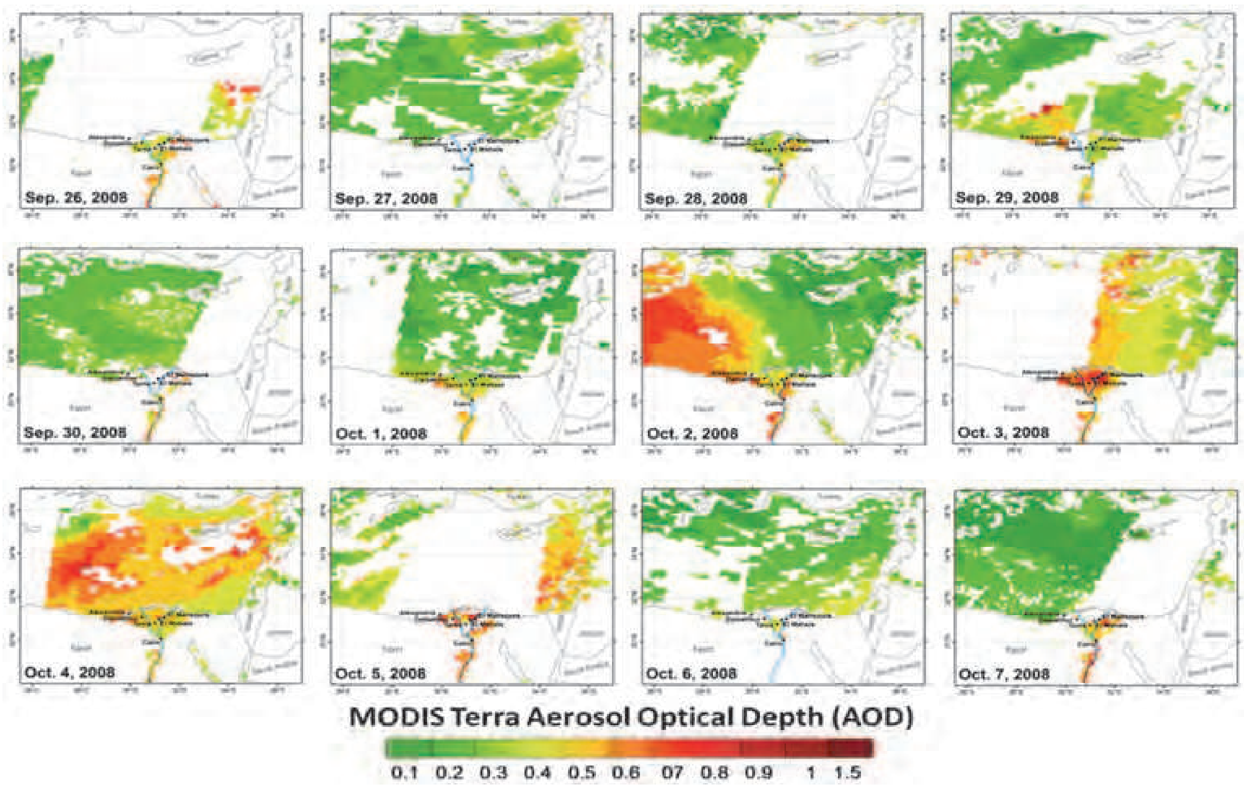

Fig. 3. The long range transport of pollution (aerosols) across the Mediterranean Sea (west to east) during Fall season.

The eastward movement of plume of desert dust (red color region, Figure 3) is visible over the Mediterranean using daily MODIS AOD during the month of October, 2008 (Figure 3). The high altitude desert dust gets deposited over the Nile Delta due to the presence of favourable wind field (subsidence) over the region. This phenomena not only causes large increase in the aerosol loading over the region but also increases the complexity of nature and source of aerosols (Prasad et al., 2010) (Figure 3). The mixing of anthropogenic pollution with the desert dust eventually increases the total pollution load and also affect the climatic conditions over the region. The variability in AOD follows this known pattern (Figure 4).
Small error bars in the plot reflect a narrow region of uncertainty; in other words, the accuracy of the plotted data with varying AOD values over different months of the year is high. The primary peak is during the spring season in all cities and can be easily attributed to the contribution from desert dust (Figure 4). This is due to the well known intense dust storms over Sahara associated with the prevailing south western winds, called Khamasine, affecting the Greater Cairo region. Figure 2 also indicates a smaller increase in the aerosol levels during October of each year compared to April and May, with particularly high values over Cairo, El Mahalla and Tanta; while the data show slightly earlier increase during the month of September over Alexandria, Damanhur and El Mansoura, and continuing through November. Higher AOD values have been observed from the AOD seasonal mean plots over Cairo, El Mahala and Tanta during September and October of each year, yet lower values have been observed over El Mansoura, Damanhur and Alexandria. The highest AOD values are observed over Cairo owing to its low topography and the frequent appearance of an inversion layer during this time of the year (El-Askary, 2006). As it is well known, during autumn, the prevailing winds are from northern and west sectors

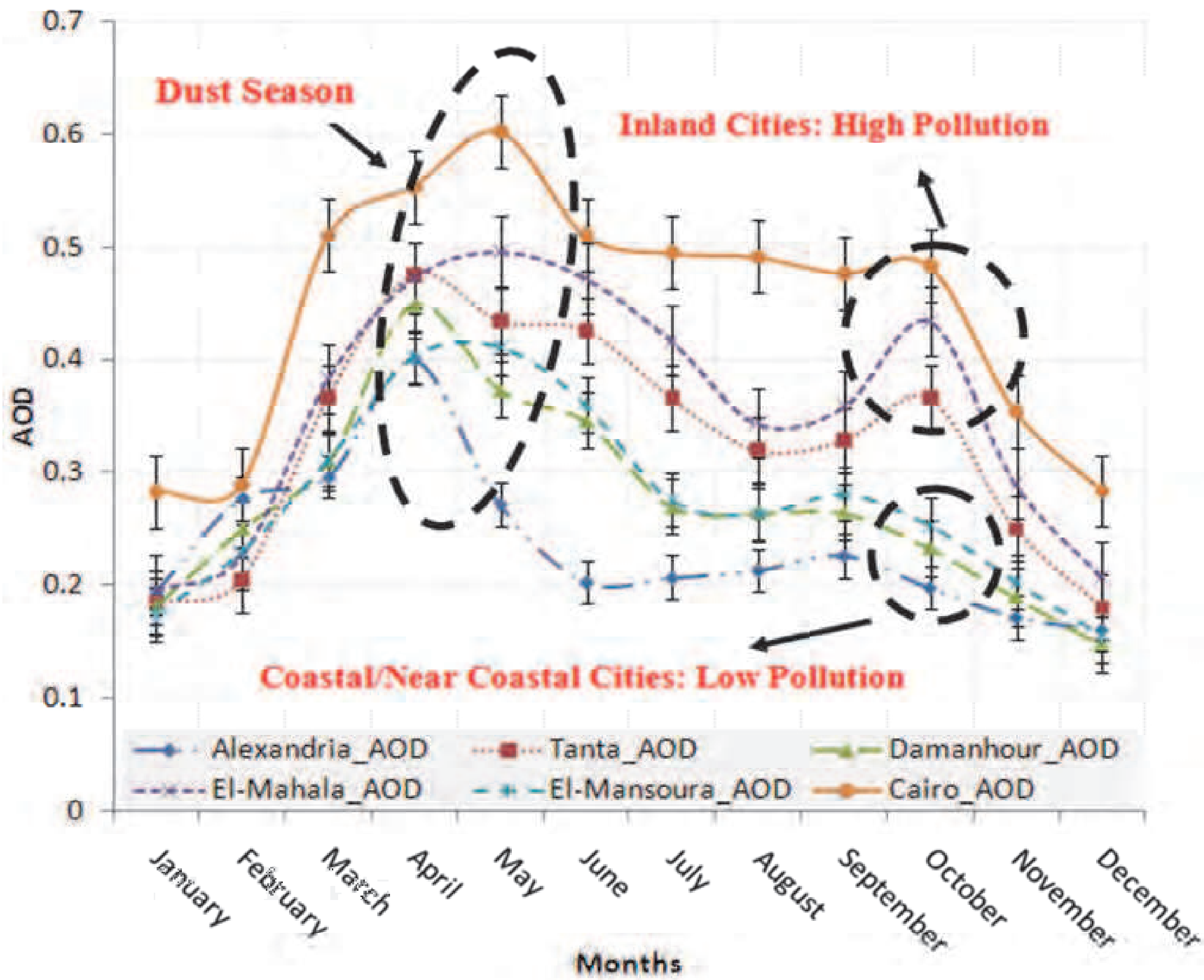

Fig. 4. Seasonal means of Aerosol Optical Depth (unitless) from February 2000 until August 2009 over the Delta region

with moderate to low speeds (>65%) (Favez et al., 2008). This is attributed mainly to the sea breeze formation that exhibits a daily variability. These sea breezes penetrate deep inside from the coast since they are supported by the regional circulation. Since Cairo is downwind from well known pollution sources (e.g. the industrial area of Alexandria, seasonal biomass burning in Nile Delta, and other major urban areas), the resultant air pollution concentrations in the vicinity of it must have a considerable contribution over regional scale.

2.2 Enhanced total column water vapor with dust storms and pollution aerosols

Our aerosol related results have been corroborated through studying the WVC during the same time frame over the same locations. The relationship between water vapor and aerosols of all kind is well known (Steyn and Kallos, 1992). Therefore, looking at the water content in the atmosphere over the area under consideration we will be able to derive useful correlations with the aerosol concentrations (or AOD) and better explain the seasonal variability. For this reason, time series of WVC were constructed for the same time period and locations as for AOD (Figure 5).

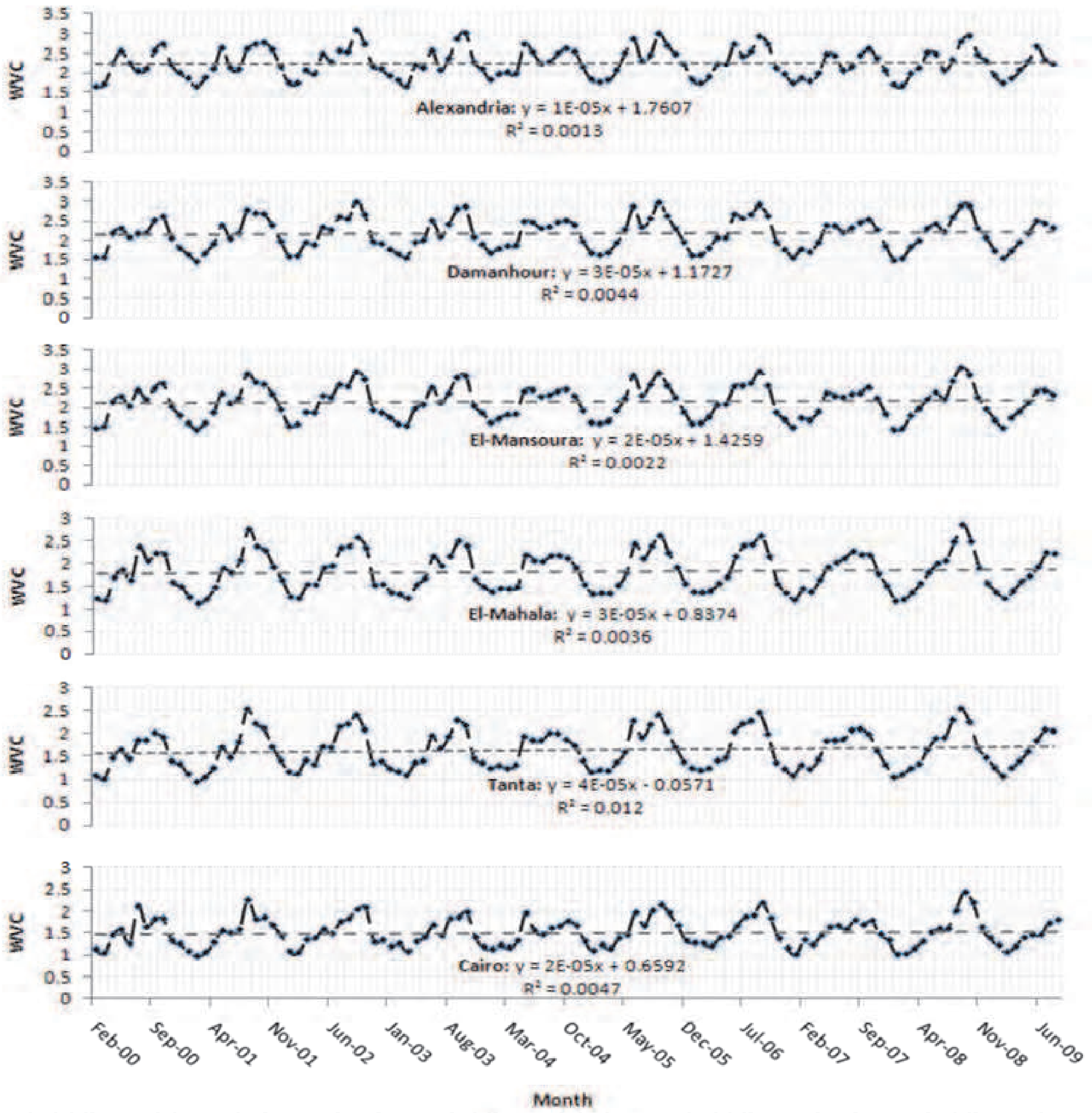

Fig. 5. Water Vapor Column (cm) over the Delta region cities and Alexandria from February 2000 until August 2009

Precipitable water vapor is a measure of the water vapor content of the air. It is one of the most important greenhouse gases of the atmosphere, participating in a major way in the energy cycle (latent heat). Moreover, it regulates the planetary temperatures through absorption and radiation emission, most significantly in the thermal infrared (the greenhouse effect). However, the indirect forcing involving the interactions between aerosols and clouds, impacting climate, has large uncertainties (Houghton et al., 2007).

Satellite data over the area under consideration show that there is an increasing trend in WVC off the coast of Egypt and over the Nile Delta region. The increase over Cairo and the Delta region is consistent with pollution patterns, implied by the AOD values, during 2000–2009. This is due to the existence of absorbing and non-absorbing aerosols emitted from the

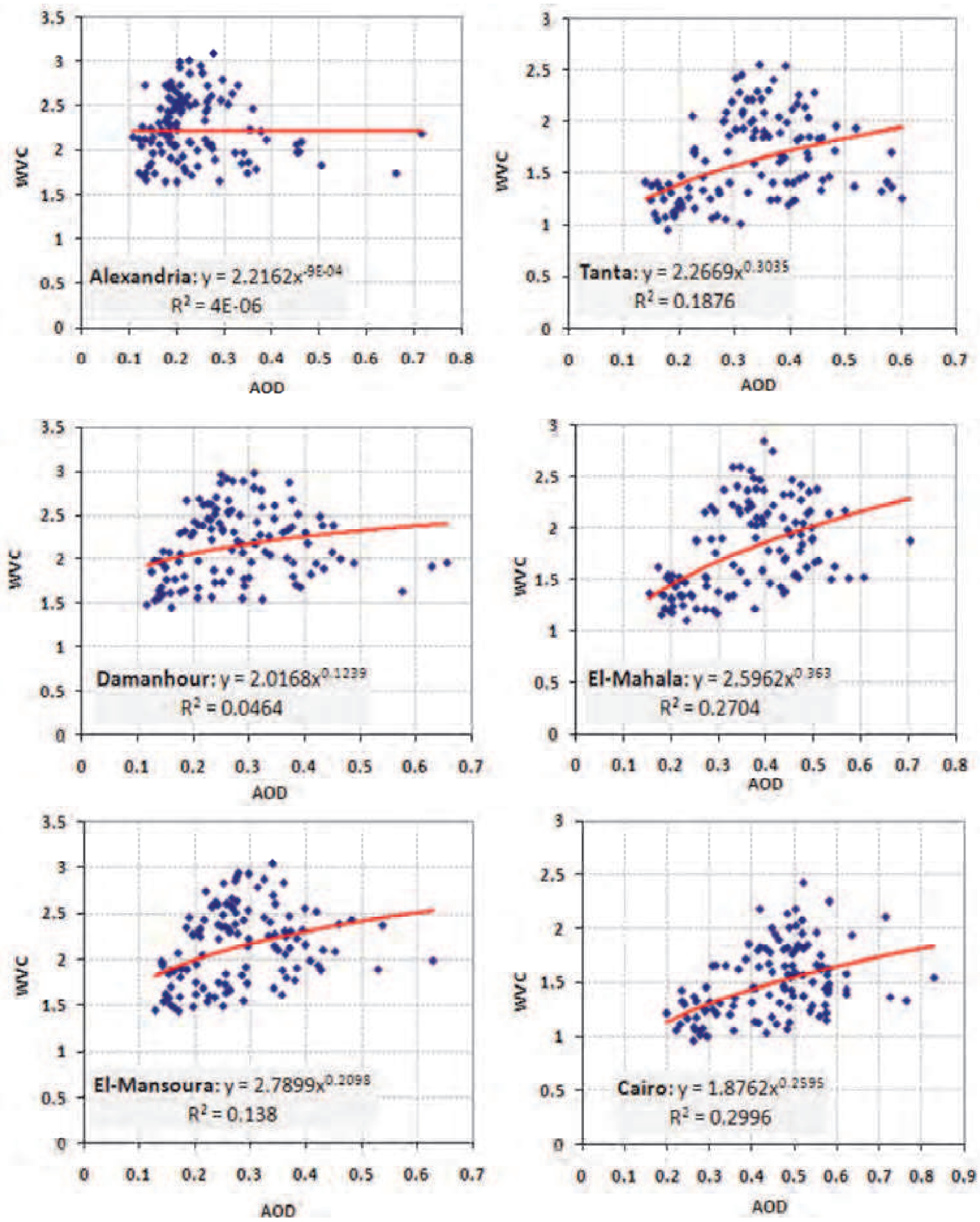

Fig. 6. Power correlation between MODIS AOD and MODIS water vapor (near infra-red, clear column) from February 2000 till May 2009 the six cities.

different cities (Prasad et al., 2006) (Figure 5). However a more increasing trend has been observed over Alexandria, Damanhur and Mansoura as compared to the increasing trend over Cairo, Tanta and El Mahala. This is likely due to the near coastal location of the first three cities compared to the inland location of the later ones. Their location contributes to a higher degree in the presence of more WV particulates due to higher evaporation rates associated with the Mediterranean. The observed increasing trend of the WVC over the Delta region suggests the aerosol contribution in possible local climate changes. Figure 6 shows monthly MODIS derived AOD versus mean water vapor (near-infrared, clear column) variations.

Enhanced level of water vapor is found over the inland cities (Cairo, Mahala and Tanta) subjected to intense dust storms and anthropogenic pollution. We have studied total column aerosol loading and associated water vapor content during the whole time period. Inland cities clearly indicate an increase in power correlation between mean MODIS AOD and mean MODIS water vapor (near-infrared clear column) from 0.0004%, 4.6%, 13.8% (Over Alexandria, Damanhur, Mansoura) to 18.7%, 27%, 29.9% (Over Tanta, Mahala, Cairo) due to the influence of dust and pollution outbreaks evidenced from the absolute rise in AOD (Figure 4). Power correlation study of mean MODIS AOD with mean MODIS WVC is found to be more sensitive for such studies than the use of max MODIS AOD (Prasad et al., 2007).

2.3 AOD and WVC cross correlation analysis

A cross correlation analysis was carried out for the six cities twice, in order that any aerosol contribution from one location to another would be determined. The first analysis deals with the AOD observations while the second analysis is performed on the WVC values. For each parameter this analysis has been carried out six times having each city taken as a reference point, with lags ranging from the preceding to the following six days during the entire period of study.

(Table 2) shows only the significant correlation coefficients (CCs) for AOD with their corresponding lag values. The term rank is used here to indicate the order of the highest correlations between the ranked and the reference cities for lag 0.

High and significant CCs with confidence level 95% are observed between all the cities and their corresponding reference city at zero lag. High CC between cities indicates the regional scale of the phenomenon (i.e. subject to the same meteorology), hence are more dominant in cities within the Delta region that are more inland and away from the Mediterranean Sea. Delay in CC means local transport between cities, yet high and significant coefficients are still observed at a lag of one preceding or following days in most of the cases. This shows that pollution might not be local for some cities, in other words, some cities may be receiving most of the pollutants from the surrounding locations. Figure 7 shows high and significant CCs of AOD between Alexandria and Cairo for few days through different years at one day lag which provide the evidence of transported pollutants from Alexandria to Cairo.

The presented results strongly support the notion of contributing aerosols from surrounding cities to the pollution crisis over Cairo.

CCs and rank values in (Table 2) show that El Mahala and Tanta AOD values contribute to a great extent to the severe pollution episode experienced over Cairo. A CC of 0.995 and a rank of 1 are observed between Cairo and El Mahala in both cases when each of them is the reference city. Moreover a CC of 0.7558 is observed at lag -1 and lag 1 when El Mahala and Cairo are considered as the reference cities for each other, respectively. Since the reference city leads to positive lag values, it is clear that El Mahala is the site contributing to the Cairo pollution and not the other way around. This means that the ground based strong pollution from smokestacks of brick factories and other industrial activities located in El Mahala, are partially contributing to the black cloud events over Cairo and the Delta region.

a) Alexandria Reference*			b) Tanta Reference*			c) Damanhur Reference*		
City	CC	lag	City	CC	lag	City	CC	lag
	0.4959	-1		0.4707	-2		0.4037	-2
Tanta	0.7775	0	Alexandria	0.6890	-1	Alexandria	0.6398	-1
Rank (3)	0.6890	1	Rank (5)	0.7775	0	Rank (5)	0.8896	0
	0.4707	2		0.4959	1		0.5150	1
	0.5150	-1	Damanhur	0.4052	-2		0.6617	-1
Damanhur	0.8896	0	Rank (4)	0.7558	-1	Tanta	0.9425	0
Rank (1)	0.6398	1		0.9425	0	Rank (2)	0.7558	1
	0.4037	2		0.6617	1		0.4052	2
	0.4353	-1	El Mahala	0.7013	-1		0.6058	-1
El Mahala	0.7409	0	Rank (2)	0.9867	0	El Mahala	0.9259	0
Rank (5)	0.7122	1		0.7858	1	Rank (4)	0.7926	1
	0.4884	2		0.3982	2		0.4301	2
	0.4982	-1	El Mansoura	0.3846	-2		0.6578	-1
El Mansoura	0.8249	0	Rank (3)	0.7412	-1	El Mansoura	0.9678	0
Rank (2)	0.6915	1		0.9571	0	Rank (1)	0.7377	1
	0.4214	2		0.7064	1		0.3412	2
	0.4655	-1		0.7227	-1		0.6313	-1
Cairo	0.7519	0	Cairo	0.9902	0	Cairo	0.9276	0
Rank (4)	0.7186	1	Rank (1)	0.7874	1	Rank (3)	0.7911	1
	0.4933	2		0.4173	2		0.4416	2
d) El Mahala Reference*			e) El Mansoura Reference*			f) Cairo Reference*		
City	CC	lag	City	CC	lag	City	CC	lag
	0.4884	-2		0.4214	-2		0.4933	-2
Alexandria	0.7122	-1	Alexandria	0.6915	-1	Alexandria	0.7186	-1
Rank (5)	0.7409	0	Rank (5)	0.8249	0	Rank (5)	0.7519	0
	0.4353	1		0.4982	1		0.4655	1
	0.3982	-2		0.7064	-1		0.4173	-2
Tanta	0.7858	-1	Tanta	0.9571	0	Tanta	0.7874	-1
Rank (2)	0.9867	0	Rank (2)	0.7412	1	Rank (2)	0.9902	0
	0.7013	1		0.3846	2		0.7227	1
	0.4301	-2		0.3412	-2		0.4416	-2
Damanhur	0.7926	-1	Damanhur	0.7377	-1	Damanhur	0.7911	-1
Rank (4)	0.9259	0	Rank (1)	0.9678	0	Rank (4)	0.9276	0
	0.6058	1		0.6578	1		0.6313	1
	0.4026	-2		0.6546	-1		0.7365	-1
El Mansoura	0.7782	-1	El Mahala	0.9546	0	El Mahala	0.9950	0
Rank (3)	0.9546	0	Rank (3)	0.7782	1	Rank (1)	0.7558	1
	0.6546	1		0.4026	2		0.3527	2
	0.3527	-2		0.6750	-1		0.4180	-2
Cairo	0.7558	-1	Cairo	0.9529	0	El Mansoura	0.7725	-1
Rank (1)	0.9950	0	Rank (4)	0.7725	1	Rank (3)	0.9529	0
	0.7365	1		0.4180	2		0.6750	1

Table 2. Lag correlation analysis of daily AOD values from February 2000 until August 2009 over Alexandria and the five other cities within the Delta Region (* Reference station leads for positive lags)

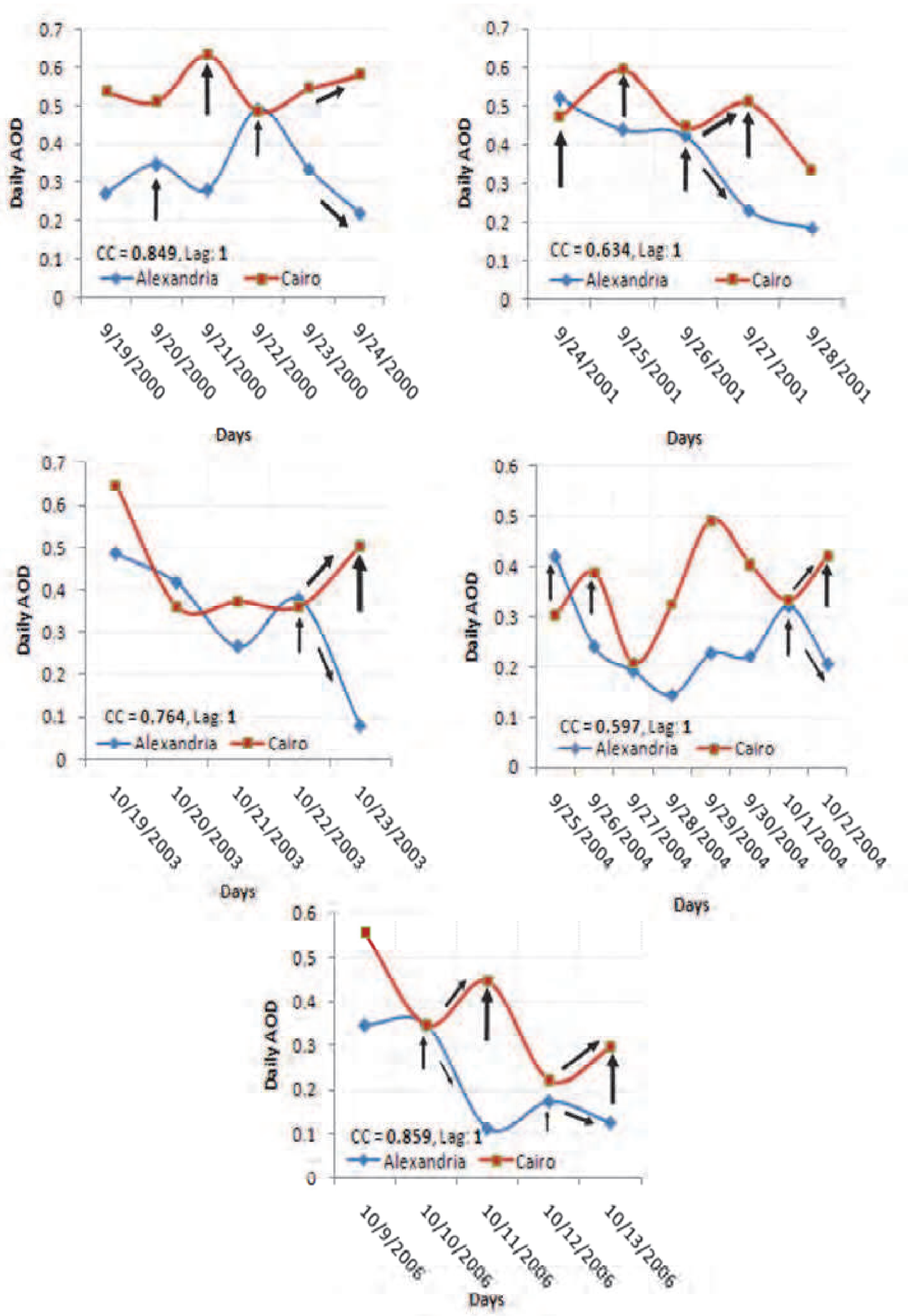

Fig. 7. Evidence of pollutants trasportation from Alexandria to Cairo for selected days with high CCs at one day lag

High CC between two cities can be explained also as that the regional scale meteorology is responsible for the formation of air pollution episodes. It can be interpreted also as plume travelling times are small and after a while polluted air masses are merged forming uniform conditions.

The CC between Tanta and Cairo shows how the AOD over Tanta played a considerable role in the Cairo pollution episodes. Having Cairo as a reference city, Tanta came in the second position with a CC of 0.9902 after El Mahala; however taking Tanta as a reference city, Cairo occupied first rank with the highest CC of 0.9902. Meanwhile, high CC of 0.7874 is also observed at lags of -1 and 1 day when Cairo and Tanta are the reference cities, respectively. This means that Tanta is also contributing to the Cairo pollution event and, again not, the other way around. From the CCs observed at 0, 1 and -1 lags for El Mahala, Tanta and Cairo, it is clear that most of pollution forming activities is mainly observed during the months of September and October per the high AOD values observed.

The CCs and the ranks of El Mansoura, Damanhur and Alexandria indicate that these cities have fixed ranking all the time, namely rank 3, 4 and 5, respectively when taking El Mahala, Tanta and Cairo as reference cities. Therefore, the AOD analysis shows that these three cities contribute less to the black cloud events over Cairo. Similar cross correlation analysis of the WVC has been performed to understand the dynamics of cloud formation in association with the aerosol loadings in the atmosphere. Due to the high observed AOD levels over the 6 locations during the dust and pollution seasons, we conclude that the Delta region is a strong source of pollution airborne particles. These particles can travel long distances to other cities and neighboring Mediterranean countries and thus influence the aerosol radiative forcing at regional scales. Moreover, aerosols are likely to affect the water cycle by suppressing precipitation in a region of the world which is already very dry (Favez et al., 2008), (Rosenfeld, 2000, 2008). Favez et al. (2008) analyzed the chemical composition of bulk aerosols over 1.5–3 years at two urban sites in Cairo. Their analysis indicated very high levels of mineral dust (over 100 μg/m3) in winter and spring; and more than 50 μg/m3 in summer and autumn. There is an important effect, namely direct and indirect radiative forcing because of the aerosol relation with water vapor (Houghton et al., 2001; Tegen et al., 1996 and Hsu et al., 2003). The use of water vapor column as an indicator for dust storms and massive pollution events has been pointed out by (El-Askary and Kafatos, 2008; El-Askary et al., 2003), owing to cloud condensation nuclei formation as an indirect effect of such atmospheric phenomena.

(Table 3) shows high and significant CCs for WVC with confidence level 95% between all the cities and their corresponding reference city at zero lag as observed in the AOD case shown in (Table 2). In this analysis we have sub-categorized the six locations under investigation into two main categories, coastal (Alexandria) and near coastal/inland (El Mansoura and Damanhur) versus further inland (Cairo, Tanta and El Mahala). We have found that the ranking of the six locations based on the cross correlation analysis of the WVC taking each one of the three further inland cities as a reference, matches very well the ranking observed from the AOD correlation analysis. However, when considering the coastal, near coastal/inland cities as the reference stations, the rankings differ from the ones obtained when correlating the AOD values.

For instance, when having any of the coastal/near coastal/inland cities designated as the reference station, the other two cities of the same category achieve the first two ranks which was not the case obtained in the AOD case (Table 2). This is because coastal cities are highly exposed to the sea breeze that transfers water vapor from the sea, leading to the formation of higher WVC. Therefore, we can say that the WVC observed over these locations is primarily due to sea breeze. When examining the inland cities, a similar ranking observed as the AOD one (Table 2), suggests higher water vapor content over the inland cities due to aerosol loading either from natural or anthropogenic origin (Figure 6).

a) Alexandria Reference*			b) Tanta Reference*			c) Damanhur Reference*		
City	CC	lag	City	CC	lag	City	CC	lag
	0.3478	-1		0.5876	0		0.5652	-1
Tanta	0.5876	0	Alexandria	0.3478	1	Alexandria	0.9620	0
Rank (5)			Rank (5)			Rank (2)	0.6190	1
							0.2570	2
	0.2570	-2	Damanhur	0.3591	-1		0.4737	-1
Damanhur	0.6190	-1	Rank (4)	0.7396	0	Tanta	0.7396	0
Rank (1)	0.9620	0		0.4737	1	Rank (5)	0.3591	1
	0.5652	1						
	0.5128	-1	El Mahala	0.5583	-1		0.2832	-2
El Mahala	0.7688	0	Rank (1)	0.9398	0	El Mahala	0.6107	-1
Rank (4)	0.3644	1		0.5881	1	Rank (3)	0.8975	0
							0.5128	1
	0.5920	-1	El Mansoura	0.3732	-1		0.2696	-2
El Mansoura	0.9466	0	Rank (3)	0.7585	0	El Mansoura	0.6314	-1
Rank (2)	0.5588	1		0.4805	1	Rank (1)	0.9947	0
							0.6410	1
	0.4937	-1		0.4979	-1		0.5618	-1
Cairo	0.7857	0	Cairo	0.9313	0	Cairo	0.8869	0
Rank (3)	0.3554	1	Rank (2)	0.5668	1	Rank (4)	0.4898	1
d) El Mahala Reference*			e) El Mansoura Reference*			f) Cairo Reference*		
City	CC	lag	City	CC	lag	City	CC	lag
Alexandria	0.3644	-1	Alexandria	0.5588	-1	Alexandria	0.3554	-1
Rank (5)	0.7688	0	Rank (2)	0.9466	0	Rank (5)	0.7857	0
	0.5128	1		0.5920	1		0.4937	1
	0.2433	-2		0.4805	-1		0.2617	-2
Tanta	0.5881	-1	Tanta	0.7585	0	Tanta	0.5668	-1
Rank (2)	0.9398	0	Rank (5)	0.3732	1	Rank (2)	0.9313	0
	0.5583	1					0.4979	1
	0.5128	-1		0.6410	-1		0.4898	-1
Damanhur	0.8975	0	Damanhur	0.9947	0	Damanhur	0.8869	0
Rank (4)	0.6107	1	Rank (1)	0.6314	1	Rank (4)	0.5618	1
	0.2832	2		0.2696	2			
	0.5164	-1		0.2745	-2		0.2693	-2
El Mansoura	0.9151	0	El Mahala	0.6119	-1	El Mahala	0.5886	-1
Rank (3)	0.6119	1	Rank (3)	0.9151	0	Rank (1)	0.9799	0
	0.2745	2		0.5164	1		0.5493	1
	0.5493	-1		0.5623	-1		0.4897	-1
Cairo	0.9799	0	Cairo	0.9035	0	El Mansoura	0.9035	0
Rank (1)	0.5886	1	Rank (4)	0.4897	1	Rank (3)	0.5623	1
	0.2693	2						

Table 3. Lag correlation analysis of daily WVC values from February 2000 until August 2009 over Alexandria and the five other cities within the Delta Region (* Reference station leads for positive lags)

Favez et al., (2008) observed very high chloride levels during the autumn season over Cairo. At most 50% or even less of this is attributed to sea salt particles. However, the high concentrations of non-sea-salt chloride are thought to be of industrial origin. This observation matches well with our conclusions not only over Cairo but also is more evident with our AOD and WVC analyses over the other five cities. The higher increasing trends of the WVC observed over the coastal and near coastal cities, as compared with lower still increasing trends over the inland cities, are now better understood. Although sea salt contributes to some extent in such trends, yet the anthropogenic component appears to be dominant.

3. Hysplit air mass back-trajectories showing possible sources of pollution outbreaks

The black cloud extent is believed to be of regional nature yet it is more dominant over Cairo. AOD, WVC and cross correlation analyses have demonstrated the contribution of other cities to Cairo pollution. For better understanding the climatology, we have used the NOAA Air Resources Laboratory (ARL) HYSPLIT_4 model (http://www.arl.noaa.gov) (Draxler and Hess, 1998; Draxler, 1997) for computing trajectories over Cairo and hence supporting our investigation of the different sources of the pollution episodes over Cairo. Gridded meteorological data, at regular time intervals, are used in calculation of air mass trajectories. For the back-trajectories, data are obtained from existing archives.

A complete description of input data, methodology, equations involved, and sources of error for calculation of air mass trajectory is presented by (Draxler and Hess, 1997). The back trajectories of the black cloud event of October 2006, showing its source and path followed before its arrival over Cairo, are studied using a one day back-trajectory (Figure 8). In this analysis we show air mass back-trajectory at four different sets of heights above the earth's surface to locate vertical extent of the different contributions in the pollution during the black cloud season over Cairo. These heights are panel a) 1100, 1200 and 1300 m, panel b) 800, 900 and 1000 m, panel c) 500, 600 and 700 m, and panel d) 200, 300 and 400m. The reason for selecting different heights is because we know that the Delta region and Cairo are subject to an inversion layer that has been described in (El-Askary and Kafatos, 2008). They concluded that anthropogenic pollutants during September, October, (mainly), and November are found at a very low altitudes, less than 1 km from the earth surface, as revealed from cloud top pressure values (> 920 mb). A disturbed temperature gradient leading to an inversion layer prevents pollutants from rising, occupying low elevation, hence, keeping the air from naturally being ventilated. Trapping aerosols and pollutants below the temperature inversion layer, results in an increase of their concentration, hence, creating a permanent haze that develops into a health hazardous situation (El-Askary and Kafatos, 2008).

The HYSPLIT back trajectory was initialized with a starting date of October 10, 2006 over Cairo, El Mahala and Alexandria at every hour interval up to the previous day over the above mentioned heights (Figure 8). Wind rose diagrams are also presented to show the dominant wind directions during the trajectory analysis at the corresponding altitudes as close as possible. These back-trajectories show that at the layer 800-1300, (panels a & b), the origin of the air masses is from the west along the coast. Since the land does not become too

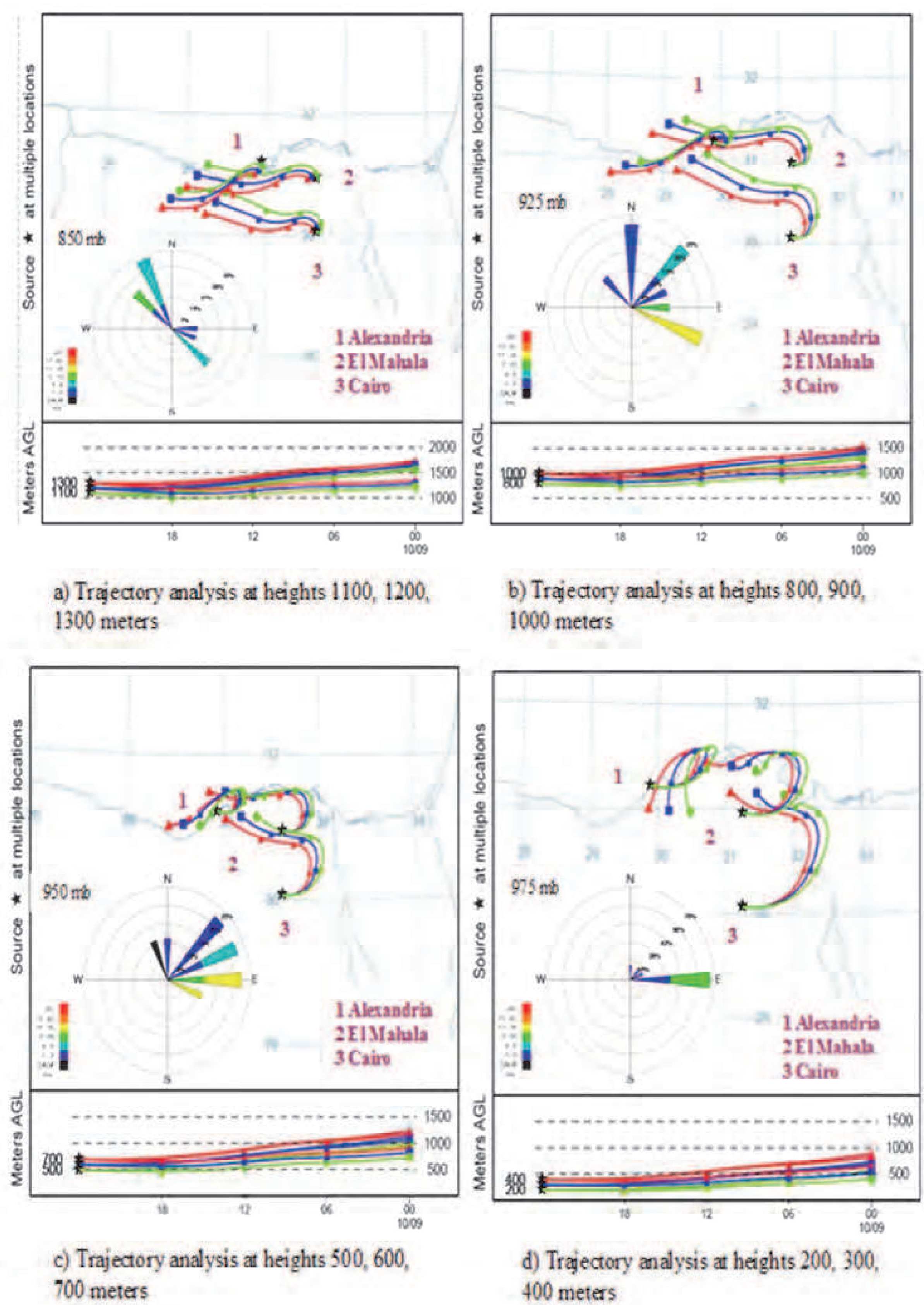

Fig. 8. OAA HYSPLIT MODEL Backward trajectories ending at 00 UTC 10 Oct 06 using CDC1 Meteorological Data over Cairo, El Mahala and Alexandria

hot during this period of the year, we assume that this layer (800-1300) is above the boundary layer especially at night hours. The layers below 800 m seem to have a daily variability that is shown as track changes. This is evident due to the sea breeze formation as well as the other non-classical mesoscale circulations, sea-land breeze type of circulations between the dry land and the wetlands at the Nile Delta, (Segal et al., 1989). This kind of atmospheric circulation with almost neutral stratification form poor dispersion and transport conditions that makes the polluted air masses remains long time over bigger areas of the cities under consideration. Therefore, it is clear that at lower altitudes, trajectories representing stationary patterns indicate the presence of polluted air masses for longer time periods over Cairo and the Delta region. This is attributed to the fact that in autumn times the local meteorology, i.e. lower wind speed and weaker convection, favour aerosols accumulation in a shallow boundary layer and thus promote Black Cloud formation. (Panel c) green curve represents the trajectory at 500 m above the surface which roughly corresponds to the middle of the boundary layer height (Favez et al., 2008). It is clear that at this level there is a great contribution from El Mahala local loadings to the pollutants observed over Cairo.

This observation matches well the CC shown in (Table 3) suggesting the great contribution of El Mahala pollutants to the black cloud outbreaks observed at Cairo.

Moreover, the red curve representing the trajectory at 700 m above the surface shows that there is a great contribution from Alexandria local loadings to the pollutants observed over Cairo. This in turn sheds light on the fact that ash burns from the rice harvest are not the only and direct reason for such pollution outbreaks. This output agrees well with the conclusion that the thermal inversion is a major player during this pollution episode as well as the varying aerosols condition over Alexandria (El-Askary, 2006; El-Askary and Kafatos, 2008; El-Askary et al., 2009). The back trajectory curves obtained in (panel d) show that a low elevated inversion is observed that keeps most of the aerosols hanging locally (Kandil et al., 2006).

The wind field over the northern part of Egypt exerts a clock wise daily rotation due to the local thermal circulations "sea breezes". Such rotation is well known in coastal areas with sea breeze formation (Kusuda and Alpert, 1986; Steyn and Kallos, 1992). It is worth noting that the sea breezes in the area penetrate deep inside Egypt because they are supported by the regional flow pattern directed from north to south "differential heating between land of Africa and Europe and the Mediterranean waters" during the warm period of the year (Astitha et al., 2008; Kallos et al., 1998, 2007). This pattern is always from north to North West, opposite the land breeze cells hence don't allow the development of land breeze circulation cell. Therefore most of the locally produced pollutants from Alexandria and other Delta cities migrate south towards Cairo and not towards the Mediterranean Sea (see Figure 1. in El-Askary and Kafatos, 2008).

4. Conclusions

This study clearly indicates the complicated pattern of aerosol production and transport over the Nile Delta and Cairo. Air masses exhibit mesoscale circulations and each city air quality is affected from other cities, mainly from North which is clearly shown over Cairo. AOD analysis clearly indicates large amounts of aerosols forming the black cloud events over various locations within the Delta region and Alexandria. We can now observe the wide spatial extent of such hazardous phenomena, not only over Cairo. Water vapor plots show a gradual increase in the WVC in accordance with the excess aerosol loading (high AOD) during the black cloud season possibly attributed to urban pollution. Power correlation of mean AOD and WVC increases over cities with higher aerosol loadings. Cross correlations among time series variations of AOD and WVC are performed to investigate their dynamics and mutual relationships. The preformed cross correlation analysis showed a high correlation in the AOD values over the different locations, emphasizing the wide extent of the black cloud over other Delta cities and not only over Cairo. Taking Cairo as the reference location, our analysis indicates the heavy contribution of El Mahala and Tanta local emissions to the permanent haze over Cairo. This in turn highlights the importance of the transportation pattern contributing to such motion. Episodes of high aerosols loading from natural and anthropogenic nature are observed over study area in varying magnitudes concurrently during April and October of each year. Moreover, cross correlation analysis shows high dependence between aerosol patterns of Cairo with El Mahala and Tanta. Moreover, it shows a higher association of WVC with AOD for inland cities as compared with the coastal ones. The atmospheric pattern is also revealed from the backward trajectory analysis performed using the HYSPLIT model. The model runs emphasized the fact of the regional contribution from other locations to the excessive pollution episodes over Cairo. Different altitudes show different wind circulation patterns and hence different vertical levels of contribution, yet higher amounts are observed below the inversion layer. Hence, it is clear that the HYSPLIT backward trajectory analysis confirmed the origination of pollution episodes over Cairo from El Mahala and Alexandria at different pressure levels that still fall below the inversion layer reported previously. Wind rose diagrams at different altitudes show a significant agreement with the trajectory directions observed.

In conclusion, our approach used here in studying the aerosol components has enabled us to obtain useful information on relationships and dynamics of atmospheric aerosols and water vapor over Cairo and the Nile Delta region with the following summary:

1. Monthly variation of aerosol and water vapor in the atmosphere indicate a consistent and accountable variation over the whole region. It has also illustrated the origin and dynamics of the black cloud over Cairo and the Nile delta
2. Cross correlations indicate strong correspondence between aerosol conditions in Cairo and those of El Mahalla and Tanta indicating feedback of pollution.
3. Back trajectories of aerosol profile variations indicate different vertical levels of pollution contribution, consistent with the picture of the prevailing low elevation temperature inversion.
4. It is suggested that observations at higher time resolution may be capable of revealing more information on relationships among aerosol components over the Nile Delta cities.
5. It is also suggested that the same techniques could be carried out at other cities of Egypt such as Suez, Arish and Aswan.

   Such analysis could have important implications for policy makers in Egypt and other highly polluted urban environments.

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6. References

Abu-Allaban, M.; Gertler, A.W. & Lowenthal, D.H. (2002). A preliminary apportionment of the sources of ambient PM10, PM2.5 and VOCs in Cairo. *Atmospheric Environment,* Vol.36, No.35, (November 2002), pp. 5549- 5557, ISSN 1352-2310

Abu-Allaban, M.; Lowenthal, D.H.; Gertler, A.W. & Labib, M. (2007). Sources of PM10 and PM2.5 in Cairo's ambient air. *Environmental Monitoring and Assessment,* Vol.133, No.1-3, (October 2007), pp. 417-425, ISSN 1573-2959

Abu-Allaban, M.; Lowenthal, D.H.; Gertler, A.W. & Labib, M. (2009). Sources of volatile organic compounds in Cairo's ambient air. *Environmental Monitoring and Assessment,* Vol.157, No.1-4, (October 2009), pp. 179–189, ISSN 0167-6369

Alfaro, S.C. & AbdelWahab, M.M. (2006). Extreme variability of aerosol optical properties: The Cairo aerosol characterization experiment case study. *Proceedings of the NATO Advanced Research Workshop on Remote Sensing of the Atmosphere for Environmental Security*, pp. 285–299, ISBN: 978-1-4020-5089-3, Rabat, Morocco, 16-19 November, 2005

Astitha, M.; Kallos, G. & Katsafados, P. (2008). Air pollution modeling in the Mediterranean Region: Analysis and forecasting of episodes. *Atmospheric Research*, Vol.89, No.4, (September 2008), pp. 358-364, ISSN 0169-8095

Barnaba, F. & Gobbi, G.P. (2004). Aerosol seasonal variability over the Mediterranean region and relative impact of maritime, continental and Saharan dust particles over the basin from MODIS data in the year 2001. *Atmospheric Chemistry and Physics Discussions,* Vol.4, No.4, (August 2004), pp. 4285-4337, ISSN 16807367

Draxler, R.R. & Hess, G.D. (1998). An overview of the HYSPLIT_4 modeling system for trajectories, dispersion and deposition. *Australian Meteorological Magazine,* Vol.47, No.4, (January 1998), pp. 295–308

Draxler, R.R. & Hess, G.D. (1997). Description of the HYSPLIT_4 modeling system. *NOAA Technical Memorandum ERL ARL-224*, 24pp

El-Askary, H.; Farouk, R.; Ichoku, C. & Kafatos, M. (2009). Transport of dust and anthropogenic aerosols across Alexandria, Egypt. *Annales Geophysicae,* Vol.27, No.7, (July 2009), pp. 2869-2879, ISSN 0992-7689

El-Askary H. & Kafatos, M. (2008). Dust Storm and Black Cloud Influence on Aerosol Optical Properties over Cairo and the Greater Delta Region, Egypt. *International Journal of Remote Sensing*, Vol.29, No.24, (December 2008), pp. 7199 – 7211, ISSN 0143-1161

El-Askary, H. (2006). Air pollution Impact on Aerosol Variability over mega cities using Remote Sensing Technology: Case study, Cairo, Egypt. *Egyptian Journal of Remote Sensing & Space Science*, Vol.9, (July 2006), pp. 31-40

El-Askary, H.; Sarkar, S.; Kafatos, M. & El-Ghazawi, T. (2003). A multisensor approach to dust storm monitoring over the Nile Delta. *IEEE Transactions on Geoscience & Remote Sensing,* Vol.41, No.10, (October 2003), pp. 2386 – 2391, ISSN 0196-2892

El-Metwally, M.; Alfaro, S.C.; Abdel Wahab, M.M. & Chatenet, B. (2008). Aerosol characteristics over urban Cairo: Seasonal variations as retrieved from Sun photometer measurements. *Journal Geophysical. Research,* Vol.113, No.D14219, (July 2008), pp. 1-13 ISSN 0148-0227

Engel-Cox, J.A.; Holloman, C.H.; Coutant, B.W. & Hoff, R.M. (2004). Qualitative and quantitative evaluation of MODIS satellite sensor data for regional and urban scale air quality. *Atmospheric. Environment,* Vol.38, No.16, (May 2004), pp.2495–2509, ISSN 1352-2310

Favez, O.; Cachier, H.; Sciare, J.; Alfaro, S.C.; El-Araby, T.M.; Harhash, M.A. & AbdelWahab, M.M. (2008). Seasonality of major aerosol species and their transformations in Cairo megacity. *Atmospheric. Environment,* Vol.42, No.7, (March 2008), pp. 1503-1516, ISSN 1352-2310

Gautam, R.; Hsu, N.C.; Kafatos, M. & Tsay, S.-C. (2007). Influences of winter haze on fog/low cloud over the Indo-Gangetic plains. *Journal Geophysical Research*, Vol.112, No.D05207, (March 2007), pp. 1-11, ISSN 0148-0227

Hossny, E.; Mokhtar, G.; El-Awady, M.; Ali, I.; Morsy, M. & Dawood, A. (2001). Environmental exposure of the pediatric age groups in Cairo city and its suburbs to cadmium pollution. *The Science of the Total Environment,* Vol.273, No.1-3, (June 2001), pp. 135-146, ISSN 0048-9697

Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; Van der Linden, P.J. & Xiaosu, D. (2001). Climate Change 2001: The Scientific Basis, Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press,* (Ed.) 1-994, ISBN: 9780521014953, UK

Hsu, N.C.; Herman, J.R. & Tsay, S.-C. (2003). Radiative impacts from biomass burning in the presence of clouds during boreal spring in Southeast Asia. *Geophysical Research Letters,* Vol.30, No.5, (March 2003), pp. 28.1-28.4, ISSN 0094-8276

Jin, M.; Shepherd, J.M. & King, M.D. (2005). Urban aerosols and their variations with clouds and rainfall: A case study for New York and Houston. *Journal Geophyssical Research,* Vol.110, No.D10S20, (April 2005), pp1-12, ISSN 0148-0227

Kallos, G.; Astitha, M.; Katsafados, P. & Spyrou, C. (2007). Long-Range Transport of Anthropogenically and Naturally Produced Particulate Matter in the Mediterranean and North Atlantic: Current State of Knowledge. *Journal of Applied Meteorology and Climate,* Vol.46, No.8, (August 2007), pp. 1230-1251, ISSN 1558-8424

Kallos, G.; Kotroni, V.; Lagouvardos, K. & Papadopoulos, A. (1998). On the Long-Range Transport of Air Pollutants from Europe to Africa. *Geophysical Research Letters,* Vol.25, No.5, (March 1998), pp. 619-622, ISSN 00948276

Kanakidou, M.; Mihalopoulos, N.; Kindap, T.; Im, U.; Vrekoussis, M.; Gerasopoulos, E.; Dermitzaki, E.; Unal, A.; Kocak, M.; Markakis, K.; Melas, D.; Kouvarakis, G.; Youssef, A.F.; Richter, A.; Hatzianastassiou, N.; Hilboll, A.; Ebojie, F.; Wittrock, F.; Savigny, C.V.; Burrows, J.P.; Ladstaetter-Weissenmayer, A.; Moubasher, H. (2011). Megacities as hot spots of air pollution in the East Mediterranean. *Atmospheric Environment,* Vol.45, No.6, (February 2011), pp. 1223-1235, ISSN 1352-2310

Kandil, H.A.; Kader, M.A.; Moaty, A.; El-Hadidi, B. & Sherif, A.O. (2006). Simulation of atmospheric temperature inversions over greater Cairo using the MM5 meso-scale atmospheric model. *Egyptian Journal of Remote Sensing & Space Science*, Vol.9, (July 2006), pp. 15-30

Kaufman, Y.J.; Tanrè, D. & Boucher, O.A. (2002). Satellite view of aerosols in the climate system. *Nature,* Vol.419, No.6903 (Spetember 2002), pp. 215−223, ISSN 0028-0836

King, M.D.; Kaufman, Y.J.; Tanrè, D. & Nakajima, T. (1999). Remote sensing of tropospheric aerosols from space: Past, present, and future. *Bulletin of American Meteorological Society,* Vol.80, No.11, (November 1999), pp. 2229−2260, ISSN 0003-0007

Kusuda, M. & Alpert, P. (1983). Anticlockwise rotation of the wind hodograph. Part I: Theoretical study. *Journal of Atmospheric Sciences,* Vol.40, No.2, (February 1983), pp. 487-499

Luria, M.; Peleg, M.; Sharf, G.; Tov-Alper, D.; Spitz, N.; Ben Ami, Y.; Gawii, Z.; Lifschitz, B.; Yitzchaki, A. & Seter, I. (1996). Atmospheric sulfur over the east Mediterranean region. *Journal Geophyssical Research,* Vol.101, No.D20, (May 1996), pp.25917-25930, ISSN: 0148-0227

Mahmoud, K.F.; Alfaro, S.C.; Favez, O. & AbdelWahab, M.M. (2008). Origin of black carbon concentration peaks in Cairo (Egypt). *Atmospheric Research,* Vol.89, No.1-2, (July 2008), pp. 161–169, ISSN: 0169-8095

Marey, H.S.; Gille, J.C.; El-Askary, H.M.; Shalaby, E.A. & El-Raey, M.E. (2010). Study of the formation of the "black cloud" and its dynamics over Cairo, Egypt, using MODIS and MISR sensors. *Journal Geophyssical Research,* Vol.115, No.D21206, (November 2010), pp. 1-10, ISSN 01480227

Millan, M.M.; Salvador, R.; Mantilla, E. & Kallos, G. (1997). Photo oxidant dynamics in the Mediterranean basin in summer: results from European research projects. *Journal Geophyssical Research,* Vol.102, No.7, (April 1997), pp. 8811–8823, ISSN 01480227

Molina, M.J. & Molina, L.T. (2004). Critical Review: Megacities and atmospheric pollution. *Journal of Air and Waste Management Association,* Vol.54, No.6, (June 2004), pp. 644-680, ISSN 1096-2247

Pace, G.; Di Sarra, A.; Meloni, D.; Piacentino, S. & Chamard, P. (2006). Aerosol optical properties at Lambeduca (Central Mediterranean). 1. Influence of transport and identification of different aerosol types. *Atmospheric Chemistry and Physics,* Vol.6, No.3, (March 2006), pp. 697−713, ISSN 16807316

Prasad A. K.; El-Askary, H.M. & Kafatos, M. (2010). Implications of high altitude desert dust transport from Western Sahara to Nile Delta during biomass burning season. *Environmental Pollution,* Vol.158, No.11, (November 2010), pp. 3385-3391, ISSN 0269-7491

Prasad, A.K. & Singh, R.P. (2007) Changes in aerosol parameters during major dust storm events (2001–2005) over the Indo-Gangetic Plains using AERONET and MODIS data. *Journal Geophyssical Research,* Vol.112, No.D09208, (May 2007), pp. 1-18, ISSN 0148-0227

Prasad, A.K.; Singh, R.P. & Kafatos, M. (2006). Influence of coal based thermal power plants on aerosol optical properties in the Indo-Gangetic basin. *Geophysical Research Letters,* Vol. 33, No.L05805, (March 2006), pp. 1-4, ISSN 0094-8276

Rosenfeld, D.; Lohmann, U.; Raga, G.B.; O'Dowd, C.D.; Kulmala, M.; Fuzzi, S.; Reissell, A. & Andreae, M.O. (2008). Flood or Drought: How Do Aerosols Affect Precipitation?. *Science,* Vol.321, No.5894, (September 2008), pp. 1309 – 1313, ISSN 0036-8075

Rosenfeld, D. (2000). Suppression of rain and snow by urban and industrial air pollution. *Science*, Vol.287, No.5459, (March 2000), pp. 1793-1796, ISSN 0036-8075

Segal, M.; Garratt, J.R.; Kallos, G. & Pielke, R.A. (1989). The Impact of Wet Soil and Canopy Temperatures on Daytime Boundary - Layer Growth. *Journal of Atmospheric Sciences,* Vol.46, No.24, (December 1989), pp.3673-3684, ISSN 0022-4928

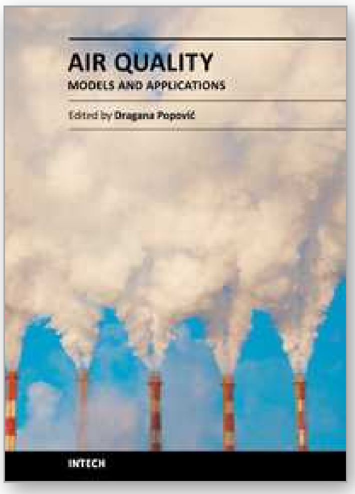
Steyn, D. & Kallos, G. (1992). A study of the dynamics of hodograph rotation in the sea breezes of Attica, Greece. *Boundary-Layer Meteorology,* Vol.58, No.3, (February 1992), pp. 215-228, ISSN 0006-8314

Tegen, I.A.; Lacis, A.A. & Fung, I. (1996). The influence on climate forcing of mineral aerosols from distributed soils. *Nature,* Vol.380, (April 1996), pp. 419–422

Xia, X.; Chen, H. & Zhang, W. (2007). Analysis of the dependence of column-integrated aerosol properties on long-range transport of air masses in Beijing. *Atmospheric Environment,* Vol.41, No.36, (November 2007), pp. 7739–7750, ISSN 1352-2310

Zakey, A.S.; Abdelwahab, M.M. & Makar, P.A. (April 2004). Atmospheric turbidity over Egypt. *Atmospheric Environment,* Vol.38, No.11, (2004), pp. 1579-1591, ISSN 1352-2310

Zakey, A.S.; Abdel-Wahab, M.M.; Pettersson, J.B.C.; Gatari, M.J. & Hallquist, M. (2008). Seasonal and spatial variation of atmospheric particulate matter in a developing megacity, the Greater Cairo, Egypt. *Atmósfera* Vol.21, No.2, (January 2008), pp. 171-189, ISSN 0187-6236



Air Quality-Models and Applications
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Air pollution has been a major transboundary problem and a matter of global concern for decades. High concentrations of different air pollutants are particularly harmful to large cities residents, where numerous anthropogenic activities strongly influence the quality of air. Although there are many books on the subject, the one in front of you will hopefully fulfill some of the gaps in the area of air quality monitoring and modeling, and be of help to graduate students, professionals and researchers. The book is divided in five sections, dealing with mathematical models and computing techniques used in air pollution monitoring and forecasting; air pollution models and application; measuring methodologies in air pollution monitoring and control; experimental data on urban air pollution in China, Egypt, Northeastern U.S, Brazil and Romania; and finally, the health effects due to exposure to benzene, and on the influence of air pollutants on the acute respiratory diseases in children in Mexico.