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Dust transport over the eastern Mediterranean derived from Total Ozone Mapping Spectrometer, Aerosol Robotic Network, and surface measurements

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[1] Multiyear surface PM_{10} measurements performed on Crete Island, Greece, have been used in conjunction with satellite (Total Ozone Mapping Spectrometer (TOMS)) and ground-based remote sensing measurements (Aerosol Robotic Network (AERONET)) to enhance our understanding of the evolution of mineral dust events over the eastern Mediterranean. An analysis of southerly air masses at altitudes of 1000 and 3000 m over a 5 year period (2000–2005), showed that dust can potentially arrive over Crete, either simultaneously in the lower free troposphere and inside the boundary layer (vertical extended transport (VET)) or initially into the free troposphere with the heavier particles gradually being scavenged inside the boundary layer (free troposphere transport (FTT)). Both pathways present significant seasonal variations but on an annual basis contribute almost equally to the dust transport in the area. During VET the aerosol index (AI) derived from TOMS was significantly correlated with surface PM_{10}, and in general AI was found to be adequate for the characterization of dust loadings over the eastern Mediterranean on a climatological basis. A significant covariance between PM_{10} and AOT was observed during VET as well, indicating that AOT levels from AERONET may be estimated by PM_{10} levels at the surface. Surface measurements are thus crucial for the validation of remote sensing measurements and hence are a powerful tool for the investigation of the impact of aerosols on climate.

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1. Introduction

[2] Atmospheric aerosols affect the Earth's atmosphere directly through interaction with both solar and terrestrial radiation, and indirectly by altering cloud properties (e.g., cloud microphysics, albedo, precipitation development) [*Intergovernmental Panel on Climate Change (IPCC)*, 2001]). Aerosol impact on climate change is difficult to quantify since great uncertainties in aerosol loading, optical properties, and spatiotemporal distribution still exist [*Kaufman et al.*, 2002]. Global radiative forcing at the top of the atmosphere (TOA) due to aerosols is estimated to be between 0 and -2 W m^{-2} [*IPCC*, 2001], corresponding to a cooling effect.

[3] Mineral dust is believed to play an important role in radiative forcing, with an estimated global TOA radiative forcing in the range -0.6 to 0.4 W m^{-2} [*IPCC*, 2001]. Several studies have shown the importance of dust generated aerosols not only to the global and regional energy balance [*Tegen et al.*, 1996; *Sokolik and Toon*, 1999], but also to weather forecasting [*Alpert et al.*, 1998] and to rain formation [*Levin et al.*, 1996]. Even though dust sources might be geographically confined, dust may influence extended areas via long-range transport. Moreover, even when no direct mobilization of dust exists, significant amounts can be still be measured in the atmosphere [*Israelevich et al.*, 2002]. Dust can be also emitted from anthropogenic activities although its contribution to climate is still poorly defined [*Haywood and Boucher*, 2000].

[4] Mediterranean Basin aerosol loads have become the subject of various studies during the last decades, since a variety of aerosol types can be found there, namely marine aerosols, anthropogenic aerosols and desert dust aerosols. The dust aerosols play an important role owing to the proximity of the extended deserted areas of North Africa (e.g., Sahara and Sahel deserts). The major dust sources in

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North Africa that influence the eastern Mediterranean have been identified with the use of back trajectories and satellite (TOMS) data [*Israelevich et al.*, 2002, 2003; *Prospero et al.*, 2002]. The seasonal dynamics of dust transport toward the Mediterranean Basin have been described by several authors [*Alpert and Ziv*, 1989; *Dayan et al.*, 1991; *Moulin et al.*, 1998]. *Moulin et al.* [1998], on the basis of satellite images (VIS and IR), reported that dust transport over the eastern Mediterranean is encountered mainly during spring under the influence of Sharav cyclones.

[5] To estimate the aerosol budget and to quantify the effects of dust particles on the optical character of the atmosphere, high spatiotemporal resolution data are needed. Surface-based measurements can give adequate temporal resolution but limited spatial coverage. On the other hand, remote sensing of aerosols either by satellite or ground-based techniques gives a global picture and can provide information on the columnar distribution of aerosol properties. However, their reliability still has to be checked against ground-based measurements. Clearly, a combination of different measurement techniques is necessary to obtain sufficient information of dust distributions so as to better ascertain their climatic effects.

[6] Several studies focusing on Sahara dust have been conducted to date by combining and comparing ground-based and satellite data [e.g., *Moulin et al.*, 1998; *Israelevich et al.*, 2003; *Chiapello et al.*, 1999, 2005; *Moulin and Chiapello*, 2004; *Prospero et al.*, 2002; *Kubilay et al.*, 2003, 2005]. These studies mainly focused on the evaluation of data collected over an extensive monitoring period, in order to investigate and quantify dust transport configurations. However, the study of individual dust events, which is an essential for assessing the climatic impact of such phenomena, has, in terms of combined columnar and surface data, so far been neglected.

[7] The current study combines AERONET data (AOT, Angström parameter) with satellite data from TOMS (aerosol index (AI)) and surface measurements (PM_{10}, scattering coefficients) during the period 2000–2005. Recent work on the eastern Mediterranean [*Gerasopoulos et al.*, 2006] showed that PM_{10} measurements can be used as a good surrogate for the study of the evolution of dust events.

[8] The main objective of this work is to shed light on the dust transport patterns over eastern Mediterranean. This is accomplished by comparing PM_{10}, AI and AERONET data and investigating (1) the agreement between columnar and surface measurements focusing on dust events and (2) the conditions under which ground-based measurements during dust events can characterize the columnar distribution of aerosols. This way a first validation of remote sensing data against surface measurements is also achieved. The study is structured as follows: (1) climatology of the vertical patterns of dust transport via trajectory analysis, (2) comparison between TOMS AI and PM_{10} measurements, and (3) presentation of a 3 year data set from the FORTH-CRETE station of AERONET and comparison with surface measurements.

2. Methods

2.1. Site Description

[9] The AERONET aerosol data used in this study derive from measurements obtained at the FORTH-CRETE station (35°19′58″N, 25°16′55″E) [*Fotiadi et al.*, 2006]. The surface measurements which are compared with the columnar properties were conducted at Heraklion (35°19′N, 25°8′E), the major city of the island, and at Finokalia (35°20′N, 25°40′E) a remote coastal site on the north east side of the island where the monitoring station of the University of Crete is situated. A description of the Finokalia site has been given by *Mihalopoulos et al.* [1997].

2.2. Measurements

2.2.1. TOMS Data

[10] TOMS-aerosol index (AI) data using the version 8 algorithm were obtained from the TOMS/Earth Probe sensor (http://toms.gsfc.nasa.gov/aerosols/aerosols_v8.html). The AI is available on a daily basis, on a 1° (latitude) by 1.25° (longitude) resolution. TOMS-AI values around our sampling stations at Crete were obtained as an average of six pixels in the small box confined by 24–26.5°E and 34.4–36.6°N.

2.2.2. AERONET Data

[11] The analysis includes data from AERONET for the sampling period January 2003 to December 2005. In particular, quality assured (level 2.0) data were processed for optical thickness (AOT) at five wavelengths (440, 500, 670, 870 and 1020 nm) and Angström parameter.

2.2.3. Surface Measurements

[12] The PM_{10} mass at both sites was monitored with an Eberline FH 62 I-R (Eberline Instruments GmbH) Particulate Monitor, designed to measure continuously the mass concentration of the suspended particles in ambient air with a resolution of 1 μg m^{-3} every 5 min. More details about the set up of the instruments at the two locations, as well as further characteristics and calibration procedures are given by *Gerasopoulos et al.* [2006].

[13] The aerosol light scattering coefficient (σ_{sp}) was measured with a monowavelength portable integrating nephelometer (M903, Radiance Research, Seattle, USA). This instrument measures the light scattering coefficient (σ_{sp}) at 532 nm. The optical and electrical background noise is sufficiently low to allow measurements of σ_{sp} (for particles) from less than 10% of air Rayleigh scattering (σ_{sp} < 1 Mm^{-1}) to greater than 1000 Mm^{-1} [*Vrekoussis et al.*, 2005].

3. Results and Discussions

3.1. Potential of Dust Transport via Trajectory Analyses

[14] The current work is focused on the identification of dust events from both columnar and surface measurements; hence it is necessary to investigate the pathways of dust transport over the area. This is performed by identifying and statistically analyzing the trajectories most likely to carry dust particles over the Finokalia station. This approach can help to evaluate the observations from remote sensing techniques, as their temporal resolution is limited by cloud screening procedures.

[15] We shall refer to these trajectories as potential dust transport trajectories and we will emphasize mainly their vertical characteristics, since the meteorological conditions that lead to certain transport patterns over the Mediterranean as well as their evolution for the different seasons are well

known [e.g., *Alpert and Ziv*, 1989; *Dayan et al.*, 1991; *Moulin et al.*, 1998]. For this reason we have calculated 5-day back trajectories with the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory Model [*Draxler and Hess*, 1998]) at two altitudes 1000 m and 3000 m, representative of the boundary layer and the free troposphere transport processes, respectively, for the period 2003–2005. This analysis includes (1) trajectories from western directions, corresponding to long-range transport of dust from northwestern Africa under the influence of well established anticyclonic systems (20–30%), (2) from SW and S representing more direct African dust pathways over the Mediterranean (70–80%), and (3) rarer cases from the SE and E sectors.

[16] *Gerasopoulos et al.* [2005] have presented a wind climatology of the area for the period 1997–2004 showing three distinct peaks in the frequency of S–SW winds in winter, spring, and fall. For the period under study (2003–2005) the same pattern is well reproduced. The frequency of dust events, as monitored by surface measurements of PM_{10} at Heraklion and Finokalia, is also found to peak during the transition periods, spring and fall, as shown by *Gerasopoulos et al.* [2006]. We discriminate between cases where trajectories both at 1000 and 3000 m indicate the possibility of dust transport, henceforth called "vertically extended transport (VET)," and cases where trajectories only at 3000 m or 1000 m are dust influenced which shall be characterized as "free tropospheric transport (FTT)" or "boundary layer transport (BLT)," respectively.

[17] Results presented in Figure 1 show that during spring both VET and FTT cases are equally distributed. In fall 57% of the potential dust transport cases are associated with VET and about 37% with FTT, while during winter a similar situation is encountered with VET being more dominant. Finally during summer, the reverse situation is observed with FTT dominating (60%) over VET (25%) and BLT (15%) which is indicative of the stability of the atmosphere during summer which blocks the vertical distribution of the dust layers. Thus, in summer dust transport occurs mainly in the free troposphere (FTT) while at lower levels pollution plumes may appear that are mainly transported from the NW–NE [*Lelieveld et al.*, 2002; *Kubilay et al.*, 2003]. The summer maximum of FTT is in agreement with observations in the Canary Islands while the winter maximum of VET is not observed in that area, where the low-altitude dust outbreaks dominate [*Viana et al.*, 2002], a fact that partly differentiates the dust transport patterns from northern Africa toward eastern Mediterranean and the Atlantic.

[18] It should be noted that BLT cases are rather rare while all percentages should be regarded with the view that the frequency of potential dust transport trajectories differs seasonally, especially in summer when they are infrequent.

3.2. Aerosol Loading via Remote Sensing

3.2.1. Total Ozone Mapping Spectrometer (TOMS) Data Versus Particulate Matter (PM_{10}) at Surface

[19] In the previous section it was shown that the presence of dust over the area is mainly related to long-range transport vertically extended up to several kilometers and thus it could be identified by satellite observations. To investigate this the aerosol index (AI) obtained by TOMS for the period 2000–2005 is presented in Figure 2a. The median AI for the whole period is 0.4 and 50% of the values are between 0.1 and 0.9 (1st and 3rd quartiles, respectively). AI shows enhanced values in spring and summer during 2002–2005 and only in 2001 the pattern is different. The average 0.6 ± 0.7 (±standard deviation) is considerably higher than the median indicative of the spiky behavior of the values that may go up to 4–4.5. In Figure 2b the PM_{10} concentrations at Heraklion (2000–2004) and Finokalia (2005) are also plotted and a number of common spikes are shown by dotted lines.

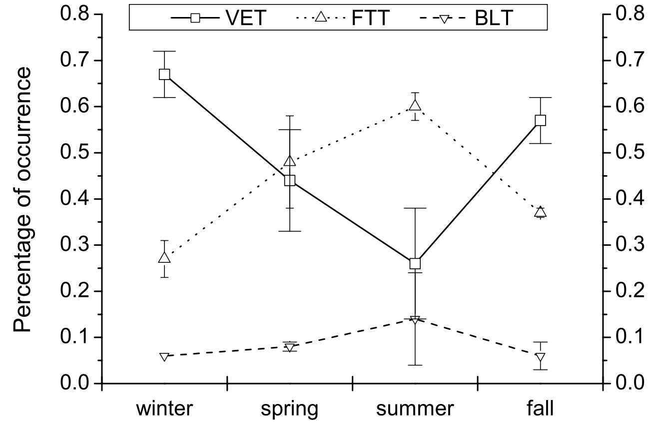

Figure 1. Seasonal variability of the various transport patterns of dust namely "vertically extended transport (VET)," "free tropospheric transport (FTT)" and "boundary layer transport (BLT)" based on trajectory analysis. Error bars correspond to the standard deviation of the values when mixed source trajectories are gradually excluded from the analysis thus providing a rough estimate of the uncertainty in our conclusions.

[20] *Gerasopoulos et al.* [2006] have shown that the main factors controlling PM_{10} levels in the region are dust transport mainly in spring and either local or transported pollution in summer. AI peaks, based on the deviation of values from the seasonal background and not on the absolute values, are more frequent in spring than in winter indicating that the presence of dust can be detected to a certain extent by TOMS.

[21] The coincidence of the spikes found in AI from TOMS and PM_{10} at the surface has been further investigated on a seasonal basis in order to obtain information on the ways in which the aerosol loading takes place over the considered area. Thus, in winter, 70% of the AI spikes are observed simultaneously with PM spikes while the other 30% includes cases in which PM followed AI with a delay of about 1 day. In summer, the situation is reversed and there is a delay between the two parameters in 60% of the cases, no PM signal following AI is found in 30% of the cases, while simultaneous peaks occur only in 10% of the cases. Finally, during the transition seasons (spring and fall) 55–60% of the AI and PM_{10} peaks are coincident; in spring the delayed PM_{10} spikes dominate over cases with no PM signal, while in fall the situation is reversed. The above are in remarkable agreement with the VET and FTT transport patterns deduced from the trajectory analysis (Figure 1) and reveal the usefulness of AI for the charac-

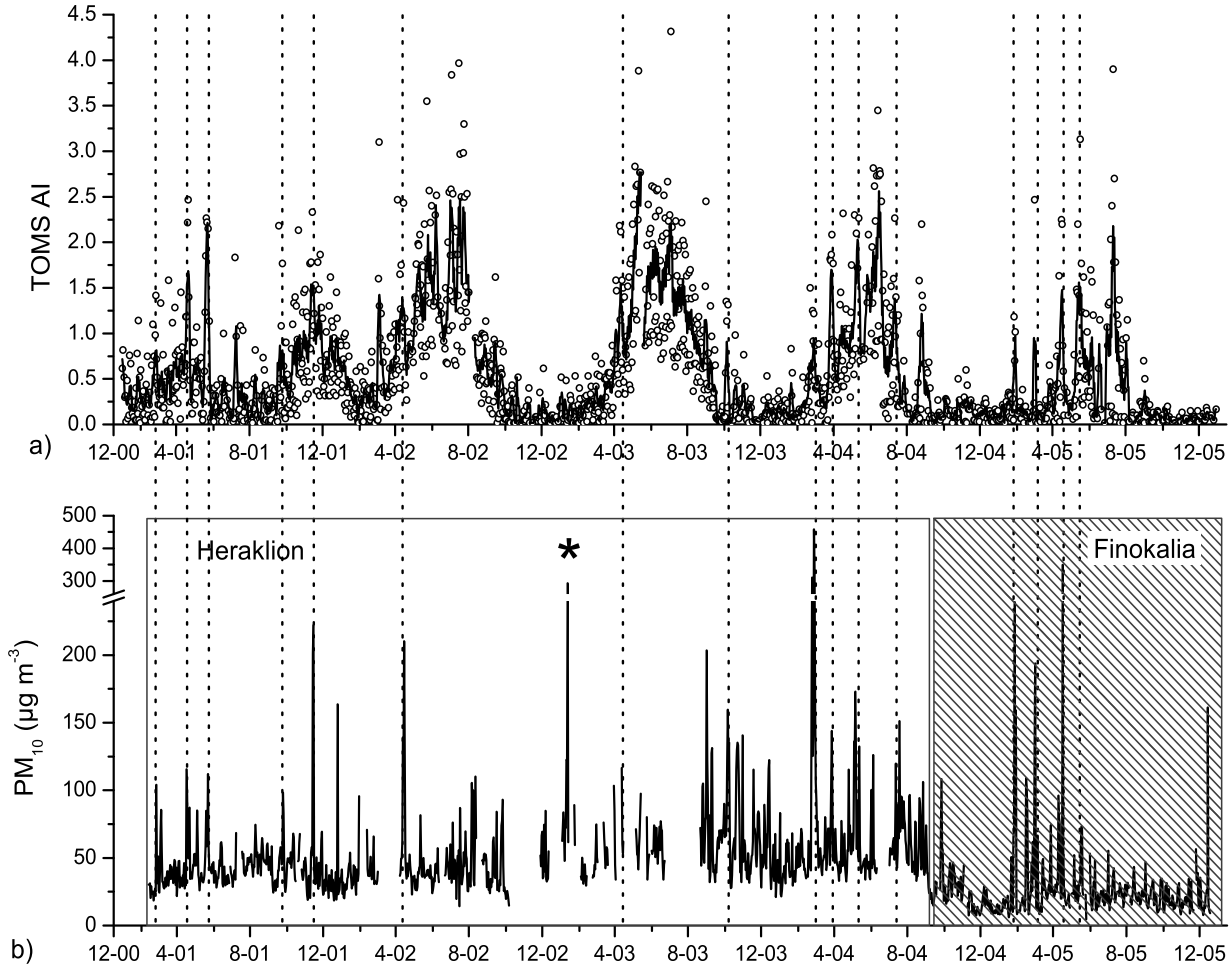

Figure 2. (a) Aerosol index (AI) from TOMS for the period 2000–2005, open circles indicate the daily values and the continuous line corresponds to a 5 point moving average, and (b) PM_{10} concentrations at Heraklion (2000–2004) and Finokalia (2004–2005). Dotted lines are used to depict examples of common spikes in both time series, whereas the asterisk identifies a case with enhanced PM_{10} but no signal in AI.

terization of dust loadings over the eastern Mediterranean on a climatological basis.

[22] However, there are episodes of either dust or pollution shown in the PM_{10} time series (e.g., the case marked with an asterisk in Figure 2b) without a corresponding AI signal (Figure 2a). Taking into account the difficulty of interpreting AI spikes due to noise and seasonal variability, 20–30% of the dust related PM_{10} spikes are not found in the AI time series. The above result is in agreement with the findings of *Kubilay et al.* [2005] reporting that in the northeastern Mediterranean 30% of the dust events predominately occurred below 850 hPa were not detected effectively by TOMS. Moreover, the mineral dust particles could be coated with sulfate and other soluble material reducing the UV absorption and thus AI values [*Levin et al.*, 1996]. All the above demonstrate the temporal limitations of TOMS data, since the use of AI as an indicator of aerosol amount is hampered by the dependencies of the AI on aerosol optical depth, elevation of aerosol layer above the ground, absorption properties and particle size distribution as documented in the literature [*Torres et al.*, 1998; *Herman et al.*, 1997].

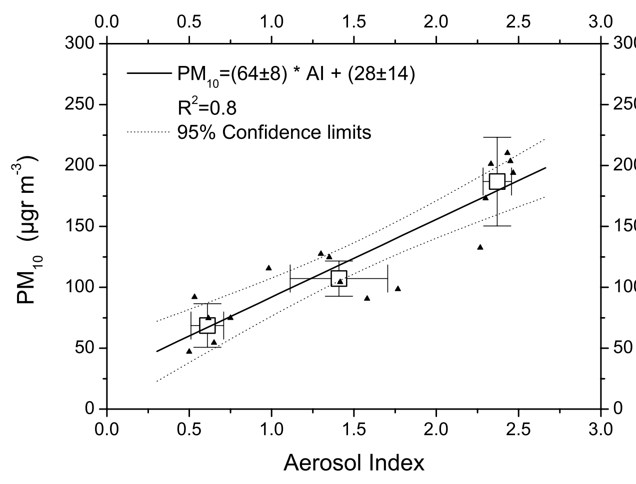

Figure 3. Aerosol index (AI) versus daily averaged PM_{10} for cases with simultaneous spikes (VET cases). Squares represent the averages of these data points after grouping them, and error bars correspond to the standard deviation.

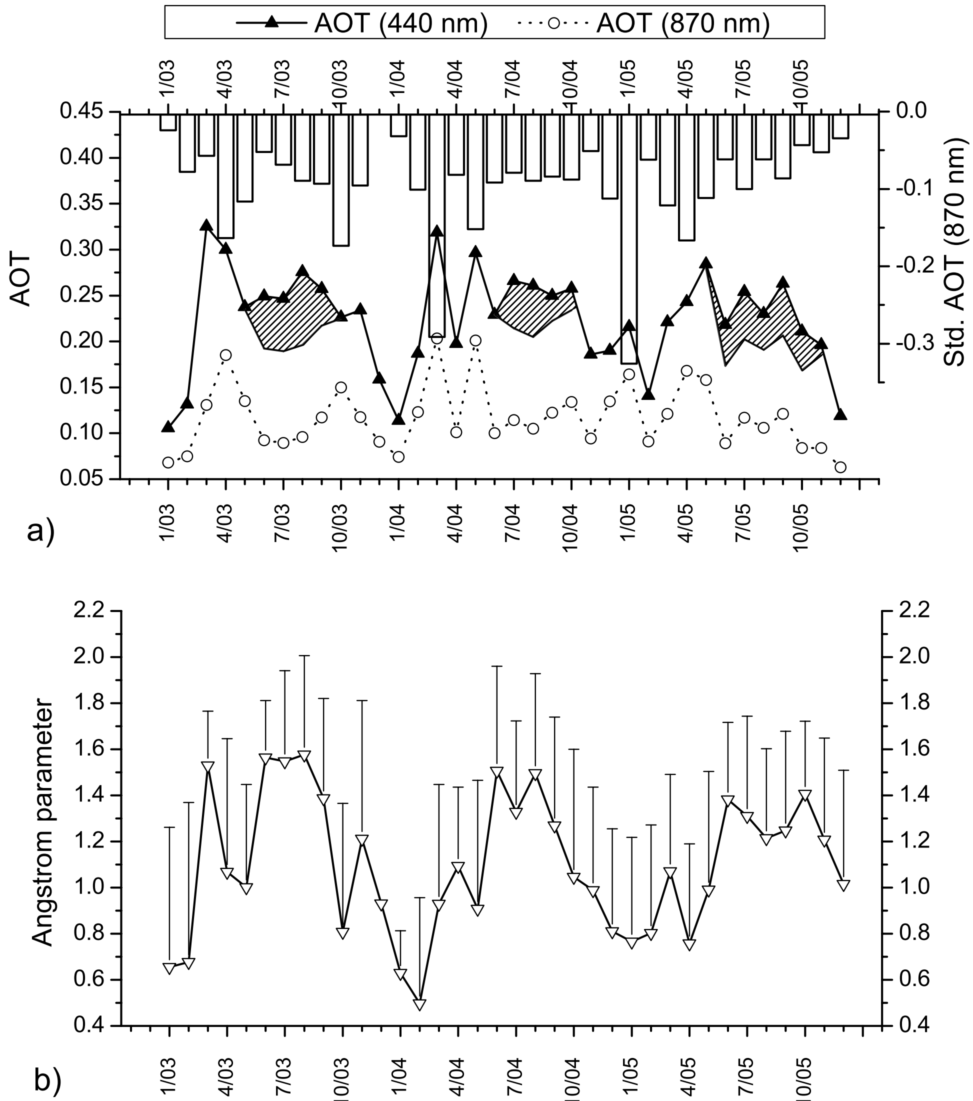

Figure 4. (a) Monthly means of AOT at two wavelengths 440 and 870 nm during the period 2003–2005. Vertical bars are the standard deviation of the monthly means. The shaded areas correspond to the difference between the two AOTs after scaling the 870 nm AOT so that minimum and maximum levels coincide with those of 440 nm AOT, (b) Monthly means and standard deviation of the Angström parameter for the same period.

[23] Despite the above mentioned drawbacks, the response of the AI value to different amounts of dust, as revealed from the PM_{10} measurements, is also examined, separately for the FTT and VET cases. For FTT cases (with delay) no covariance was found between AI and the maximum hourly value during the following days, probably because of the different scavenging rates of dust for different meteorological conditions. On the other hand a good correlation ($R^2 = 0.8$) exists between the columnar AI during VET cases and PM_{10} at the surface (Figure 3). Grouping the VET cases has revealed that AI values in the range of 0.4–0.8 correspond to PM_{10} surface concentrations between 30 and 100 $\mu g\ m^{-3}$ (95% confidence level), AI between 0.8 and 2 correspond to 70–130 $\mu g\ m^{-3}$ of PM_{10}, and finally AI ranging from 2.2 to 2.6 corresponds to 120–250 $\mu g\ m^{-3}$. The above results indicate that the new version 8 algorithm for retrieving the AI from TOMS is sensitive to dust transport over eastern Mediterranean.

[24] However satellite monitoring is limited in describing the evolution of aerosol transport and only provides an instantaneous photograph with sparse time resolution. Higher temporal resolution remote sensing measurements are required and these are provided by AERONET data, presented in the next sections.

3.2.2. AERONET Data and Identification of Dust Episodes

[25] In order to understand better the factors that control the seasonal variation of the AOT and the Angström parameter, monthly means derived from the daily values are shown in Figures 4a and 4b. AOT in the near-infrared (870 nm), is more sensitive to coarse particles, and hence was chosen to represent the seasonality of dust and sea-salt aerosols, while AOT in the near-ultraviolet (440 nm) was

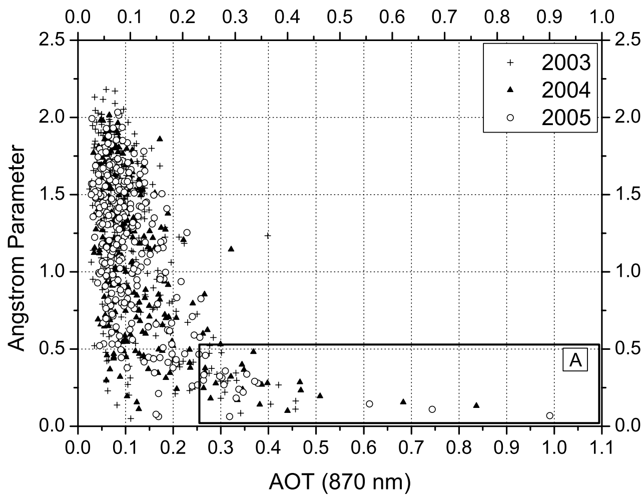

Figure 5. AOT at 870 nm versus the Angström parameter for the period 2003–2005. The area labeled as "A" corresponds to cases with Angström parameter lower than 0.5 and AOT higher than 0.25.

chosen to show the influence of anthropogenic sources. AOT at 870 nm show maxima primarily in spring and less pronounced in the fall, whereas the rise in January 2005 is due to a very intense event which took place on 27 January 2005. At 440 nm the AOT additionally exhibits a plateau in summer, probably related to the accumulation of fine anthropogenic particles due to stagnant meteorological situation. We rescaled the AOT at 870 nm so that the minima and maxima coincide with those of AOT at 440 nm. The additional contribution of either local or transported pollution was then highlighted by shaded areas. Indeed, these areas are confined to summer when pollution is shown to contribute significantly to the PM_{10} levels over the area [*Gerasopoulos et al.*, 2006]. The standard deviation of the AOT at 870 nm is also plotted as bars on the upper part of Figure 4a and demonstrates the episodic nature of the dust events during spring and fall when maximum AOT values occur.

[26] The seasonal variability of the Angström parameter (440 nm/870 nm) is presented in Figure 4b. Pronounced seasonality is revealed, with higher values in summer (~1.5) indicative of fine anthropogenic particles and lower values in winter (~0.7) representing sea salt coarse particles in the absence of local or regional pollution and dust (enhanced wet scavenging). A decrease in the Angström parameter is observed in spring and fall reflecting the increased frequency of dust outbreaks in the eastern Mediterranean. The higher values of the Angström parameter coincide with the shaded areas in Figure 4a verifying the contribution of the fine particles from anthropogenic sources during summer.

[27] AERONET data were used to estimate in more detail the columnar characteristics of the dust transport patterns that have already been depicted via the wind climatology and the AI from TOMS. To obtain an indication of the presence of dust in the atmospheric column over the FORTH-AERONET station a scatterplot of the Angström parameter against the AOT at 870 nm for the period 2003–2005 is presented in Figure 5.

[28] A distinct area at the bottom right hand side of the plot is shown for Angström parameter values lower than 0.5–0.6 and AOT at 870 nm higher than 0.2–0.25. In the majority of these cases the contribution of the coarse particles to the total extinction is more than 65% as revealed by the AERONET data and the trajectories indicate an origin from the south. The combination of these criteria allows the seasonal occurrence of the dust events recorded by AERONET to be estimated. These criteria are more frequently satisfied during spring and fall with frequencies 18% and 12%, respectively.

3.2.3. Comparison of AERONET Data With Surface Measurements

[29] A number of cases of transported dust over the eastern Mediterranean were chosen and the surface measurements (PM_{10}, scattering) were used to ascertain in which cases and to what extend the surface data reflect columnar characteristics.

[30] To illustrate the various dust transport patterns discussed above, PM_{10} values are plotted against AOT at 870 nm for the period March–May 2005 when numerous dust outbreaks of different type were encountered over the area (Figure 6). The spikes observed in both data series are labeled as follows: A, spikes that have been detected by both columnar and surface measurements (VET cases); B, spikes corresponding to transport above the mixing layer with no signal in the surface measurements (FTT cases); and C, cases of pollution inside the mixing layer.

[31] Various case studies pointing out the vertical distribution of dust have been described in detail [e.g., *Levin et al.*, 2005]. For the whole period (2000–2005) two case studies representing FTT and VET cases, respectively, are presented in detail to demonstrate the basic patterns of the two main dust transport pathways from northern Africa to the eastern Mediterranean.

3.2.3.1. FTT Case (Spring 2004)

[32] On 12 May 2004 the 4-day back trajectories at 3000 m indicated air masses that crossed NW Africa toward

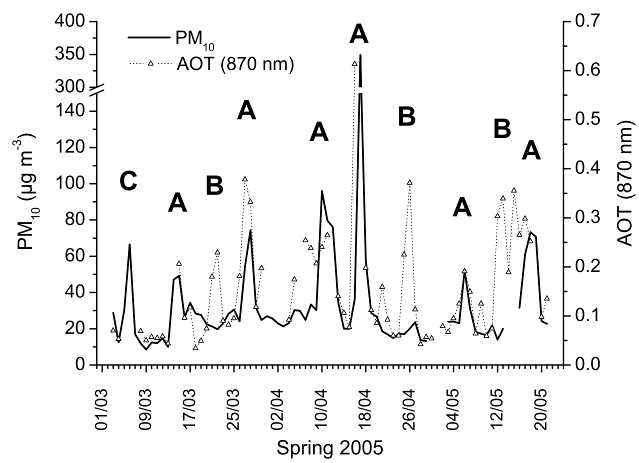

Figure 6. AOT at 870 nm and PM_{10} at Finokalia during spring 2005. The "A" cases are events with simultaneous signal in both parameters, "B" cases correspond to AOT peaks when no signal observed in the PM_{10} time series, and "C" cases are peaks in PM_{10} that are not found in AOT.

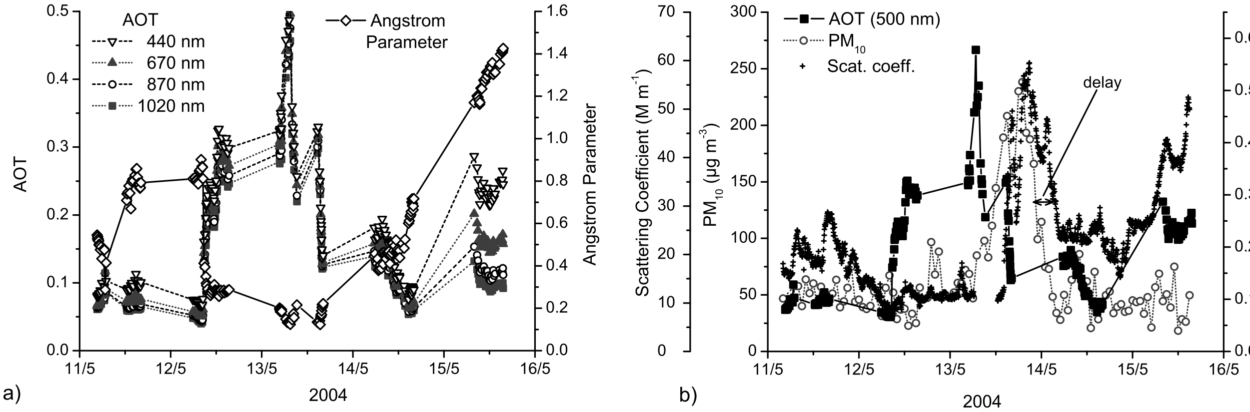

Figure 7. Evolution of a characteristic FTT event in spring 2004. (a) AOT at 440 and 870 nm and the corresponding Angström parameter and (b) AOT at 870 nm against surface measurements of PM_{10} concentration (at Heraklion) and scattering coefficient (at Finokalia).

Crete under the influence of a low- and a high-pressure system formed already since 10 May 2004 over Algeria and Libya, respectively (not shown). The high dust loading of these air masses was recorded by the AOT measurements over Crete on 12 and 13 May (0.29 and 0.53, respectively) with simultaneous reduction in the Angström parameter down to a value of 0.12 (Figure 7a). The dust load affected the ground based measurements one day later which is a common feature for most of the FTT cases. Thus, on 13 May the PM_{10} concentration at Heraklion reached 245 μg m^{-3} while the presence of strongly scattering coarse particles resulted in a scattering coefficient of about 60 M m^{-1} at Finokalia with a delay of approximately 7 hours (Figure 7b).

[33] Taking into account the time delay between the PM_{10} measurements at Heraklion and the scattering coefficients at Finokalia, a scatterplot of these two parameters is shown in Figure 8. Good correlation is revealed (R^2 = 0.7) between the two parameters indicative of the usefulness of the optical properties of aerosols for the estimation of dust load levels over the area. In Figure 8 the scatterplot between PM_{10} and AOT at 870 nm is also given and the covariance (R^2 = 0.6) is adequate to allow the prediction of the low temporal resolution AOT measurements from the surface observations, even in FTT cases.

3.2.3.2. VET Case (Winter 2005)

[34] The event in January 2005 represents one of the most intense dust episodes during the whole period. The dust transport resulted by three consecutive low-pressure systems over Italy, North Africa and the Sahara desert (not shown).

[35] During the first phase of the episode (25–28 January), AOT values at 870 nm reached their maximum value of 1.19 on 27 January with near zero Angström parameter values for consecutive days (Figure 9a). At this point trajectories indicated direct transport of dust from Libya (not shown). Surface measurements evolved in line with the columnar values as a result of a VET process, typical for winter events. The PM_{10} concentrations reached 333 μg m^{-3} and the maximum scattering coefficient was 87 M m^{-1} on 27 January (Figure 9b).

[36] On 29 January, another long-range transported wave of dust directly from the Sahara desert arrived over Crete adding to the existing aerosol load. AOT values rose to 0.80 at 870 nm and the Angström parameter remained low 0.10 (Figure 9a). The PM_{10} and scattering coefficient values were 265 μg m^{-3} and 78 M m^{-1}, respectively (Figure 9b), and again concurrent with the columnar signal in AOT.

[37] Finally, the scatterplot between PM_{10} and scattering (Figure 10) shows very high covariance (R^2 = 0.9) and it is interesting to note that the similar slopes and intercepts are found in both FTT and VET cases. This leads to the conclusion that during dust events the optical properties of aerosols can be used as an index of the mass concentration of the particulate matter at the surface. In addition, the covariance between PM_{10} and AOT is also significant (R^2 = 0.9) indicating that during VET, AOT levels from AERONET can be estimated well by PM_{10} levels at the surface.

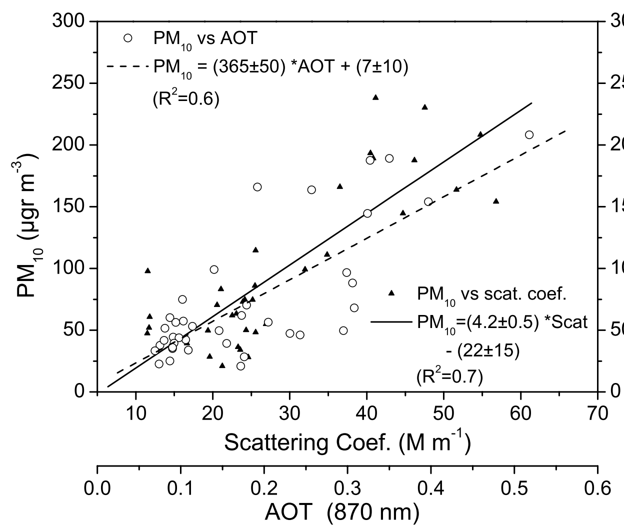

Figure 8. Hourly values of PM_{10} at Heraklion versus scattering coefficient at Finokalia and AOT from AERONET during the FTT event in May 2004. The PM_{10} and scattering coefficient time series were first shifted so that maximum correlation is achieved to account for the different location of the measurements. Linear regressions are also plotted for each case.

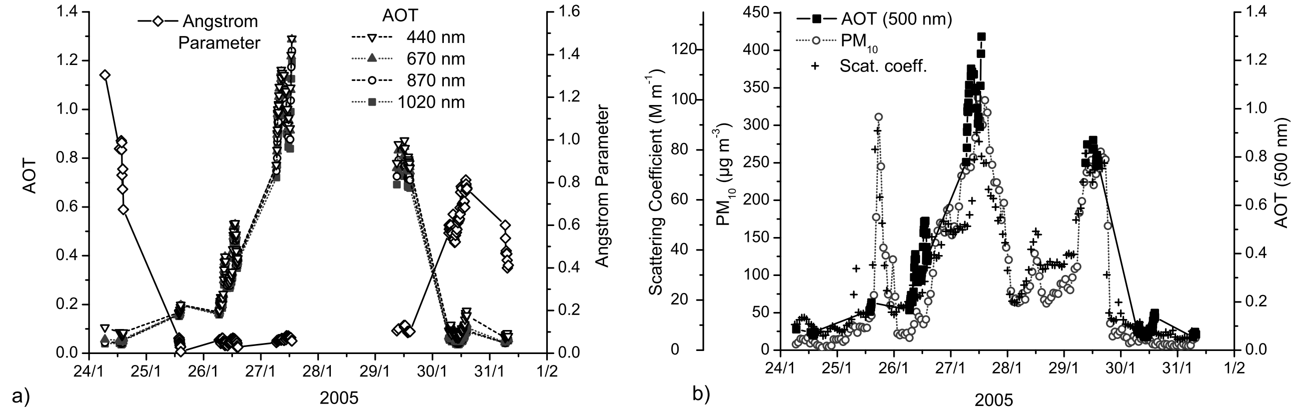

Figure 9. Evolution of a characteristic VET event in winter 2005. (a and b) As in Figure 7.

[38] To validate the good covariance between PM_{10} and AOT revealed in the two case studies a plot of the two parameters is shown in Figure 11. The points are selected during VET cases and correspond to maxima and minima (also for intermediate patterns) that are simultaneously observed at both time series. The revealed linearity allows a first-order prediction of the PM_{10} levels near the surface based on the AOT of the column. The enhanced uncertainty of PM_{10} for medium AOT values is probably due to the different vertical distribution of dust during the VET events.

4. Summary and Conclusions

[39] In this study focus was given on the investigation of different vertical dust transport patterns over the eastern Mediterranean. This was accomplished using satellite and ground-based remote sensing measurements (TOMS and AERONET) as well as surface measurements of aerosol mass and optical properties. The period covered by the measurements was 2000–2005.

[40] In all cases, dust particles occur more frequently in spring and fall. A 5-year climatology of southerlies at 1000 and 3000 m showed that dust can potentially arrive over Crete, either simultaneously in the lower free troposphere and inside the boundary layer, or initially over the BL with the heavier particles gradually scavenged during the following day. These are the main types of transport labeled as vertically extended transport (VET) and free tropospheric transport (FTT), respectively. In both cases dust is lifted into the free troposphere near its source and this is possibly related to the fact that transport occurs in the eastern side of low-pressure systems where convection may result to upward transport of the dust. In winter and fall VET cases dominate, in summer FTT cases are more frequent while in spring both cases are equally encountered.

[41] The aerosol index (AI) derived from TOMS is found to be adequate for the characterization of dust loading over the eastern Mediterranean despite the fact that 20–30% of the dust related spikes in the PM_{10} time series that do not correspond to AI spikes. AI peaks are more frequent in spring indicating that the presence of dust can be detected to a certain extent by TOMS. Combining the AI with surface

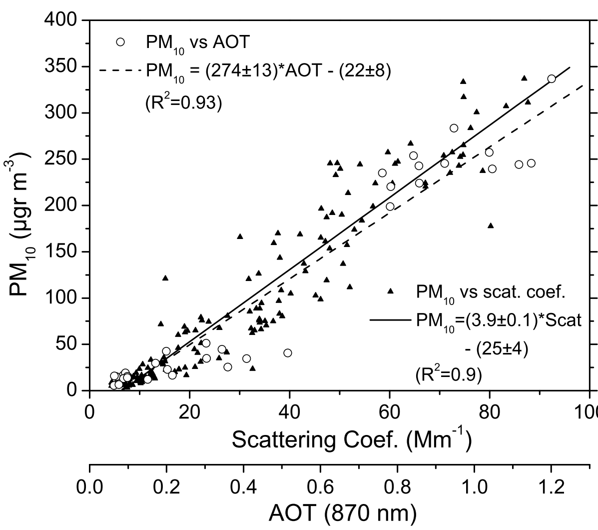

Figure 10. Hourly values of PM_{10} at Finokalia versus scattering coefficient at Finokalia and AOT from AERONET during the VET event in January 2005. Linear regressions are also plotted for each case.

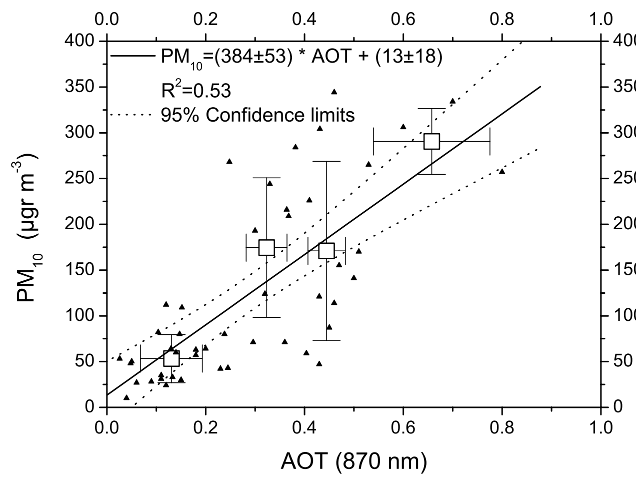

Figure 11. AOT at 870 nm against PM_{10} during VET cases. Squares correspond to the averages of these data points after grouping them, and error bars are the standard deviation.

PM_{10} the seasonal distribution of VET and FTT was reproduced. Especially during VET cases the correlation of AI with surface data is significant indicating that the new version 8 algorithm for retrieving the AI from TOMS is sensitive to dust transport over eastern Mediterranean.

[42] Since satellite monitoring has sparse time resolution (once per day) progress is provided by ground-based measurements from AERONET. It has been shown that the optical properties of aerosols during dust events can be very useful for the estimation of particles mass at the surface and that surface measurements of PM_{10} can be used in turn for the estimation of the columnar AOT, provided by AERONET on sparse intervals. Overall, surface measurements are shown to be crucial for the validation of measurements from the remote sensing techniques that in turn are a powerful tool for the investigation of the impact of aerosols on climate.

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