



## Remote sensing of cirrus clouds and aerosols by a sun photometer in Tunisia

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**Cirrus clouds and  
aerosols study**

H. Chtioui et al.

# Remote sensing of cirrus clouds and aerosols by a sun photometer in Tunisia

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Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

EGU

## Abstract

Some ground based measurements of solar radiation by using a sun photometer, have been conducted in Tunisia during the period of November 2000–February 2002. Five key measurement sites were selected: Three Sites (Tunis, Sousse, Gabes) are located on the Mediterranean coast and Two sites (Gafsa, Tozeur) on the boarder of Sahara. Over a total of 149 measurement days, 21 days are identified as clear sky, 114 days as Cirrus clouds and 14 days as aerosols.

Aerosols and Cirrus clouds Optical Thickness (AOT) are derived from photometric measurements at 532 nm wavelength. Spatial and temporal variabilities of AOT are presented and discussed in this paper.

Cirrus clouds were frequently observed at Gafsa and Tozeur where saharan aerosol events are expected to be more frequent than cirrus clouds. The mediterranean sea and saharan aerosols are suspected to have the main role in cirrus clouds formation, by providing water vapor and high concentrations of cloud condensation and ice forming nuclei.

## 1 Introduction

Saharan dust can seriously affect the regional climate by changing interaction with solar radiation and by influencing the precipitation (Israelevich et al., 2003). They play a significant role in cirrus and contrails formation (Liou, 1986; Schumann, 2002; Sassen et al., 2003). The Mediterranean area is strongly affected by saharan aerosols coming from Norhern Africa (Dulac et al., 2003). The main sources and trajectories of the saharan dust storms over Northern Africa and the mediterranean were identified by Israelevich et al. (2002), Dayan et al. (1991).

Cirrus clouds cover permanently more than 20% of the Earth (Liou, 1986; Chepfer et al., 2001). They interact with aerosols and solar radiation and affect the earth's radiation budget (D'Almeida et al., 1987). The optical and microphysical properties of cirrus

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

clouds and aerosols are important parameters for the earth radiation budget modelling (Chepfer et al., 1999). Their detailed and accurate characterization is an absolute need for the radiative transfer models which are used for atmospheric transmittance relevant to earth radiative budget and climate modelling.

5 In southern Europe and middle East, several experimental and numerical studies have been published on the impact of cirrus clouds and saharan aerosols on climate (Tanré et al., 1988; Deuze et al., 1988; Dulac et al., 1992; Müller et al., 2003).

Up to day, in Northern Africa, there is not sufficient ground stations and experimental equipment for appropriate atmospheric monitoring and ground based measurements of solar radiation by sun photometer are limited either in space or in time. The whole amount of studies on saharan dust outbreaks over Northern Africa are based on satellite observations.

10 In Tunisia, we use a home made sun photometer to measure solar fluxes at 532 nm wavelength and derive aerosols and cirrus clouds optical thickness (AOT).

## 15 2 Experiment design

As mentioned above, North African regions and especially Tunisia and Libya are not yet covered by routinely operated ground based measurements of solar radiation such as the Aerosol Robotic Network (AERONET, Holben et al., 1998). It is only in the frame of EMAGPOT project (Etude à Mésoéchelle des Aérosols, Gaz et Précipitations en Tunisie) that a sun photometer (CIMEL CE318) was installed temporarily in Thala (35.55° N, 8.68° E) in Tunisia by Laboratoire d'Optique Atmosphérique (LOA), Lille, France. These measurements have been done during March-November 2001 period and presented by Masmoudi et al. (2003) on spatial and temporal variabilities of aerosols optical thickness and size distribution. However, cirrus clouds were not part of their study in their paper.

25 In order to characterize aerosols layers and cirrus clouds over Tunisia, we have conducted a study using sun photometer during the period November 2000–March 2002.

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### Cirrus clouds and aerosols study

H. Chtioui et al.

---

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[I◀](#)[▶I](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The measurements were conducted in five key sites (Fig. 1): Tunis (36.50° N, 10.13° E), Sousse (35.50° N 10.38° E), Gabes (33.52° N 10.06° E), Gafsa (34.28° N, 8.43° E) and Tozeur (33.50° N, 8.07° E). Tunis, Sousse and Gabes are located on the Mediterranean coast, when Gafsa and Tozeur are located in the South West part of the country, at the boarder of the Sahara.

A summary of the field campaign is presented in Table 1.

### 3 Instrumentation

The sun photometer which is used in this work is a hand apparatus. It was designed in 1982 by LMD (Laboratoire de météorologie dynamique, Ecole Polytechnique, France) and LOA (Laboratoire d'optique atmosphérique, Lille, France).

The detector is a silicium photo-voltaïque cell with a 200–1113 nm wave band. Sun aiming is manually accomplished. So it is hard to ensure measurements every day and every 15 or 30 min. The sun photometer is equipped with five filters in the solar spectrum: F<sub>1</sub>(532 nm), F<sub>2</sub>(647 nm), F<sub>3</sub>(850 nm) F<sub>4</sub>(940 nm) and F<sub>5</sub>(937 nm). However in this work, just the filter F1 is used for Atmospheric optical thickness determination.

### 4 Data processing

Instrument calibration and data processing methods are the same as presented by Masmoudi et al. (2003). Here below a short description is presented. Measurements are just used to derive Atmospheric (Aerosol and Cirrus) Optical Thickness at  $\lambda=532$  nm where Solar attenuation is due to Rayleigh and Mie scattering (No atmospheric absorption at this wavelength).

The total extinction of solar radiation is:

$$U_{\lambda} = (U_{0\lambda}/S) \exp(-\tau_t m) \quad (1)$$

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**Cirrus clouds and aerosols study**

 H. Chtioui et al.
 

---

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[◀](#)
[▶](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

where  $\tau_t$  is the total atmospheric thickness and  $U_\lambda$  is the measured signal (in volts) at wavelength  $\lambda$  and  $m$  is the optical air mass.  $U_{0\lambda}$  is a calibration constant. In practice it is determined from a Langley plot. Clear sky conditions are used for such a calibration.

$S=(d/d_0)^2$  is the normalized earth-sun distance.  $d$  is the earth-sun distance on the measurement day and  $d_0$  is the mean earth-sun distance (Paltridge and Platt, 1976)

$$1/S = (d_0/d)^2 = 1.000110 + 0.034221 \cos(a) + 0.001280 \sin(a) + 0.000719 \cos(2a) + 0.000077 \sin(2a) \quad (2)$$

where  $a=2\pi n_j/n_t$ ,  $n_j$  is the day number in the year and  $n_t$  the total number of days per year.

$$\text{Log}(U_\lambda) = \text{Log}(U_{0\lambda}/S) - \tau_t m \quad (3)$$

$\tau_t$  is determined using a mean square fitting of  $\text{Log}(U_\lambda)$  against  $m$  plot.

$$\tau_t = \tau_a + P/P_0 \tau_n \quad (4)$$

$P$  and  $P_0$  are pressure at measurement station level and at sea level respectively.

$\tau_n$  is the Rayleigh optical thickness which is computed for a standard atmosphere (Paltridge and Platt, 1976).

$\tau_a$  is the Atmospheric Optical thickness (AOT) due to particles extinction. The retrieved AOT are computed with an error of  $\pm 0.02$  (Chiapello et al., 1999).

## 5 Data analysis

About 2000 photometric measurements were obtained during the period November 2000–February 2002 at Tunis ( $d=6$ ,  $n=85$ ) Sousse ( $d=114$ ,  $n=1438$ ), Gabes ( $d=3$ ,  $n=52$ ), Gafsa ( $d=11$ ,  $n=162$ ) and Tozeur ( $d=15$ ,  $n=263$ ), where  $d$  is the number of measurement days and  $n$  the total number of measurements during  $d$  days. Time interval between two measurements is about 20–30 min.

**Cirrus clouds and aerosols study**

H. Chtioui et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

As shown in Table 2, most of the measurements have been conducted at Sousse which is our home station. The other sites were visited during a few days but at different times of the year. Table 2 contains average AOT versus month.

The maximum AOT (=0.6) is measured during the March-April-May period. It is well known in South Tunisia that saharan dust events occur more frequently at this time (Israelevich et al., 2003). Minimum AOT values (0.15) were measured during December–January.

It is important to mention that cirrus clouds are identified by eyes by the experimenter during measurements. As shown in Table 2, cirrus clouds are frequently observed at all sites especially during the saharan dust events over Tunisia.

At Sousse, a total of 114 days are classified as 88 as cirrus days, 14 as clear sky days and 12 aerosols days. At Gafsa and Tozeur, which are about 200 km away from the mediterranean coast, the AOT values (0.14–0.24) are lower than those measured at Sousse and Tunis. Sousse and Tunis are located on the Mediterranean coast.

In order to check that cirrus clouds amount is enhanced by the Saharan dust transport over Sousse, wind direction at 200 hPa is examined by using The European Meteorological Bulletin. During the field campaign (149 days), It was found that frequent wind directions were West (50 days), North-West (36 days) and South-west (20 days) directions. In other words, Instances of wind coming from the Sahara and North Algerian land (106 days) were higher than instances of wind coming from Europe and the Mediterranean areas (22 days). Most Tunisian aerosols could be Saharan. The presence of Mediterranean moisture and Saharan aerosols seems to be responsible for cirrus clouds formation (Schumann, 2002; Sassen et al., 2003). Total values of AOT versus month for the different sites are presented in Fig. 2. At Sousse, most AOT values range from 0.2 to 0.4. Highest values were measured at Tunis. They may be due to antropogenic aerosols and also contrails due to nearly international airport.

Two stack histograms are presented in Fig. 3. Because Gafsa and Tozeur are far from The mediterranean coast, more frequently the AOT values do not exceed 0.14. However near the mediterranean (Tunis, Sousse, Gabes), most values range from 0.1

to 0.4. Here, AOT values lower than 0.1 are identified as aerosols cases.

In order to understand the interaction between the mediterranean and saharan aerosols, available Satellite images showing saharan dust events over the mediterranean during November 2000–February 2002, were downloaded from <http://www.osei.noaa.gov/Events/Dust/> and in <http://www.saa.noaa.gov> websites. During our field campaign, no significant dust events were observed by satellite over Tunisia. Most interesting events occurred over the Libyan coast. However, a few satellite images were selected: they clearly show contrails over the saharan dust layer (Fig. 4).

## 6 Conclusions and perspectives

In order to characterize north african aerosols and cirrus clouds events, sun photometric measurements have been conducted at five Tunisian sites. Three of them are located on the Mediterranean coast and the others are near the saharan boarder.

Three concluding remarks may be derived from this experiment:

- In all regional sites and at most of the time, Cirrus clouds have been more frequently observed than Saharan dust.
- Also at all sites, higher AOT values (0.4–0.6) were obtained during the saharan dust period (March–May). Lower values (0.15–0.25) were, however obtained during summer and winter.
- According to satellite observations, saharan aerosols can enhance contrails formation especially in Europe where air traffic is denser than over North Africa.

### Perspectives

- Using satellite images, contrails formation over Europe could be studied during Saharan dust transport.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- It would be very useful to make lidar measurements with sun photometer measurements, because lidar can distinguish between Cirrus clouds and Aerosols layers and determine their height, optical and geometrical thickness.

*Acknowledgements.* Thanks are due to National Oceanic and Atmospheric Administration, “Satellite Active Archive” (NOAA-SAA) team for their free satellite images which are available at <http://www.saa.noaa.gov> web site.

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## Cirrus clouds and aerosols study

H. Chtioui et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

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**Cirrus clouds and aerosols study**

H. Chtioui et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

## Cirrus clouds and aerosols study

H. Chtioui et al.

**Table 1.** Experiment field campaign chronology,  $d$  is the number of measurements days per period. Total days: 149, with 6 days in Tunis, 3 in Gabes, 11 in Gafsa, 15 in Tozeur and 114 in Sousse.

Site	Period	$d$
Tunis	May 2001	6
Sousse	November 2001–March 2001	62
	March 2001–April 2001	6
	May 2001	2
	August 2001–October 2001	20
	October 2001–November 2001	4
	November 2001–December 2001	14
	January 2002–February 2002	6
Gabes	November 2001	3
Gafsa	April 2001	7
	November 2001	4
Tozeur	March 2001	8
	December 2001	7

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

**Table 2.** Atmospheric Optical Thickness (AOT) and Standard deviation (Std) of Cirrus Clouds (Ci), Saharan Aerosols (Ae) and Clear Sky (CS) cases observed at each regional site.  $d$  is the number of measurement days per month from November 2000 to February 2002. 76.5% of cases are Cirrus clouds, 9.5% Aerosols and 14% Clear sky. Std varies from mean AOT to half.

Site	Date	$d$	CS	Ae	Ci	Mean AOT	Std
Gabes	October 2001	3	2	0	1	0.24	0.20
Gafsa	April 2001	7	0	1	3	0.28	0.27
	November 2001	4	1	1	5	0.20	0.10
Tozeur	March 2001	8	1	0	7	0.20	0.15
	December 2001	7	2	0	5	0.14	0.13
Tunis	May 2001	6	1	0	5	0.40	0.23
Sousse	November 2000	7	1	0	6	0.60	0.17
	December 2000	11	1	6	4	0.15	0.08
	January 2001	15	0	4	11	0.22	0.21
	February 2001	19	0	2	17	0.31	0.22
	March 2001	7	2	0	5	0.42	0.26
	April 2001	3	0	0	3	0.31	0.13
	May 2001	2	0	0	2	0.49	0.09
	August 2001	4	2	0	2	0.20	0.11
	September 2001	8	0	0	8	0.27	0.19
	October 2001	13	3	0	10	0.16	0.11
	November 2001	13	2	0	11	0.25	0.16
	December 2001	6	2	0	4	0.13	0.09
	January 2002	2	0	0	2	0.32	0.11
	February 2002	4	1	0	3	0.38	0.16
Total days		149	21	14	114		
		100%	14%	9.5%	76.5%		

## Cirrus clouds and aerosols study

H. Chtioui et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

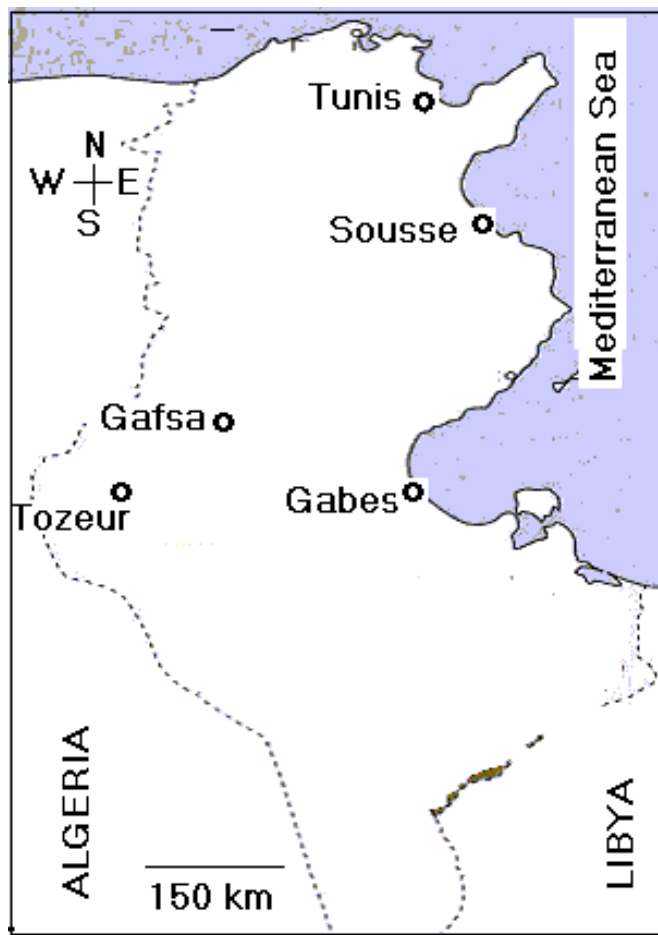


Fig. 1. Tunisian map showing the five sites of measurements.

**Cirrus clouds and aerosols study**

H. Chtioui et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

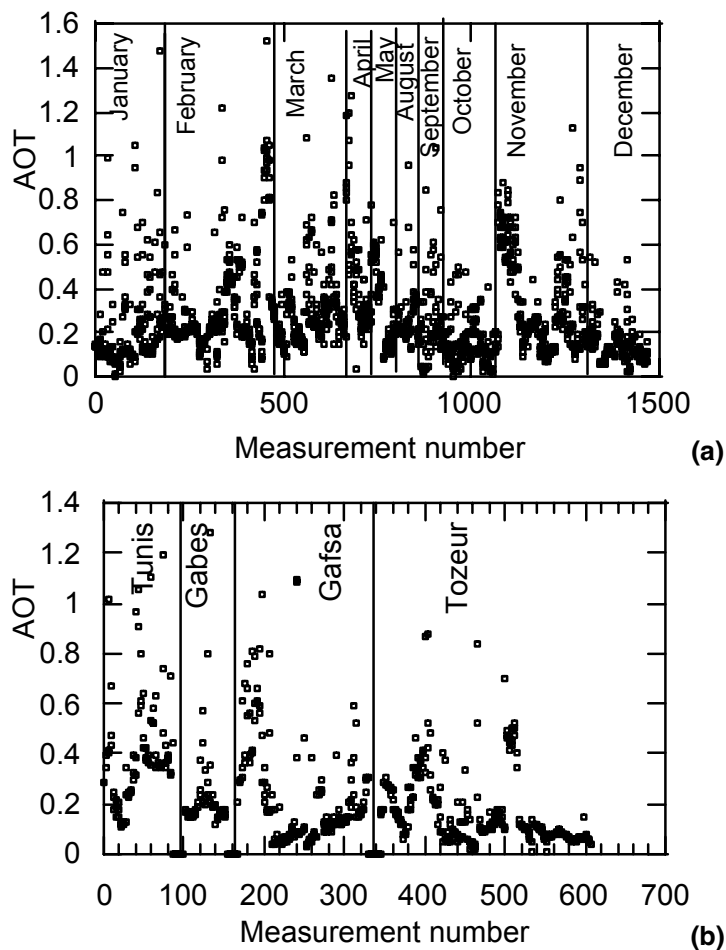
Full Screen / Esc

Printer-friendly Version

Interactive Discussion

## Cirrus clouds and aerosols study

H. Chtioui et al.

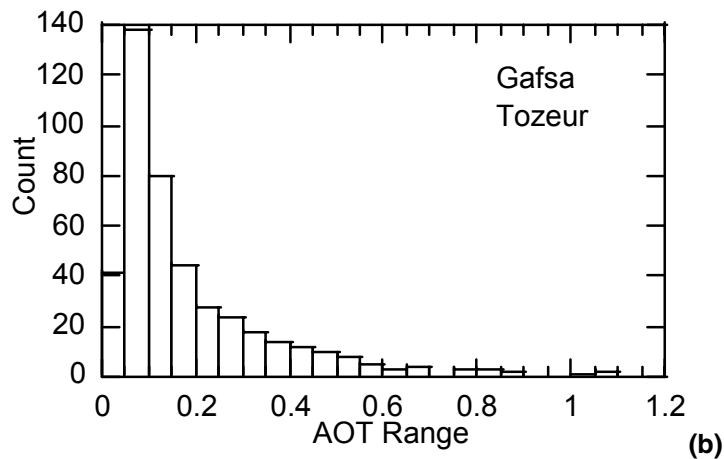
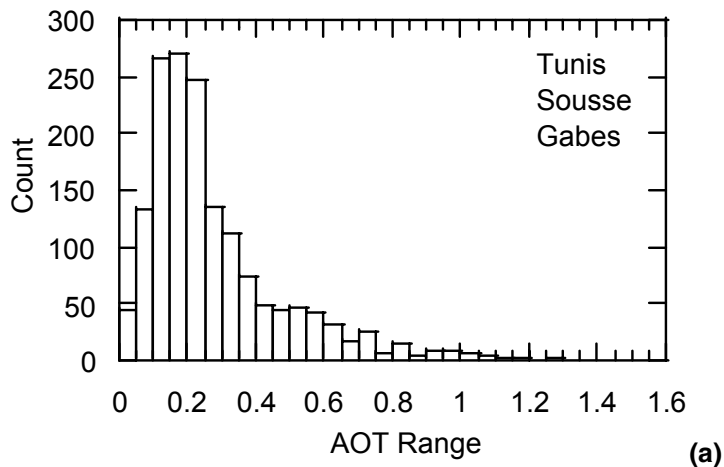


**Fig. 2.** Total Atmospheric Optical Thickness (AOT) measured during the field campaign (November 2000–February 2002). **(a)** measurements at Soussse as a function of month of the year, **(b)** measurements at Tunis, Gabès, Gafsa and Tozeur.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

## Cirrus clouds and aerosols study

H. Chtioui et al.

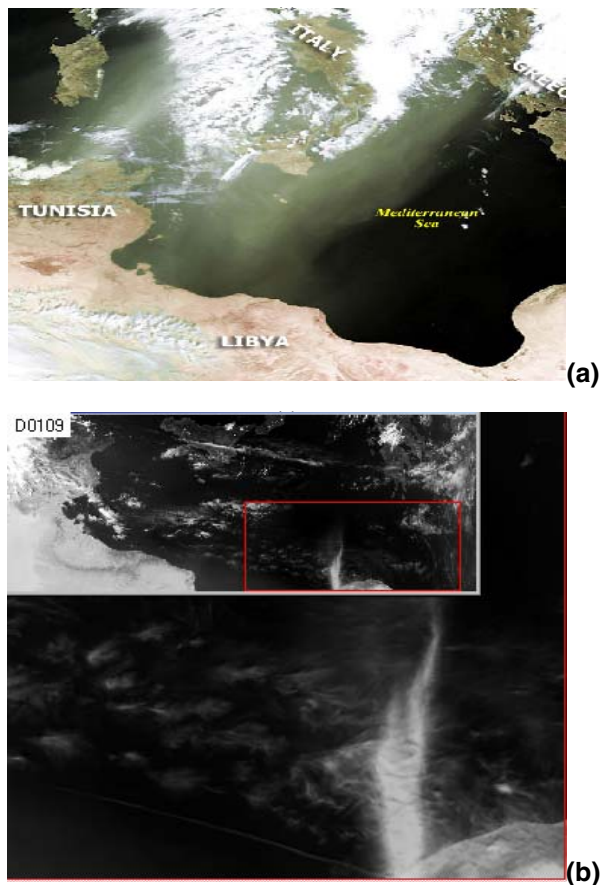


**Fig. 3.** Atmospheric Optical Thickness (AOT) histograms for sites **(a)** near the mediterranean coast and **(b)** near the Sahara boarder.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

**Cirrus clouds and aerosols study**

H. Chtioui et al.



**Fig. 4.** NOAA AVHRR Satellite images showing Saharan dust storms and contrails over the Mediterranean Sea. **(a)** NOAA 16 image of 3 March 2002 at 11:45 UTC over Tunisia (image source: <http://www.osei.noaa.gov/Events/Dust/>). **(b)** NOAA 16 image showing dust plume coming from Libyan area on 19 April 2001. Zoomed image shows a thin contrail near the dust plume. Reference image: NSS.LHRR.NL.DO1109.S1229.E1241.B0296363.GC downloaded from <ftp://ftp.class.noaa.gov>.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion