Study on the effect of dust aerosols over Riyadh

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Abstract

Atmospheric aerosols are linked to the climate system and to the hydrologic cycle. Dust is one of the major types of tropospheric aerosols. Dust particles affect both solar and terrestrial radiation, and are thus considered an important parameter in radiation budget studies. In this study, we investigate the impact of two dusty events that occurred on the 12th and between the 17th and 20th July 2000 on both Aerosol Optical Depth and Angstrom Exponent using ground-based measurements. High turbidity values and low Angstrom exponents during the events, in comparison with the previous days, were found. Theoretical calculations using the SMART model show that the dusty conditions significantly decreased the global and direct-beam irradiances, and increased the diffuse component.

Keywords: dust storm; Angstrom component; AOD; July 2000; CIMEL; Riyadh.

1 Introduction

Aerosols are an important factor affecting air quality, health, and radiation budget. There are two main sources of aerosols: natural sources and anthropogenic aerosols. On a global scale, the former is more important than the latter, whereas on the regional scale the latter is important. In reality, aerosols are mixed together from both sources; hence their chemical composition and physicals properties are not constant [1–2]. Aerosols from deserts are the most abundant aerosol type found in the atmosphere on the global scale. Dust is one of the main sources of tropospheric aerosols. Dust storms are natural threats that affect daily life for short-time intervals from a few hours to a few days. They cause a variety of problems, such as failure of mechanical and communication systems, car accidents, damage to crops, and air pollution [3]. Dust aerosols have a significant impact on Earth's climate system and have significant implications for human health [4–5]. They affect both solar and atmospheric radiation by scattering and absorption [6].

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Radiative effects caused by atmospheric aerosols are considered as one of the most ambiguous characteristics of climate models, due to the varied concentrations of the aerosols both spatially and temporally, and due to the different forms of aerosol shapes [7–8].

Aerosol Optical Depth (AOD) and the Angstrom Exponent (α) are two of the most important optical properties of aerosols used in radiation transfer studies. AOD is the integral atmospheric attenuation of the solar radiation passing through the atmosphere due to aerosols [8]. This parameter is important in climate changes, visibility degradation monitoring, and is significant in assessments of the atmospheric aerosol burden using remote sensing techniques from ground-based equipment [9]. The Angstrom exponent is a measure of particle size distribution, and it is a useful indicator used to characterise the aerosol types [10].

Dust storms are common in Saudi Arabia mainly in the pre-monsoon season and early summertime. These storms are transported to the region by southwesterly winds from the arid regions (such as the Empty-Quarter Desert) around the kingdom. Dust storms from Saudi's desert have been studied previously to describe the dust loading of the atmosphere over the Arabian Peninsula [8, 11–12]. The optical properties of these dust storms are rarely investigated. This paper studies the influence of severe dust events that occurred on the 12th and between the 17th and 20th July 2000 in Riyadh, on both AOD and the Angstrom exponent.

2 Experimental data

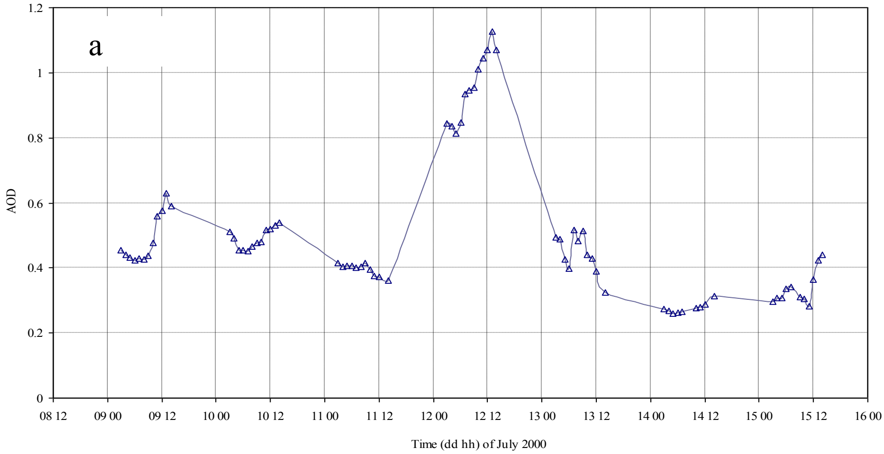
Riyadh (24° 43′N; 46° 40′E, 764 m above sea level) is the capital and largest city in Saudi Arabia; a purely urbanised area and considered as one of the most polluted areas in the kingdom. The Empty-Quarter Desert, heavy traffic, and industrial areas surrounding Riyadh are the main aerosol sources [8].

AOD data were obtained from CIMEL sun photometer (CE-318) installed on the rooftop of the solar village (20 km northwest of Riyadh). This instrument has a 1.2° full FOV and measures direct solar radiation every 15 minutes at 340, 380, 440, 500, 675, 870, 940, and 1020 nm. The instrumentation, data acquisition, retrieval algorithms, and calibration procedures followed AERONET standards [13–14]. In this study, hourly-averaged, clear sky and quality assured level 1.5 products were used. The results will focus on the measured AOD at 500 µm and the Angstrom parameter for the wavelength ranges 340–440 nm.

3 Results and discussion

3.1 The 12th July event

Figure 1 shows the hourly variations of the AOD and Angstrom component values for the period between the 10th and 14th July 2000, in which the effect of the 12th July dust event can be compared to non-dusty days. Table 1 gives the daily average values of the AOD, the Angstrom component α, and three meteorological parameters for that period. The last two columns indicate the changes in percentages of the AOD and α for specific days compared to the twelve-year averaged values.



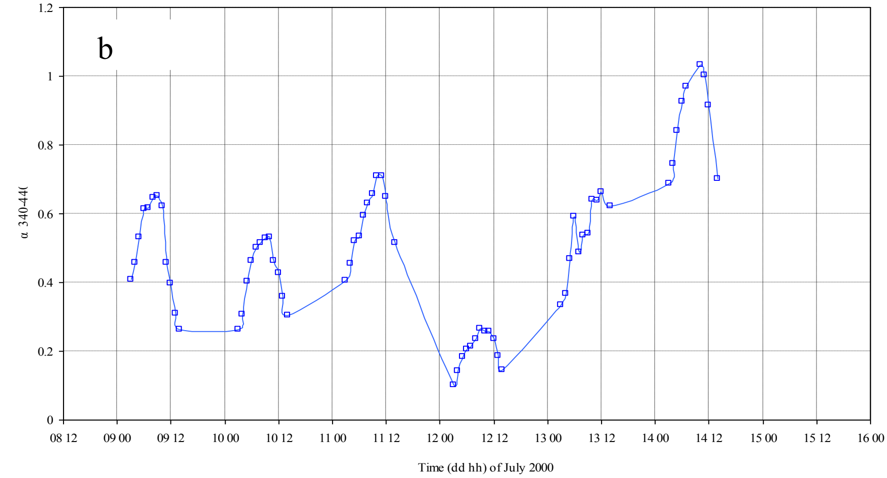


Figure 1: Day-to-day variability of (a) AOD at 500 nm and (b) Angstrom component α for the wavelength 340–440 nm from 10th to 14th July 2000.

Table 1: Summary of the average daily values of AOD at 500 nm, α for the wavelength 340–440 nm, air temperature (T), relative humidity (RH), and visibility (Vis), for the period from 10th–14th July 2000. The last two columns, respectively compare the changes in AOD and α with the twelve-year averaged (1999–2010) values.

Day	AOD	α	T °C	RH%	Vis (m)	$AOD_{average\ 1999-2010}$ = 0.32	$\alpha_{average\ 1999-2010}$ = 0.52
10	0.49	0.40	39.29	6.67	8.29	55.57	-31.51
11	0.40	0.57	38.79	7.29	8.00	24.21	-2.13
12	0.97	0.20	37.71	9.33	4.00	202.13	-65.11
13	0.45	0.52	37.67	8.00	9.00	41.37	-11.15
14	0.27	0.83	38.25	7.63	9.00	-14.38	43.11

On 10th July, the AODs were between 0.45 to 0.53 with a mean of 0.49 ± 0.014. During the morning hours of the 11th, AOD was 0.41, then declining steadily to 0.311. On the morning of the 12th, AOD was around 0.82 before it jumped to 1.3 at midday. The AOD stayed around 1.01 for the rest of the day. The mean AOD value for that day was 0.97 ± 0.50. This value is, respectively, 202% and 168% greater than the twelve-year average ($AOD_{average\ 1999–2010}$ = 0.32) and the year 2000 ($AOD_{average\ 2000}$ = 0.36) averages. For most of the 13th AOD was between 0.4 and 0.51 and decreased to 0.31 by the end of the day. There were no variations on AOD on the 14th and it remained between 0.27 and 0.31. The AOD values for the last two days were 0.45 ± 0.02 and 0.27 ± 0.01 respectively, and no major changes of the meteorological parameters were observed.

Apart from the 13th July, there is an observed diurnal variation of α for the other four days. On the 10th, α increased from 0.26 to 0.52 around midday, when it then dropped to 0.30 by the end of the day. On the 11th α values follow a continuously increasing trend, from 0.41 to a maximum of 0.71, and then decreasing to 0.51. Around the early morning of the 12th α dropped dramatically to 0.1 following the arrival of the dust plume to the region. The mean value of α on the 12th was 0.2 ± 0.17, which is 64% lower than the previous day's value. This value is 65% lower than the twelve-year ($\alpha_{average\ 1999–2010}$ =0.52) average value. On the 13th, α increased from 0.33 to 64, then it resumed its daily variation on the 14th.

3.2 The 17–21st July 2000 events

The situation here is rather different from the previous case: the study area experienced high aerosol loads in several days during this period. Figure 2 shows the hourly variations of the AOD and α, and Table 2 summarises their daily averages.

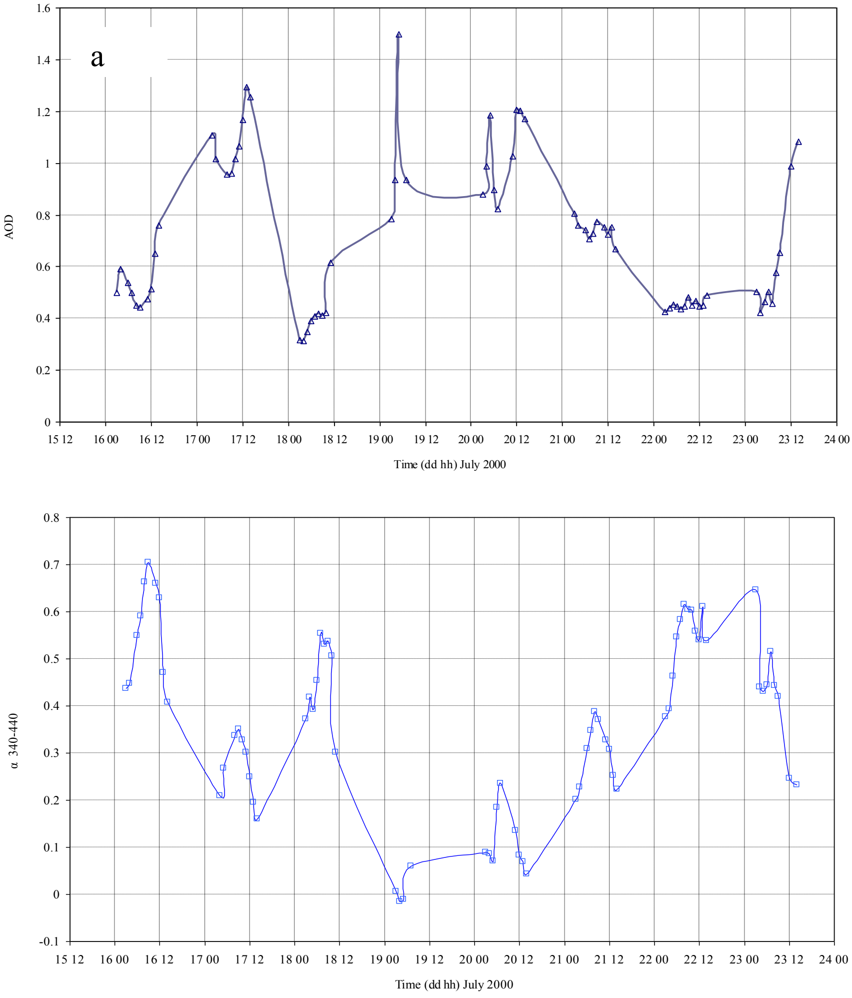


Figure 2: Day-to-day variability of (a) AOD at 500 nm and (b) the Angstrom component α for the wavelength 340–440 nm for the period between 15th and 23rd July 2000.

Table 2: Same as Table 1, but for the period between 16th and 22nd July 2000.

Day	AOD 500 nm	α 340-440	T °C	RH %	Vis (m)	average 1999-2010= 0.32	α average 1999-2010 =0.52
16	0.54	0.57	38.77	7.82	9.05	69.97	8.40
17	1.13	0.26	39.68	8.41	8.32	253.35	-49.85
18	0.37	0.43	39.96	8.58	4.23	15.32	-16.97
19	0.92	0.00	38.46	6.67	6.17	186.69	-99.24
20	1.05	0.11	38.38	7.75	3.60	229.00	-79.37
21	0.72	0.28	37.79	8.71	6.46	126.54	-46.48
22	0.45	0.52	37.96	14.17	6.46	41.24	0.03

On the 16th the AOD was between 0.49 and 0.6 and it reached a value of 0.78 by the end of the day. The first dust storm arrived on the early morning of the 17th causing a drop in the visibility to reach a value of 2 km. AOD was 0.89 and it increased to reach a maximum of 1.38. After the arrival of this dust storm, α was reduced from 0.18 to 0.11. No major changes on both the air temperature and relative humidity were observed. The effect of the 17th dust event disappeared very fast and the AOD for the 18th stayed between 0.31 and 0.41, and α was between 0.14 and 0.22.

A strong and long-lived dust storm event arrived on the late night of the 18th and remained until the 21st of July. The changes of the AOD and α were remarkable. During this period, AOD values were between 0.78 and 1.3. A similar increase in the standard deviation of the AOD was found, due to the high amount of atmospheric aerosol brought by the dust storm. AOD values were 253%, 186% and 229% higher than the twelve-year averages ($AOD_{average\ 1999\text{-}2010} = 0.32$) for the 17th, 19th and 20th respectively. Angstrom exponents, α, during these three days were between -0.004 and 0.1. The small α values indicate the presence of large coarse particles, as observed on the 19th whereas high α values like those recorded for 16th and 18th are linked to the dominance of fine particles. On the other hand α values for the 17th, 19th and 20th were 49%, 99%, 79% smaller than the twelve-year ($\alpha_{average\ 1999\text{–}2010} = 0.32$) average. Relative humidity and air temperature changed slightly during this period. However, a sharp increase of 13% in the RH was recorded on the evening of the 21st, which may not be due to the effect of these dust episodes.

4 Attenuation of solar radiation by aerosols – theoretical simulation

Theoretical simulations are a common practice adopted by many investigators to study the influence of different atmospheric conditions on the spectral and/or solar radiation components. In this study, the effect of the dust storms on the global (G), Direct (Dir), and Diffuse (Dif) components was calculated theoretically using Simple Model of Atmospheric Radiative Transfer of Sunshine (SMARTS) code [15–16]. The code was designed to calculate the spectral solar irradiance components (between 280 and 4000 nm) under clear sky conditions. The several inputs available in SMART allow the user to study the effect of different atmospheric conditions on the amount of the solar radiation reaching the detection sensor. For instance, the user can specify the amount of aerosols and water vapour content to study their effect on the incoming radiation. Additionally, solar geometry characterised by zenith angle, date and time can also be defined.

The simulation methods followed here consist of (1) selecting the standard atmosphere, (2) choosing the input parameters, (3) running the code, and (4) treating the simulation's outputs. There are two types of the inputs, the fixed and the changeable variables. The former are those that are set up once during the whole simulation process and remain unchanged, e.g. solar geometry and standard atmosphere (mid-latitude summer, used here). On the other hand, the changeable inputs are those we vary during each run, such as the amount of the aerosol loads. Other atmospheric inputs, such as the water vapour, CO_2 and O_3 concentrations and mixed gases were also set to SMART's standard atmosphere. The total radiation components were calculated by integrating the simulated spectral irradiances between the desired wavelength ranges. The calculations were carried out for clear atmosphere (low AOD = 0.100) and high aerosols values experienced on the 12th, 17th, 19th, and 20th July 2000, which had, respectively, AOD values of 0.97, 1.13, 0.92 and 1.05. Figures 3–6 show the estimated global, diffuse, and direct-beam irradiances for the spectral band 280–1100 nm under clear sky and dusty conditions.

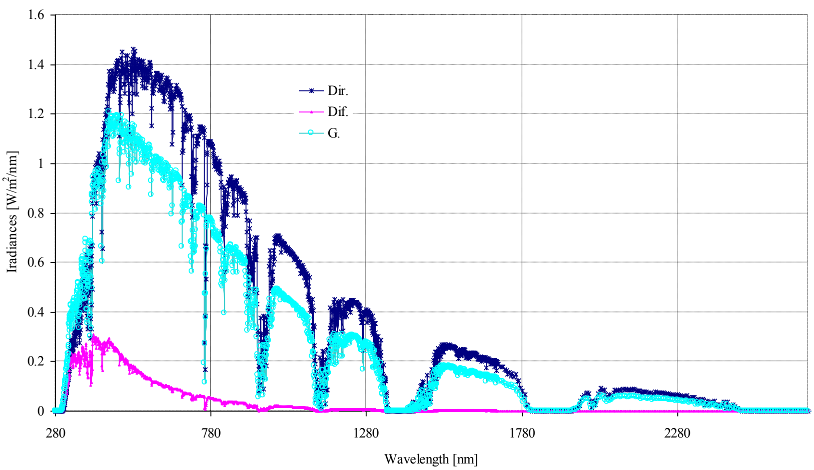


Figure 3: Estimated spectral irradiances under clear sky conditions using SMARTS model, for the Global, Direct, and Diffuse components.

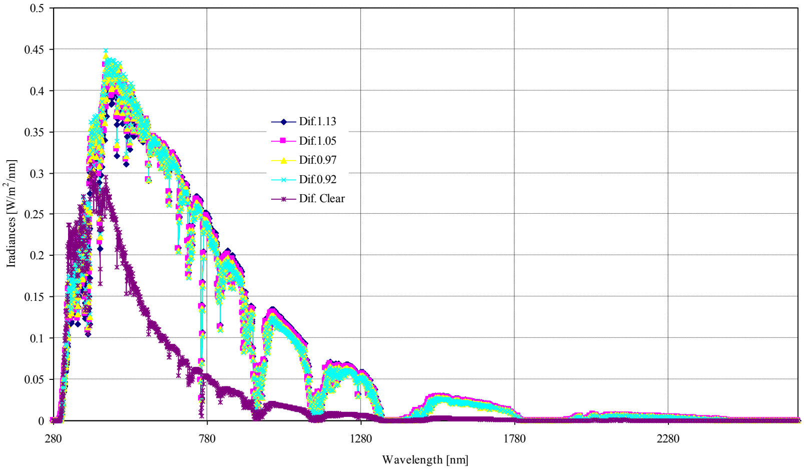


Figure 4: Estimated Diffuse (Dif.) spectral irradiances for different AOD values representing the dusty days. The clear diffuse spectral distribution is plotted for comparison.

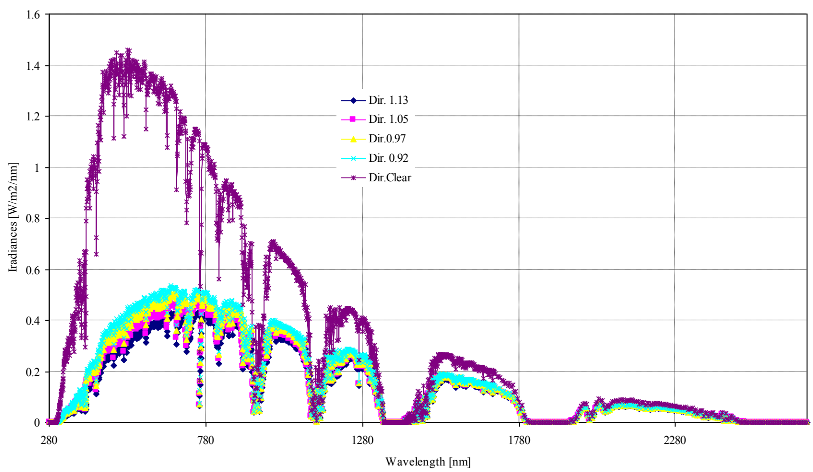


Figure 5: Estimated Direct (Dir.) spectral irradiances for different AOD values representing the dusty days. The clear direct spectral distribution was plotted for comparison.

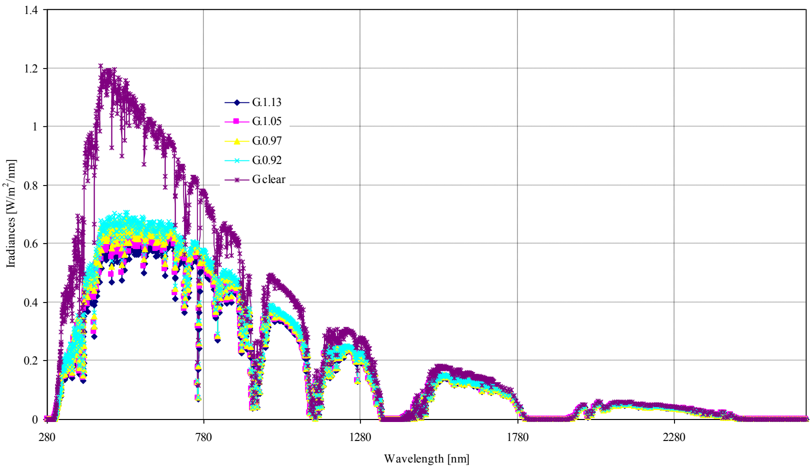


Figure 6: Estimated Global (G) spectral irradiances for different AOD values representing the dusty days. The clear global spectral distribution was plotted for comparison.

For low AOD values, the spectral distribution for the three components resembles that of clear skies [17]. In contrast, high aerosols affect the solar irradiances differently from one wavelength to another. While the diffuse irradiance increases at longer wavelengths due to higher aerosol values, the direct and global irradiances increase at shorter wavelengths [18]. For instance, the diffuse radiation at AOD value of 1.05 increases by 15%, 51%, 208%, and 300% at the wavelengths 500 nm, 600 nm, 1500 nm and 3100 nm respectively. On the other hand, for the same amount of AOD the global radiation at these wavelengths reduced, respectively, by 45%, 38%, 19%, and 11%; and the direct radiation decreased by 77%, 70%, 34% , and 16% respectively.

The integrated solar radiation components across the whole spectrum for the period between 10th and 23rd July were calculated, and are presented in Figure 7.

The results demonstrate that the dusty conditions decreased the global irradiance, by 5%, 4.87%, 4.9%, and 1.1% for the 12th, 17th, 19th, and 20th respectively in comparison with the previous days. The direct irradiances dropped by 25% on the 12th, 17th, and 19th; and 7% on the 20th. On the other hand diffuse radiation increased significantly in comparison with the previous days by 52%, 43%, 56% and 7% for the 12th, 17th, 19th and 20th respectively.

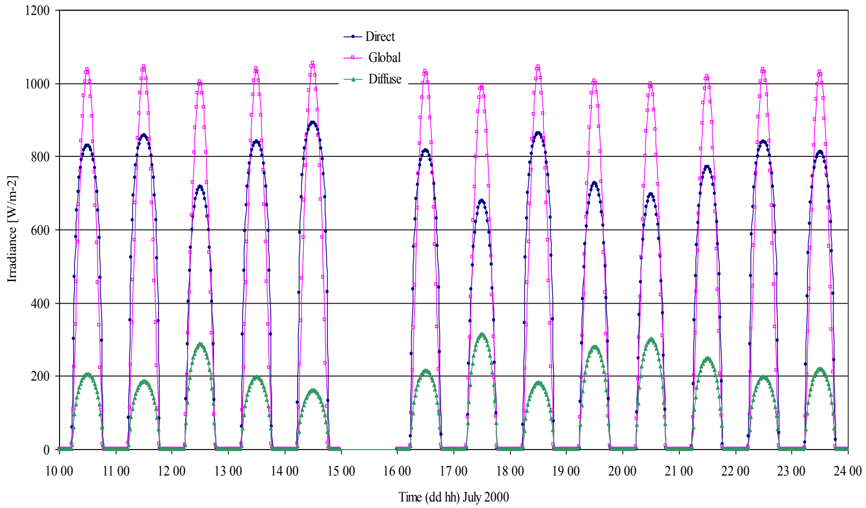


Figure 7: Theoretically calculated integrated global, diffuse, and direct beam using the mean daily AOD values, for the period 10th to 23rd July 2000.

5 Conclusions

In this study, we investigated the effect of two dusty events that occurred during July 2000, on both the Aerosol Optical Depth (AOD) and the Angstrom exponent, α, over Riyadh, Saudi Arabia. We showed high AOD and low Angstrom values during the dusty days. Theoretical simulations using the SMART model showed that the dusty conditions significantly decreased (spectral and integrated) global and direct beam components and increased the diffuse radiation in comparison with the non-dusty days.

Acknowledgements

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