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ATMOSPHERIC TURBIDITY STUDY USING GROUND AND ORBIT DATA

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Abstract*- In this work, three basic parameters for aerosol characterization, Aerosol Optical Thickness, Angstrom Exponent and Angstrom Coefficient are used for aerosol analysis over Ghardaia site. We have found that the transmission of solar radiation can reach 95 %.The values of the Angstrom Exponent and the Angstrom Coefficient determined from MODIS compared to those obtained by measurement global irradiance component using Iqbal C model show the same trend during the year 2005. The monthly mean values of the Angstrom exponent and the Angstrom coefficient are 1.248 and 0.037 determined from orbit data and those from Iqbal C model are 2.026 and 0.067 respectively.

Keywords – Aerosols, Optical Thickness, MODIS, Turbidity parameters, Iqbal C model.

I. INTRODUCTION

Atmospheric aerosols are defined as suspended particles in the atmosphere in liquid or solid phase. The presence of aerosols in atmosphere can affect our weather and climate because they change the amount of sunlight reaching Earth's surface [1]. Aerosol Optical Thickness (AOT, also called aerosol optical depth) is basically a measurement of transparency of the atmosphere. The larger the AOT at a particular wavelength, the less light of that wavelength reaches Earth's surface. This information is important for determining the concentration, size distribution and variability of aerosols in the atmosphere.

The aerosols have different size distributions, shapes, and residence times. They originate from different sources such as gases condensation and action of wind on the Earth's surface. Aerosol size properties are one of the most important information for both modeling and experiments. They are tiny particles in the range 0.001 to $100\mu m$ suspended in the atmosphere. In the other words, the Aerosol optical thickness (AOT) is a wavelength dependent measure of the total extinction of sunlight due to scattering and absorption by aerosols [2]. AOT is considered the most important unknown parameter in any atmospheric correction algorithm since it is used to solve the radiative transfer equation and remove atmospheric effects from satellite images [3].

Aerosols have an impact on human respiratory, global climate and weather changes [4]. In the case of climate and weather, the presence of solid particles in the Earth's atmosphere has important consequences on the transmission of solar radiation and on the nature of the radiation regime at the ground. The absorption of solar energy by a layer of aerosol increases the radiative heating of the atmosphere and decreases the amount of energy available at the surface. Scattering by aerosol increases the amount of radiation which is reflected by the atmosphere into space and increases the downward flux of diffuse radiation at the Earth's surface. In fact, there is a simple relationship between the Aerosol Optical Thickness (τ) and the percentage of transmission which can be explained by this formula [5]:

$$transmission = 100 \times e^{-\tau} \qquad (1)$$

The Moderate Resolution Imaging Spectro-radiometer has two satellites, Terra and Aqua, where is making near-global daily observations of the Earth in a wide spectral band (0.41–15 μm). These measurements are used to derive the characteristics of the atmosphere of the studied area. In this work we have focused on the spectral Aerosol Optical Thickness and aerosol size parameters over land. Due to their variability, atmospheric aerosol monitoring is difficult and significant efforts to improve aerosol characterizations have included using in-situ measurements, ground-based remote sensing and satellite observations [6].

As mentioned before, the present paper studies the characteristics of aerosol over Ghardaia site. After a brief introduction in section 1, the section 2 provides the site characterization and data used. Section 3 describes the two turbidity parameters (the Angstrom exponent α and the Angstrom coefficient β). In section 4 a brief description of Iqbal C model is given with the obtained values of (α, β) using global irradiance measurements. In section 5, discussion of the obtained results is presented.

II. SITE AND USED DATA

Our studied area is located in the center of the northern part of Algerian Sahara about 600Km far from the capital city (Fig 1). It is considered as arid and dry area. Its geographical coordinates are: +32°37'N in latitude and +3°77'E in longitude. This area is characterized by significant insolation rate[7]. The mean annual global solar radiation measured on a horizontal plane exceeds 6000

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(Wh/m^2) and the sunshine duration is more than 3000 (hours/year) [7].

The winter in Ghardaia is described by an extreme cold due to windblown of snow from the highlands; sandstorms from the southwest. The end of winter is particularly troublesome, which is the result of extreme dustiness. The annual average values of temperature and humidity are respectively 27° and 25%. The monthly average values are between 13° and 43° for the temperature and between 10% and 46% for humidity. The predominant wind direction is south-west.

This study uses 1km resolution TERRA/MODIS of level 2 aerosol products (MOD04) of the year 2005. The level 2.0 MODIS data have been used to retrieve the AOT and consequently α, β values. We validate the obtained values by those obtained by the empirical Iqbal C model using measurement of global irradiation due to the unavailability of a photometer instrument in the studied area.

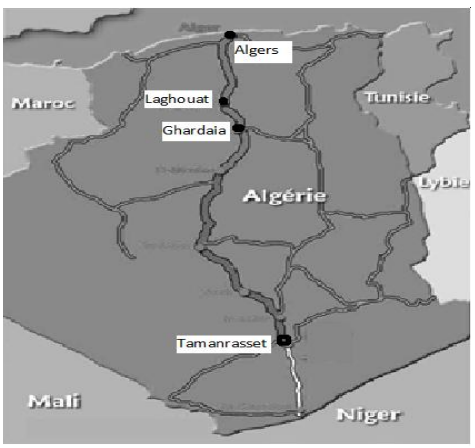

Fig. 1 Location of Ghardaia city.

III. AEROSOL OPTICAL THICKNESS AND TURBIDITY PARAMETERS

Aerosol Optical Thickness (AOT) at wavelength (λ) is the standard parameter measured by Sun photometers. The Aerosol Optical Thickness depends not only on aerosol characteristics (size distribution, refractive index, etc.) but also on aerosol total loading [8].

Angstrom suggested a single formula for aerosol scattering optical thickness evaluation generally known as Angstrom's turbidity formula given by the following [9]:

$$\tau = \beta . \lambda^{-\alpha} \qquad (2)$$

Where β is the Angstrom coefficient and α is the Angstrom exponent.

The Angstrom coefficient β is one of the most widely used indicator, because it represents the amount of aerosols in the atmosphere in the vertical direction [10]. In addition, it represents the combined effects of both scattering and absorption caused by aerosols [11] [12]. The range of β parameter varies between 0.0 and 0.5 and it may exceed the value 0.5 for a highly charged atmosphere.
The Angstrom exponent α is a reliable index of the size distribution of these aerosols. It is a good indicator of the dominant size of the atmospheric particles [13] [14]. This coefficient varies between 0 and 4.When the aerosol particles are very small, of the order of the air molecules, αtakes value 4, and it approaches 0 for great particles. This indicator can be obtained by using the Angstrom exponential formula (equation 2), which is giving by:

$$\alpha = -\frac{log\frac{\tau_1}{\tau_2}}{log\frac{\lambda_1}{\lambda_2}} \qquad (3)$$

Where τ_1 and τ_2 represent the AOD values at the wavelengths of λ_1 andλ_2 respectively.

IV. TURBIDITY PARAMETERS FROM MEASUREMENTS

The unavailability of a photometer instrument at Ghardaia site conducts us to use an indirect way to estimate the turbidity parameters. This will be based on using measurements and empirical solar radiation model. In the literature, there are two categories of solar radiation models that predict the radiation component based on measured data, the parametric model and the decomposition model [15]. The Iqbal C model has been used in this work, its offers extra-accuracy over more conventional models as reviewed by Gueymard [16].The mathematical description of this model is given in the following subsection.

1- Mathematical formula

This model is described in Iqbal [17]. The beam irradiance according to this model is given as follows:

$$I = 0.9751 E_0 I_0 \tau_r \tau_0 \tau_g \tau_w \tau_a \qquad (4)$$

Where$I_0$is the solar constant (1367w/m^2) and $E_0$is the eccentricity correction-factor of the Earth's orbit and is given by:

$$E_0 = 1.00011 + 0.034221 cos\varphi + 0.00128 sin\varphi + 0.000719 cos2\varphi + 0.000077 sin2\varphi \qquad (5)$$

and the day angle φ (radians) is given by :

$$\varphi = 2\pi(\frac{N-1}{365}) \qquad (6)$$

N is the day number of the year, ranging from 1 on 1 January to 365 on 31December.

τ_0, τ_g, τ_w , τ_r and τ_a are the Ozone, Gas, Water, Rayleigh and Aerosols scattering transmittances, respectively.

- The absorption coefficient by the ozone τ_0 is given by:

$$\tau_0 = 1 - 0.1611 \times U_0 \times (1.0 + 139.48U_0)^{-0.3035}$$
$$-0.002715 \times U_0 \times (1 + 0.044U_0 + 0.0003{U_0}^2)^{-1} \quad (7)$$

- The transmittance after absorption by Gases is given by:

$$\tau_g = \exp\,[-0.0127 \times m_a^{0.26}] \quad (8)$$

- The transmittance after absorption of solar radiation by the Water vapor is given by:

$$\tau_w = 1 - 2.4959 \times U_w \times [(1 + 79.03 \times U_w)^{0.6828} + 6.385 \times U_w]^{-1} \quad (9)$$

- The transmittance after Rayleigh diffusion is given by:

$$\tau_r = \exp\,[-0.0903 \times m_a^{0.84}(1.0 + m_a - m_a^{1.01})] \quad (10)$$

- The transmittance after Aerosol scattering can be calculated by:

$$\tau_a = \exp[-k_a^{0.873} \times m_a^{0.9108} \times (1.0 + k_a - k_a^{0.7088})] \quad (11)$$

Where k_a is the attenuation coefficient determined from experimental measurements, m_a is the corrected air mass, U_0 is the thickness of the ozone layer and U_w is the water depth.

The horizontal diffuse irradiance at ground level (D) is a combination of three individual components corresponding to the Rayleigh scattering (D_r), the aerosols scattering (D_a) and the multiple reflection processes between ground and sky (D_m) [15]. The expression of (D) is given by the following equation:

$$D = D_r + D_a + D_m \quad (12)$$

The global radiation on a horizontal plane is the sum of both direct and diffused solar components:

$$G = I + D \quad (13)$$

Thus, the Iqbal C model depends on five parameters which are $\alpha, \beta, F_c, w, and\ \rho$. The determination of these parameters consist to look for the best fit of to the global measured solar radiation of clear days by the model. In the following section we will use the measured global solar radiation component for the clear days of 2005 using the clear day's criterion [18] and we fitted it by Iqbal C model using the least square fit method.

2- Model turbidity parameters values

The obtained monthly average values of the five parameters ($\alpha, \beta, F_c, w, \rho$) are summarized in Table 1. The second column is the number of clear day in the month and Δ is the standard deviation of the obtained values.

Table1. The monthly average values of $\alpha, \beta, F_c, w, and\ \rho$ parameters.

Months	**Number of clear days**	**β**	**Δ β**	**ρ**	**Δ ρ**	**α**	**Δ α**	**w**	**Δ w**	**Fc**	**ΔFc**
1	15	0.017	0.007	0.461	0.183	0.923	0.764	0.863	0.076	0.623	0.185
2	9	0.032	0.023	0.731	0.120	2.186	0.879	0.854	0.062	0.577	0.123
3	1	0.069	0.000	0.899	0.000	3.169	0.000	0.819	0.000	0.588	0.000
4	15	0.017	0.007	0.461	0.183	0.923	0.764	0.863	0.076	0.623	0.185
5	8	0.097	0.048	0.717	0.149	2.516	1.024	0.748	0.058	0.597	0.166
6	10	0.131	0.041	0.640	0.199	1.628	0.553	0.778	0.034	0.519	0.030
7	4	0.130	0.016	0.672	0.120	1.648	0.240	0.766	0.030	0.501	0.001
8	5	0.101	0.024	0.341	0.376	2.920	0.980	0.816	0.078	0.762	0.216
9	3	0.101	0.031	0.670	0.226	1.999	0.738	0.738	0.066	0.632	0.125
10	5	0.044	0.029	0.142	0.138	2.877	1.460	0.810	0.128	0.804	0.163
11	11	0.053	0.033	0.708	0.263	2.344	0.881	0.830	0.060	0.678	0.155
12	11	0.016	0.010	0.330	0.267	1.178	1.419	0.792	0.075	0.684	0.174

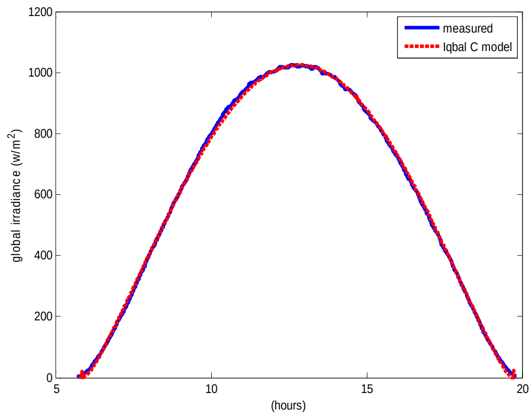

Fig. 2 A measured global solar irradiation component fitted by Iqbal C model.

Figure 3 shows the variation of Angstrom coefficient and Angstrom exponent obtained from measurements and using Iqbal C model. The monthly mean values of α show a significant variation (Figure 3a) from month-to-month with values ranging between 0.923 and 3.169. This is due in one part to the different number of clear days used in the calculation for each month (see the second column of the Table 1). The mean value of α is 2.026 which corresponds to a mean size of aerosols of the order of 50 µm.

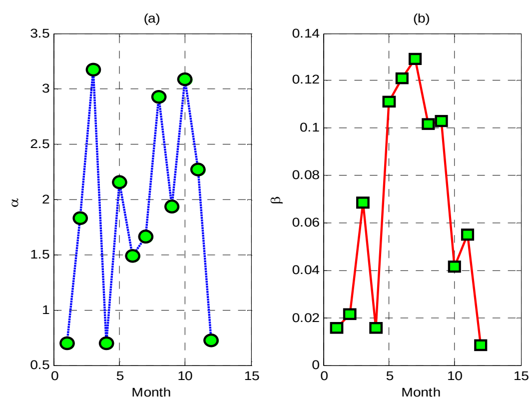

Fig. 3 (a) Angstrom exponent obtained from measurements using Iqbal C model, (b) Angstrom coefficient obtained from measurements using Iqbal C model.

The monthly mean values of β show higher turbidity values (Figure 3b) during summer and autumn months. This behavior has been already shown by Djafer and Irbah [12]. These higher values are explained by a hot summer climate and winds of the south sectors (Sirocco) that characterize the region of Ghardaïa. This kind of winds brings with them particles of dust and sand, which leads to an increase of Angström coefficient [19]. The period of winter is characterized by rains that wash the atmosphere and this contribute to diminish the value of β. The maximum and minimum values of β are 0.131 and 0.016 and correspond to July and December months respectively. The higher values of β during March are due to the fact that there is only one clear day that is, a single value of α and a single value of β.

V. TURBIDITY PARAMETERS FROM MODIS DATA

We have determined the terra MODIS Aerosol Optical Thickness (AOT) values and the corresponding turbidity parameters α and β using equations 2 and 3.For each acquired image by MODIS we extract the sub-image by introducing the geographic coordinates of Ghardaia city (Figure 4).

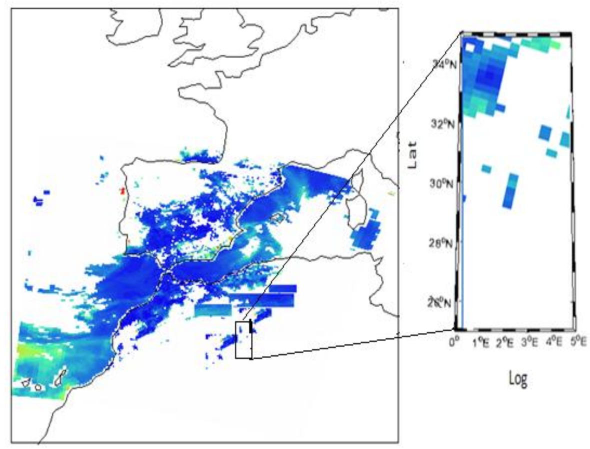

Fig. 4 Location of studied area(Log: longitude, Lat: latitude).

MODIS product images are stored in Hierarchical Data Format (HDF). HDF is a multi-object file format for sharing scientific data in multi-platform distributed environments. The number of acquired MODIS images is 0 to 3 images per day. The steps to determine the mean values of AOT are shown in the flowchart of Figure 5.

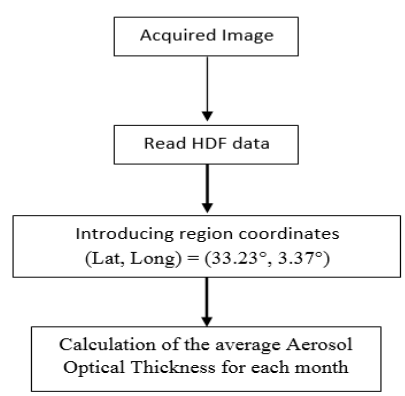

Fig. 5 Flowchart to determine the mean AOT from an acquired MODIS image.

For the year 2005, the obtained mean value and the corresponding standard deviation of AOT at two different wavelengths (0.47µm and 0.55µm) are given in Table 2.

Table 2. The monthly average values ofAOT and the corresponding standard deviation for the year 2005.

Month	**Median of AOT**		**Standard deviation of AOT**		**Number of measurements**
	λ1=0.47	**λ 2=0.55**	**λ1=0.47**	**λ 2=0.55**	
J-2005	0,052	0,043	0,068	0,056	8
F-2005	0,051	0,042	0,027	0,022	5
M-2005	0,157	0,129	0,066	0,055	2
A-2005	0,052	0,043	0,058	0,048	3
M-2005	0,047	0,039	0,035	0,029	1
J-2005	0,122	0,101	0,021	0,018	1
J-2005	0,149	0,122	0,002	0,001	1
A-2005	0,147	0,121	0,037	0,030	2
S-2005	0,154	0,126	0,160	0,138	5
O-2005	0,092	0,076	0,053	0,050	4
N-2005	0,050	0,041	0,055	0,045	6
D-2005	0,055	0,045	0,039	0,032	9

Figure 6 shows the variation of Aerosol Optical Thickness during the year 2005. We note for both wavelengths that aerosols concentration is more important in mars and between June and October. On part of the variations of AOT is due to the statements indicated in the second paragraph of the subsection 4-2.

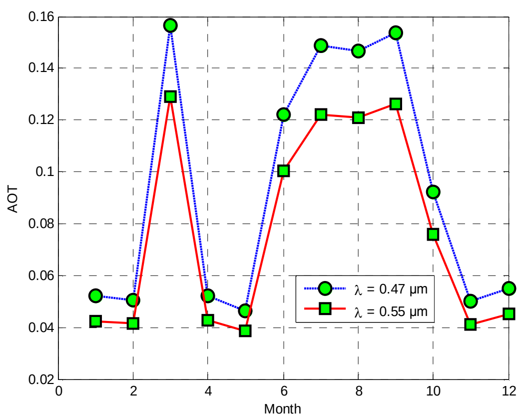

Fig. 6 Variation of AOT during 2005for two wavelengths 0.47µm and 0.55 µm.

A frequency distribution of AOT for 0.47 and 0.55 µm channels are shown on Figure 7. We observe that 95%of AOT values lie between 0.02 and 0.03.

This implies that the transmission of solar radiation can reach 95% at Earth surface using equation 1.

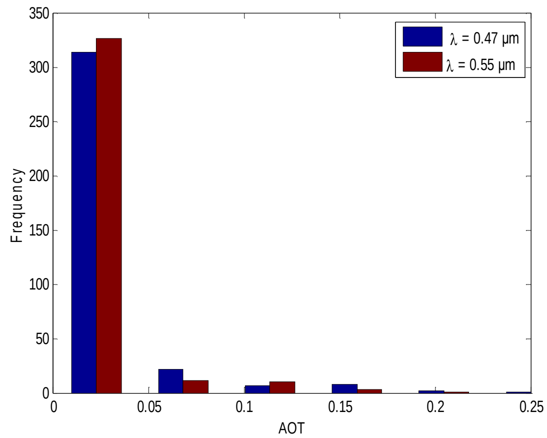

Fig. 7 Frequency distribution of AOT at the wavelength 0.47µm and 0.55 µm.

Table 3 summarizes the Angstrom coefficient and Angstrom exponent values calculated using equations 2 and 3.

Table.3. Monthly average values of α and β.

Months	**α**	**β**	**Δα**	**Δβ**	Number of measurements
J-2005	1,235	0,020	0,039	0,026	8
F-2005	1,249	0,020	0,039	0,011	5
M-2005	1,235	0,062	0,004	0,028	2
A-2005	1,243	0,020	0,006	0,023	3
M-2005	1,201	0,019	0,000	0,000	1
J-2005	1,246	0,048	0,000	0,000	1
J-2005	1,248	0,058	0,000	0,000	1
A-2005	1,243	0,058	0,029	0,010	2
S-2005	1,243	0,060	0,121	0,079	5
O-2005	1,224	0,036	0,271	0,037	4
N-2005	1,256	0,019	0,043	0,022	6
D-2005	1,250	0,021	0,034	0,015	9

Table 4.Monthly average values of α and β obtained from MODIS data and measurements using Iqbal C model.

	Angstrom exponent (α)		**Angstrom coefficient (β)**		**Number of measurements**	
Month	Orbit values	Model values	Orbit values	Model values	Orbit values	Model values
J-2005	1,283	0,923	0,020	0,017	8	15
F-2005	1,249	2,186	0,020	0,032	5	9
M-2005	1,234	3,169	0,062	0,069	2	1
A-2005	1,246	0,923	0,020	0,017	3	15
M-2005	1,201	2,516	0,019	0.097	1	8
J-2005	1,246	1,628	0,048	0,131	1	10
J-2005	1,248	1,648	0,058	0,130	1	4
A-2005	1,241	2,920	0,058	0,101	2	5
S-2005	1,243	1,999	0,060	0,101	5	3
O-2005	1,245	2,877	0,036	0,044	4	5
N-2005	1,256	2,344	0,019	0,053	6	11
D-2005	1,277	1.178	0,021	0,016	9	11

A frequency distributions of α and β are shown on Figure 8. We observe that 94% of the Angstrom exponent values lie between 1.20 and 1.27 and 70% of Angstrom coefficient lies between 0.01 and 0.07.

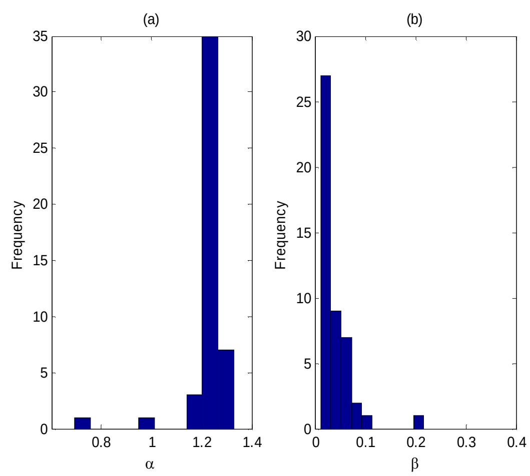

Fig. 8 (a) Frequency distribution of Angstrom exponent according to MODIS data during 2005, (b) Frequency distribution of Angstrom coefficient according to MODIS data during 2005.

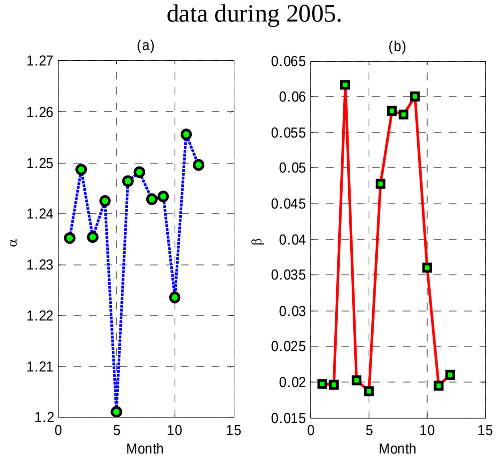

Fig. 9 (a) Angstrom exponent obtained from MODIS data, (b) Angstrom coefficient obtained from MODIS data.

Figure 9 shows the variation of Angstrom coefficient and Angstrom exponent for MODIS data. The values of α show a variability from month-to-month with values ranging from 1.256 to 1.201. For those of β, they indicate higher turbidity values during summer and autumn months. The maximum and minimum values of β are 0.062 and 0.019 respectively. We can notice a significant value of β during March month as shown in Figure 3b. This is due to the lack or the small number of measurements during the month.

VI. COMPARISON AND DISCUSSION OF THE OBTAINED RESULTS

Table 4 summarizes the monthly average values of the Angstrom coefficient and the Angstrom exponent obtained from MODIS data and from measurements using Iqbal C model. The values of β obtained from MODIS data are superposed to those obtained from measurements using Iqbal C model as shown on Figure 10.

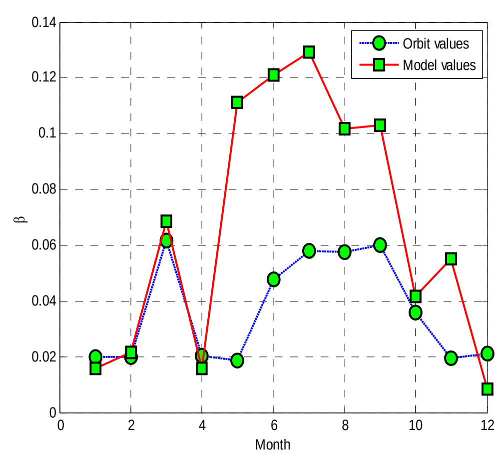

Fig. 10 Angstrom coefficient obtained from MODIS data and those obtained from measurements using Iqbal C model.

We note that the two values show the same trend with a correlation coefficient of 0.70. The differences between the two results are due to:

(i) The number of clear days and acquired images per month is not the same as shown in the two last columns of Table 4.

(ii) Measured values represent more the reality of atmospheric turbidity state.

(iii) The resolution of satellite.

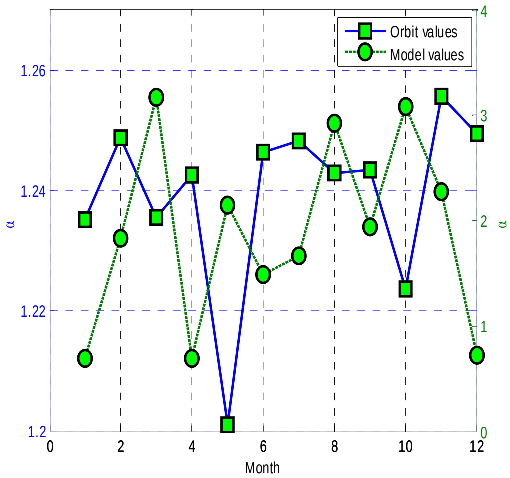

Fig. 11 Angstrom exponent obtained from MODIS data and those obtained from measurements using Iqbal C model.

Figure 11 shows the variation of the Angstrom exponent obtained from orbit data and ground measurements. They show more or less the same trend with time. The difference between them may be due to same statements stated above.

VII. CONCLUSION

The present work is divided in three parts. In the first part we calculate the turbidity parameters (the Angstrom exponent α and the Angstrom coefficient β) from measurements of global solar irradiance during 2005 component using Iqbal C model. We have found that the Angstrom exponent values lie between 0.923 and 3.169 and for the Angstrom coefficient values between 0.131 and 0.016. The monthly mean values of β are higher during summer and autumn months. The maximum value of β (0.131) is to be in July.

In the second part, we determine the turbidity parameters from the analysis of MODIS data acquired during 2005. We have found that the most dominant values of Aerosol Optical Thickness lie between0.020 and 0.030. This implies that the transmission of solar radiation can reach 95%. We have found also that the Angstrom exponent values lies between 1.201 and 1.283 and for the Angstrom coefficient between 0.019 and 0.062. The monthly mean values of β are higher during summer and autumn months.

In the last part we have compared the obtained values of α and β from MODIS data with those obtained from measurement using Iqbal C model. We have found that the orbit and model values show the same trend along the year. We have found a correlation coefficient of 0.70 between β_{model} and β_{orbit}. One part of thedifference between model and orbit valuesare due to thesmall number of collected values per day and due to the resolution of satellite.

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