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Estimation of the Linke turbidity factor over Ghardaïa city

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***Abstract*— From five years (2004-2008) of measurements, the Linke turbidity factor is estimated over Ghardaïa city. Results show a seasonal trend along the year with a maximum value around summer months and a minimum value around winter months. The annual average values of the Linke turbidity factor varied between 3.594 and 3.750. About 75.3% of the cloudless days had a Linke factor less than 4.5 and only 1% of the cloudless days had a Linke factor that exceeds the value of 6.**

Keywords— solar radiation, turbidity parameters, Linke factor.

I. Introduction

The quality and quantity of the solar radiation in a given ground site should be considered before installing solar energy conversion systems. Photovoltaic and solar thermal energy systems are usually designed considering their performance in standard test conditions without taking into account local atmospheric ones [1]. The reason is often the non-availability of atmospheric data for a specific location for which solar systems are designed. It is nevertheless essential that variations of solar cell/module efficiency in various atmospheric turbidity and weather conditions are known to optimize their performances since an increase in turbidity reduces the output current of solar cells [1]. Ground solar radiations are strongly dependent on the Earth's atmosphere. Its constituents (aerosols, water, ...etc.) absorb and diffuse significantly the direct solar radiation. Thus, it is important to quantify their temporal effects when recording solar irradiance in a local area. This helps to establish models and to accurately estimate the clear sky radiation in the future.

Among several turbidity parameters, the most frequently used is the Linke turbidity factor [2]. The determination of this turbidity factor is one of the important elements to study the performanceof solar radiation devices at a particular location. The Linke turbidity factor can be used in climate modelling, in pollution studies [3] and to predict the availability of solar energy under cloudless skies essential for the design of solar thermal power plants and other solar energy conversion devices with concentration systems.

Five years (2004-2008) of data daily recorded will be used to estimate the Linke turbidity factorover Ghardaïa city. I will recall first the definition of the Linke turbidity factor. Then I will present the used data to perform this work and I will discuss the obtained results.

II. The Linke turbidity factor

The Linke turbidity factor T_L has been used since 1922 as an indicator of the number of clean dry atmospheres that would be necessary to produce the attenuation of the extraterrestrial radiation produced by the real atmosphere [3]. It describes the optical thickness of the atmosphere due to both the absorption and scattering of the solar radiation by the water vapour and the aerosol particles relatively to a dry and clean atmosphere. The Linke turbidity factor is useful to model the atmospheric absorption and scattering of the solar radiation during clear skies. It value depends on the air mass and most popular methods normalize the measured values of T_L to an air mass equal to 2 ([4], [5]). The value of the Linke turbidity factor can be then derived from the direct component of the measured solar irradiance([3], [6], [7], [8], [9]). Typical values of the Linke turbidity factor vary between 1 and 10. High values of this factor mean that the solar radiations are more attenuated in a clear sky atmosphere.

To calculate the Linke turbidity factor T_l, we will use the following equation ([3],[8]):

$$T_l = T_{lk} \frac{\frac{1}{\delta_{Ra}(m_a)}}{\frac{1}{\delta_{Rk}(m_a)}} \quad (1)$$

Where T_{lk} is the Linke factor according to Kasten [10], $\delta_{Rk}(m_a)$ the Rayleigh integral optical thickness and $\delta_{Ra}(m_a)$ the integral optical thickness given by Louche et al. [11] and adjusted by Kasten [12]. The subscript k stands for the author "Kasten" and the subscript *a* for the word "adjusted".

The Linke factor T_{lk} is related to the normal incidence solar irradiance by this equation ([3],[10]):

$$T_{lk} = (0.9 + 9.4\sin(h))[2\ln(I_o\,(R_o/R)) - \ln(I_n)] \quad (2)$$

Where h is the Sun's elevation in degrees, I_n the direct normal solar irradiance at normal incidence and I_o the solar constant ($1367\frac{W}{m^2}$). R and R_o are respectively the instantaneous and mean Sun-Earth distances. The value of I_n is measured directly through a pyrheliometer in ($\frac{W}{m^2}$).

The expression of $\delta_{Ra}(m_a)$ and $\delta_{Rk}(m_a)$ are given respectively by these equations:

$$\frac{1}{\delta_{Ra}(m_a)} = 6.6296 + 1.7513m_a - 0.1202m_a^2 + 0.0065m_a^3 - 0.00013m_a^4 \quad (3)$$

$$\frac{1}{\delta_{Rk}(m_a)} = 9.4 + 0.9m_a \quad (4)$$

Where m_a is the air mass given by:

$$m_a = m_r\left(\frac{P}{101325}\right) \quad (5)$$

The parameter m_r is the air mass at the standard conditions [13] defined by the following equation:

$$m_r = [\sin(h) + 0.15(3.885 + h)^{-1.253}]^{-1} \quad (6)$$

P is the local pressure in Pascal given by [14]:

$$P = 101325\exp(-0.0001184z) \quad (7)$$

Where z is the altitudeof the location in meter.

III. Site Location and Solar Radiation Data

The data used to perform the present study has been recorded at the Applied Research Unit for Renewable Energies (URAER) situated in the south of Algeria far from Ghardaïa city of about 18 km. The latitude, longitude and altitude of the URAER are respectively +32.37°, +3.77° and 450 m. The direct solar irradiance, the diffuse solar irradiance, the temperature and the humidity used to calculate the Linke turbidity factor are recorded every 5 minutes. A pyrheliometer instrument of type EKO installed since June 2004 measures the direct and the diffuse solar irradiance. Five years of data are used to calculate the Linke turbidity factor. A selection of the data that corresponds to clear sky conditions is applied for that reason. This criterion consists to choose data where the direct normal solar irradiance is greater than $200\frac{W}{m^2}$ and the ratio of the diffuse solar irradiance to the global solar irradiance is less than 1/3 ([15],[16],[17]).

IV. Results and Discussion

Equation (1) is used to calculate the Linke turbidity factor T_l .Some algorithms have been developed to determine the necessary ephemerides to perform this calculation. The annual and the monthly average values of the Linke turbidity factor obtained from the data recorded from June 2004 and December 2008 are given in Table I. The daily and monthly variations for the same period are shown on Fig.1. We note that the values of the calculated Linke factor show a seasonal trend along the year and have their maximum and minimum values respectively during summer and winter months. This phenomenon can be 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 increase the Linke factor [18]. The period of winter is however characterized by a dry climate and rains that contribute to the diminution of this factor. Fig.2 represents the seasonal variation of the Linke turbidity factor from June 2004 to December 2008.

The monthly average values of the Linketurbidity factor variedbetween a minimum value of 1.344 and a maximum value of 5.567. For the annual average values, they varied between 3.594 and 3.750 with is a slight increase (1.3 %) from2004 and 2008. This small increase can be associated to the atmospheric changes of the region or to the solar properties.

The frequency of occurrence of the Linke turbidity factor values has been computed and analysed. Fig. 3 shows the frequency distribution of the Linke turbidity factor values with a sampling bin of 0.1. We observe that the maximum value of the Linke factor occurred near 2.3 with a frequency of about 4.41% and the distribution was asymmetric around this maximum value. Fig. 4 represents the cumulative frequency distribution. We note that the Linke factor was less than 4.5 for 75.3% of the cloudless days and only 1% of the cloudless values had a Linke factor that exceeded the value of 6.

V. Conclusions

We have used five year of data (June 2004 to December 2008), recorded each five minutes at the Applied Research Unit for Renewable Energies (URAER), to study the turbidity of the atmosphere over the region of Ghardaïa using the Linkefactor. The calculated values of this factor show a seasonal trend along the year. The maximum attenuation occurred in summer while the minimum one in winter. This seasonal trend is related to the climate of the region which is characterized in summer by a hot weather and Sirocco winds that bring dust and sand particles and in winter by a dry weather and rains. The monthly average values of the Linke factor varied between 1.344 and 5.567 and the annual one between 3.594 and 3.750. These later show a slight increase (1.3 %) from2004 and 2008 which can be associated to the atmospheric changes of the region or to the solar properties.

The analysis of the frequency of occurrence of the Linke turbidity factor values shows a maximum value near 2.3 with a frequency of about 4.41%. The cumulative frequency reveals that about 75.3% of the cloudless days had a Linke factor less than 4.5 and only 1% of the cloudless days had the Linke factor that exceeded the value of 6.

The data reported in this paper can be used to design and check the performance of solar devices of any locality that have a similar climate to Ghardaïa and to have a reference point for global studies of the evolution of atmosphere turbidity and aerosols of the region.

Table I
Monthly and annual average values of the Linketurbidity factor.

	2004	2005	2006	2007	2008
January	-	2.332±0.378	2.374±0.321	1.344±0.413	2.528±0.304
February	-	2.570±0.574	2.684±0.455	2.595±0.931	3.149±0.732
March	-	3.005±0.782	2.855±0.527	3.283±1.911	3.245±0.713
April	-	3.525±0.821	3.804±0.752	4.872±1.120	3.526±0.781
May	-	4.223±0.979	4.319±0.690	4.148±0.897	4.117±0.718
June	4.681±0.650	4.521±0.652	4.135±0.949	4.777±0.772	4.708±0.701
July	4.075±0.464	5.060±0.634	4.617±0.625	5.064±0.748	5.567±0.499
August	5.020±0.569	4.554±0.750	4.776±0.387	4.850±0.744	-
September	3.688±1.087	4.192±0.666	4.567±0.734	4.984±0.716	4.601±0.689
October	3.519±0.405	3.555±0.435	4.107±0.709	3.561±0.617	4.005±0.708
November	2.428±0.342	3.110±0.480	2.901±0.746	2.840±0.598	2.857±0.519

December	2.376±0.397	2.486±0.353	2.007±0.799	2.685±0.558	2.734±0.335
Average	3.684±0.559	3.594±0.625	3.595±0.641	3.750±0.836	3.731±0.609

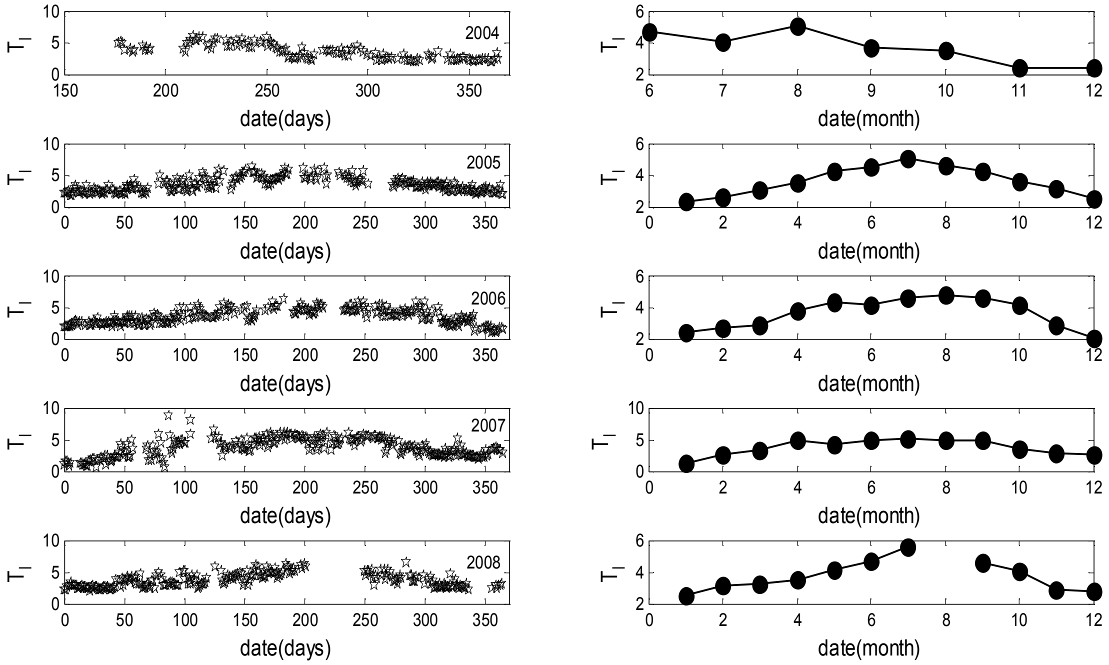

Fig.1 The Linketurbidity factor T_l , left: daily variations, right: monthly variations.

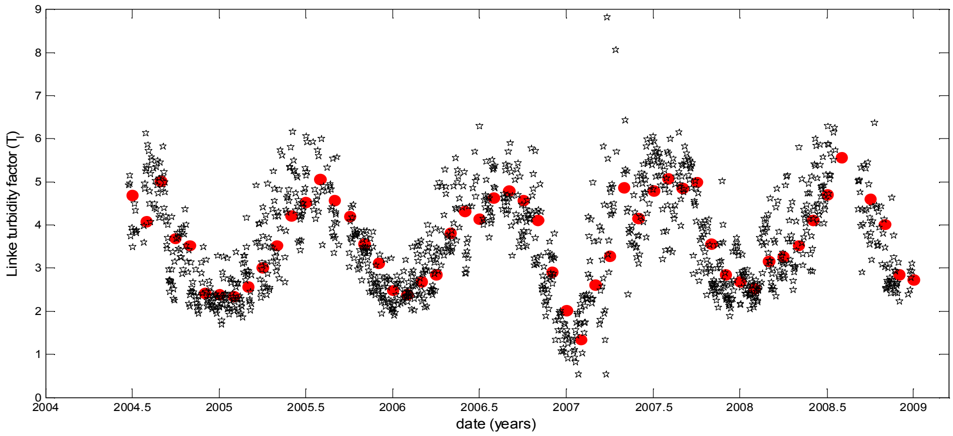

Fig. 2 Seasonal variation of the Linketurbidity factor. The circles are the daily variations while the points are the monthly ones.

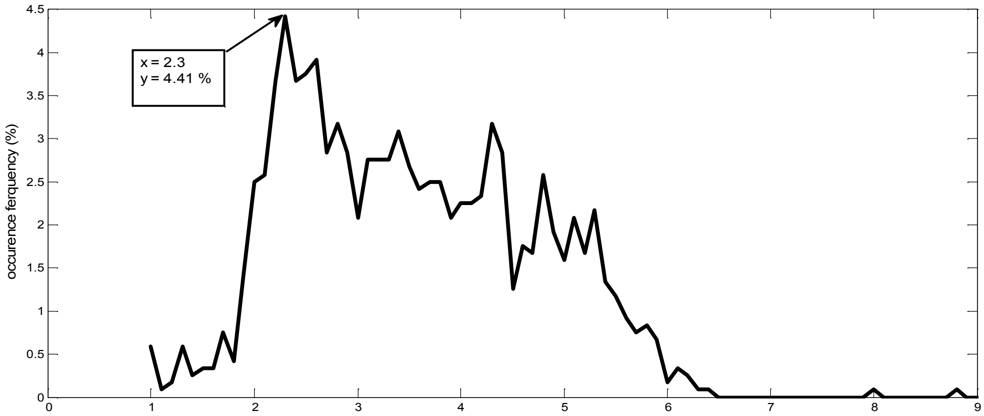

Fig. 3The frequency of occurrences for the Linke turbidity factor.

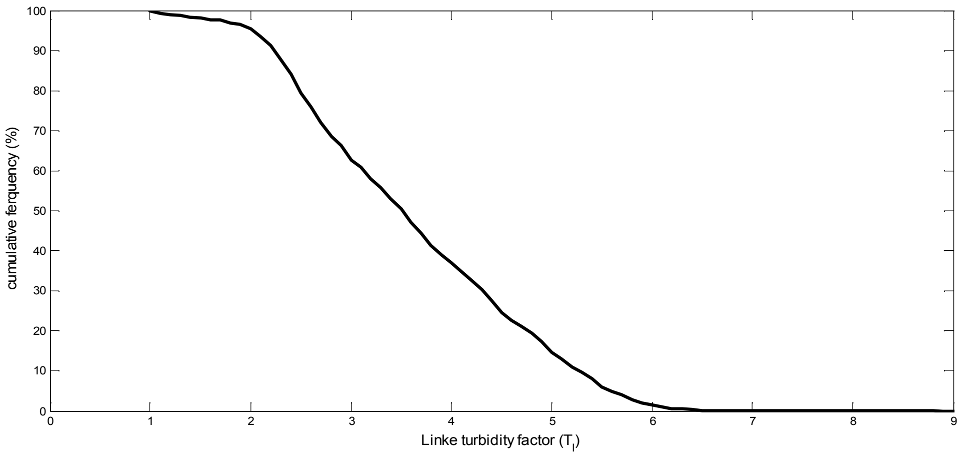

Fig. 4The cumulative frequency distribution for the Linke turbidity factor.

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