ESTIMATE OF ANGSTROM'S TURBIDITY COEFFICIENT TO NATAL CITY

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Abstract. *The transmission of solar radiation through the atmosphere is dependent of three factors, the Rayleigh's scattering, of scattering and absorption by solids and liquids particles (aerosols), the steam water absorption and atmospherics gases uniform mix. Among these factors, the aerosols are more complex due to variations in their forms, sizes and types. They have absorptive, diffusive and hygroscopic effect, exerting influence on the global energy balance, optical properties and the lifetime of clouds. The Angstrom's turbidity coefficient, β, is an aerosols concentration indicator in the atmosphere, which informations are applied in modelling of direct, global and diffuse radiations, in the absence of clouds (clean sky condition). It is also fundamental parameter to estimate the performance maximum of solar collectors. To determine the β value generally requires spectrometric measurements of solar radiation, which is not simple to obtain mainly by necessity of equipment such as solar spectrometers and photometers. However, the β value can be estimated if the global and diffuse (or direct) radiations are known. This paper shows a mathematic metodology using parameters and equations that must be applied to estimate the Angstrom coefficient β. The results obtained in the summer are different than expected.This may be occurred because of atypicals conditions to this time of the year, and the fews collected datas.*

Keywords*: Angstrom's turbidity coefficient, Solar irradiance, Direct normal irradiance, Natal.*

!. INTRODUCTION

The solar radiation that enters the earth's atmosphere is attenuated by absorption and dispersion of the molecules and atoms of dust and air, also knows as aerosol, and by absorption of gases that compose the atmosphere, such as ozone, steam, oxygen and carbon dioxide.

Some atmospheric components are permanent and almost constant, however, others components, especially the aerosols, vary with the instantaneous local conditions and the local latitude (Pedrós et al., 1999).

It is know that in clear days the aerosols are the atmospherics constituents that cause greater solar radiation attenuation in the visible wavelengths to infrared (Szymber e Sellers, 1985). To be variable, the assessment of aerosol's effect in the solar radiation estimative is hard to do. To achieve an complete assessment of aerosols effect about the solar radiation should perform frequent measurements, at different locations, with differences aerosols types and differences climatic conditions (Kaufman et al., 1994).

The amount of aerosols has been represented in terms of the number of particles by cubic meter, or by their weight micrograms per cubic meter. However, is more common to represent the aerosol's amount for a turbidity index. (Louche et al., 1987).

Some turbidity indexes has been proposed, among them an index named Angstrom turbidity coefficient β. This coefficient proposed by Angstrom (1961) is a function of aerosols in the atmosphere. Their minimum value is 0 for an atmosphere without particles, while values higher than 1 are found in extremely turbid climates. However, their typical values varies between 0,0 and 0,5 (Cañada, et at., 1993).

The equation of Angstrom's turbidity also gives an index, α. This index is a function of aerosol's quantity in the atmosphere. Small values of α corresponding to a large quantity of particles. According Gueymard (1989), the most of natural's atmospheres has been value α = 1,3±0,5.

The two parameters, α e β, can be related through of Eq. (1).

$$Ka\lambda = \beta \lambda^{-\alpha} \tag{1}$$

Where Kaλ is the coefficient of attenuation aerosol monochromatic, also called of optical thickness of aerosol in the vertical direction, and λ is the wavelength in μm.

The parameters α e β can be determined from measurement techniques. With a double solar photometers α e β can be simultaneously determined by measuring of the aerosol attenuation and two wavelength of molecular absorption, where this is absent or minimal. This paper shows a methodology to determine β through of Direct Normal Irradiance (DNI). The method showed is used to determine the Angstrom turbidity coefficient under clear sky conditions.

2. PARAMETERIZATION MODEL

The DNI can be expressed in terms of individually transmittances of different atmospherics parameters. For the clear sky condition, a set of equations called "Parameterization Model" is available in the literature and the expressions more known are resumed by some authors. This parameterization formulation is considered accurate, and is developed in this work. According Louche et. al. (1987), o DNI (In) can be written as Eq. (2).

$$In = 0{,}975\ Eo\ Isc\ \tau r\ \tau o\ \tau g\ \tau w\ \tau a \tag{2}$$

Where Eo is the earth's eccentricity correction factor and Isc is the solar constant (1367 W/m^2).
The transmittances are showed bellow.
The transmittance by Rayleigh scattering is given by Eq. (3).

$$\tau r = \exp[-0{,}0903 ma^{0,84}(1 + ma - ma^{1,01})] \tag{3}$$

Where ma is the air mass, modified by pressure of medition station. This value of mass is given by Eq. (4).

$$ma = mr(P/Po) \tag{4}$$

Where P is the local atmospheric pressure and Po is the atmospheric pressure to the sea level.
The value of mr, showed in the Eq. (4), is given by Eq. (5).

$$mr = [cos\theta z + 0{,}15(93{,}885 - \theta z)^{-1,253}]^{-1} \tag{5}$$

Where θz is the zenith angle.
The transmittance is given by Eq. (6).

$$\tau o = 1 - [0{,}1611U3(1 + 138{,}48U3)^{-0,3035} - 0{,}002715U3(1 + 0{,}044U3 + 0{,}0003U3^2)^{-1}] \tag{6}$$

Where U3 is given by Eq. (7).

$$U3 = mr\ l \tag{7}$$

In Eq. (7), l is the thickness, in centimeters, of total quantidity of ozone in the vertical direction.
The trnasmittance by uniformly mixed gases is given by Eq. (8).

$$\tau g = \exp(-0{,}0127 ma^{0,26}) \tag{8}$$

The transmittance by water vapour is given by Eq. (9).

$$\tau w = 1 - 2{,}4959U1[(1 + 79{,}034U1)^{0,6828} + 6{,}385U1]^{-1} \tag{9}$$

Where U1 is given by Eq. (10).

$$U1 = w\ mr \tag{10}$$

The precipitable water thickness (w) is given by Eq. (11).

$$w = 0{,}493\left(\frac{\phi r}{T}\right)\exp(26{,}23 - \frac{5416}{T}) \tag{11}$$

Where T is the ambient temperature and ϕr is the relative humidity in fractions of one.
The transmittance by aerosol is given by Eq. (12).

$$\tau a = (0{,}12445\alpha - 0{,}0162) + (1{,}003 - 0{,}125\alpha)\exp[-\beta\, ma(1{,}089\alpha + 0{,}5123)] \tag{12}$$

Combining Eq. (2) and Eq. (12) obtains na explicit equation for β, given by Eq. (13).

$$\beta = \frac{1}{ma\ D}\ln(\frac{C}{A - B}) \tag{13}$$

Where

$$A = In/(0{,}975\ Eo\ Isc\ \tau r\ \tau o\ \tau g\ \tau w) \quad (14)$$

$$B = 0{,}12445\alpha - 0{,}0162 \quad (15)$$

$$C = 1{,}003 - 0{,}125\alpha \quad (16)$$

$$D = 1{,}089\alpha + 0{,}5123 \quad (17)$$

It is because of parameterization of aerosol's transmittance, Eq. (12), that β can be obtained explicitly from the total DNI measurements.

3. DATA

The measurements were collected by a weather station located on the roof of Gas Technology Center and Renewable Energy (CTGÁS-ER), located in Natal (elevation, 30 m; latitude 5,47°S, longitude 35,12°W). The measurements were carried out between June 2015 and January 2016, and the values of DNI used in the study were those days with clear sky. The measurements were made hourly, and to eliminate the cloudy effects used only figures for clear days.

Three hundred and seventy nine points were selected to analysis, always in the range between 8 e 16 h. The Figure 1 shows the typical variation of DNI throughout the day.

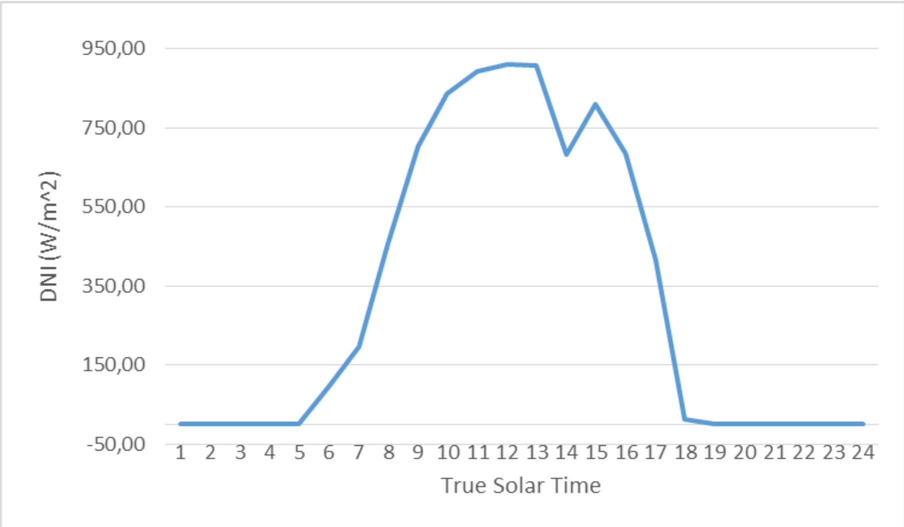

Figure 1. Daily variation of DNI in Natal on Dec 4, 2015.

The values of ambient temperature and relative humidity also were collected by weather station of CTGÁS-ER. The values of vertical ozone layer thickness were obtained of NASA's maps over the months of the year. An example of this maps is showed in Figure 2, where 100 DU equals 0,1 cm.

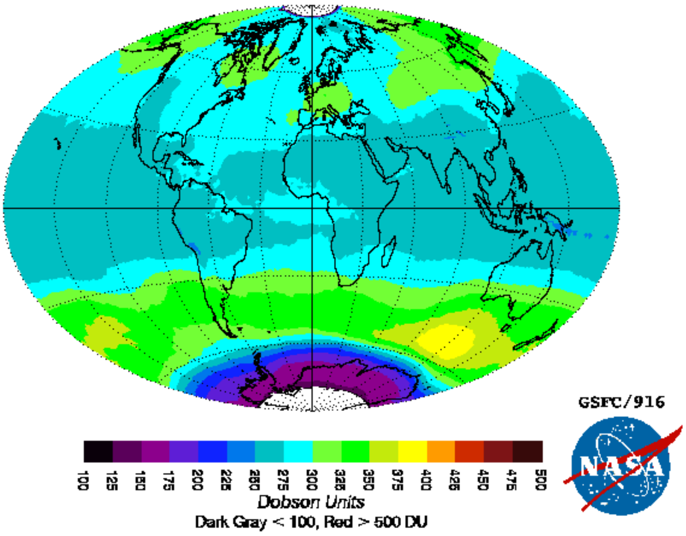

Figure 2. Monthly average total ozone September 2001.

The wavelength exponent α is related to the size distribution of particles. We assumed α = 1,3 as suggested by Angstrom.

4. RESULTS AND DISCUSSION

After collecting and analyzing the data, we calculated the average value and standard deviation of β for the studied months. These values are shown in Tab. 1. In works of (Louche et al., 1987), which estimated the β value to Ajaccio, and (Cañada et al., 1993), which estimated the β value to Valencia, β values were higher in summer and lower in winter, which did not happen in Natal. The Table 1 shown that the values in the winter's months are the lowest of the year, however, the summer's months are not the largest.

The Table 2 shows a comparison among the obtained results to Natal, Valencia and Ajaccio. Remembering that in the North hemisphere the winter occurs between December 21 and March 20, and the summer occurs between June 21 and 20 September, that is unlike to South hemisphere.

Table 1. Average values and standard deviation of β to the studied months.

Month:	Jun/15	Jul/15	Aug/15	Sep/15	Oct/15	Nov/15	Dec/15	Jan/16
Average:	0,097	0,094	0,104	0,117	0,117	0,126	0,113	0,108
Standard deviation:	0,032	0,031	0,044	0,041	0,052	0,046	0,039	0,033

Largest values of β in the summer are expected by fewer days with rain and higher tempeartures, that can induce an increased in the atmospheric turbidity (Cañada et al., 1993).

Table 2. Comparison among the obtained values of β to Natal, Valencia and Ajaccio.

	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan
Natal	0,097	0,094	0,104	0,117	0,117	0,126	0,113	0,108
Valencia	0,163	0,183	0,212	0,180	0,120	0,073	0,061	0,032
Ajaccio	0,081	0,132	0,102	0,091	0,090	0,077	0,059	0,060

The Fig. 3 shows graphically this comparison of results.

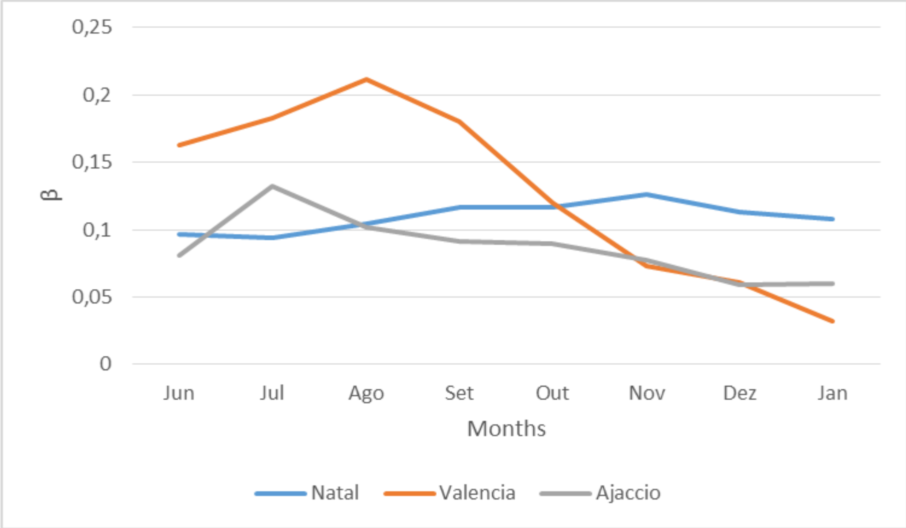

Figura 3 – Comparison among obtained values of β to Natal, Valencia and Ajaccio.

From Fig. 3 is possible see that there is a tendency, as cited by (Cañada et al., 1993), of β to be higher in the summer's month, and lower in the winter's month. Thus, it is believed that this value of β lower than expected in the summer occurs by atypical climate conditions in the studied months (Dec 2015 and Jan 2016). According the Empresa de Pesquisa Agropecuária do Rio Grande do Norte (EMPARN), Natal showed in this period a rainfall index higher than the average of last ten years (2005 – 2014), and was considered by the EMPARN as "Very Rain". The Figure 4 shows this data to December 2015, and Figure 5 to January 2016.

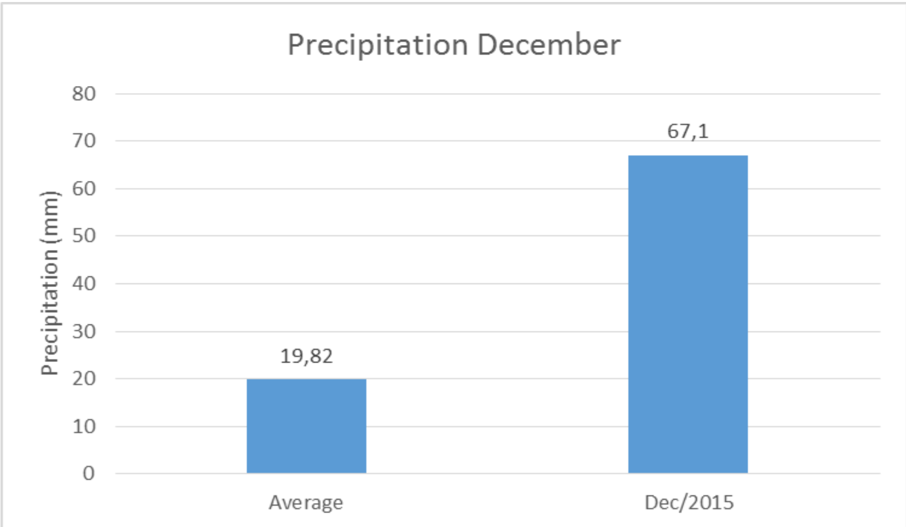

Figure 4. Precipitation in mm to December 2015.

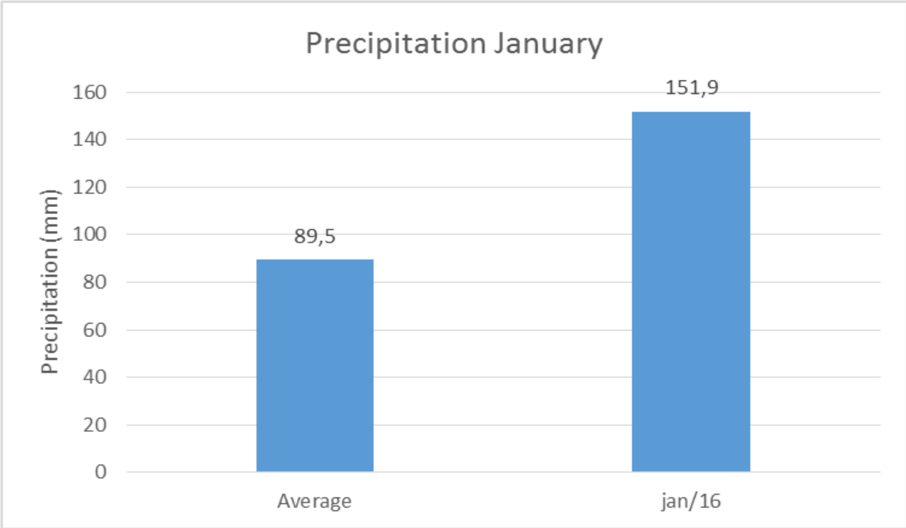

Figure 5. Precipitation in mm to January 2016.

The Figure 6 and Figure 7 shows an analysis of accumulate rains to state of Rio Grande do Norte in the months of December 2015 and January 2016, respectively. The red color shows the counties considered "Very Dry", the yellow color the counties considered "Dry", the clearer blue "Normal", the intermediate blue "Rainy", the dark blue "Very Rain", and the white "without information". In the figures Natal is indicated with na arrow.

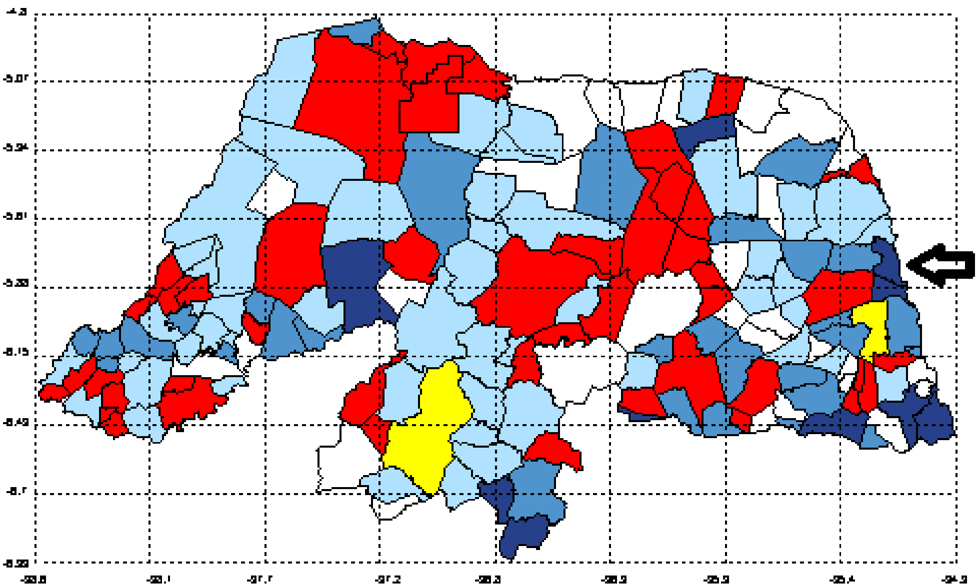

Figure 6. Analysis of accumulated rain – December 2015 (Source: EMPARN).

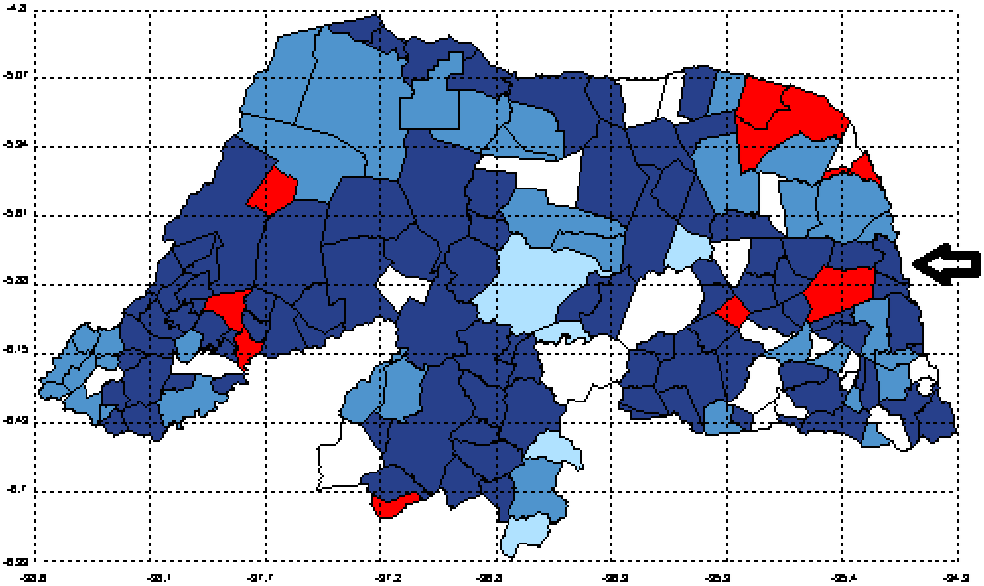

Figure 7. Anylise of acumullated rain – January 2016 (Source: EMPARN).

This high amount of rain also did not allow the collection of a large quantity of data with clear sky conditions. The works done in this area used collected data over two or three years, enabling a large reliability about the results obtained.

As mentioned in this paper, was used 379 points to analyses of results during eight months, while in others papers was used 1018 points during three years of data collected (Cañada et al., 1993), and 1175 points during three years of data collected (Louche et al., 1987). This difference of data collected, amongst the analyze in a shorter period, does not provide a definitive result of the variable studied. To achieve this result it is necessary to analyze data for a longer period time.

5. CONCLUSION

In this work was used a methodology proposed by (Louche et al., 1987), to estimate Angstrom's turbidity coefficient β, under clear sky conditions at Natal. This method is based in the measurement of DNI and atmospherics and climate conditions

It is expected that the maximum values of β, showed in Table 1, occurs in the summer, and the lowers values occurs in the winter, however, it didn't happen. The values obtained in the summer were not the greatest, and this can be explained by the fact of atypical climate conditions in the months of December 2015 and January 2016, where the amount of rain in these months was higher than average of last ten years.

Another fact that can explain this difference of expected result is the among of collected data, which was lower than commonly done, due to the time used to make this collection, which was eight months, while usually used at least three years.

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