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Analysis of Influence Factors on Clearness Index for the City of Fortaleza

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ABSTRACT

This paper aims to analyze the influence of internal factors in the sun and Earth's atmosphere, represented by the International Sunspot Number and cloudiness, respectively, in the value of the clearness index, given by the relation between the incident radiation on the surface and at the top of the atmosphere, over a solar cycle, for the city of Fortaleza. The data of insulation hours and cloudiness were obtained from the National Institute of Meteorology and the International Sunspot Number from the Sunspot Index and Long-term Solar Observations. From these data, we calculated the annual average clearness index using the Ãngstrom-Prescott equation and a comparison was made with the average cloudiness and the solar activity. The results showed a great influence by the cloudiness (-0.808) and very little by the solar activity. However, it also shows that the clearness index (0.187) presents in most of the cycle a behavior similar to that of solar activity.

General Terms

Analysis, Influence Factors

Keywords

Clearness index, Cloudiness, Solar activity, Ãngstrom-Prescott equation

1. INTRODUCTION

Radiation is the propagation of energy from one point to another, in any material medium and even in the vacuum. Such energy transfer can occur in the form of particles or electromagnetic waves[1].

Every body whose temperature is greater than 0 K emits radiation, and this value will be proportional to the fourth power of the temperature in which it is, according to Stefan-Boltzmanns Law. The wavelength of the emitted radiation also depends on temperature, according to Planck's Law. According to Wien's Law, the hotter the emitting body, the lower the wavelength of its emission peak [2, 3]. The sun has an average surface temperature of approximately 5762 K, and it radiates preferably from the ultraviolet to the infrared range. Since the sun is the main source of energy for the Earth, the radiation emitted by the sun is the input energy in Surface-atmosphere System (SAS)[4].

The amount of energy provided by the sun in the form of radiation varies spatially and temporally, and its value is a function of the wavelength of the electromagnetic wave and of other phenomena that occur on the solar surface along its cycle, such as the presence of sunspots, temperature variations and solar flares. In the most recent sunspot cycles, for instance, there was a change of approximately 0.1% of the total solar irradiance [2, 5].

When it reaches the Earth's surface, the intensity of solar radiation is attenuated due to the phenomena of absorption and scattering. Therefore, part of the solar energy is absorbed, spread and reflected by molecules of air, vapor, dust and clouds. Among the elements previously mentioned, clouds are the ones that participate most actively in the attenuation of solar radiation and are responsible for intercepting approximately 25% of the total energy that reaches the surface-atmosphere system [6, 7].

The solar radiation that reaches the surface, besides relying on all the factors previously mentioned, is also related to elements such as latitude, solar declination, time angle, azimuth and zenith angle of the sun. The intensity at which these radiations reach the ground is called the intensity of sunshine and is related to the angle of solar height, which in turn depends on the latitude and the solar declination [8].

Highest values of sunshine occur in the tropical zone. One should note that the peaks do not occur in the equatorial zone but in the latitudes 20 in both hemispheres. This fact is a consequence of the most intense cloudiness in the equatorial zone [7].

With the expansion of renewable sources, caused by the desire to mitigate environmental problems such as global warming [9], studies related to solar radiation have gained more importance, with several researchers using the clearness index to quantify surface global solar irradiance [10, 11].

Some studies deal with the evaluation, quantification and modeling of irradiance through this index.

Some papers evaluate, quantify and model the irradiance through this index. [12] sought to quantify and model the effect on tropical forests. [13] proposed a hybrid neuro-fuzzy model to model the radiation forecast. [14] analyzed the irradiance in the different Brazilian climatic zones.

This work aims to analyze the influence of solar activity and cloudiness on the value of the clearness index, given by the ratio between incident radiation at the surface and the incident at the top of the atmosphere, calculated from the ngstrom-Prescott equation for the city of Fortaleza, which is located at $3^o45'$ south latitude and $38^o32'$ west longitude and at 21 meters of altitude.

In section 2, it was a methodology used to carry out this work, as well as a location and its specific characteristics, the appropriate materials and, finally, as equations with their own descriptions. In section 3, the results are shown with due discussions and comparisons between the values acquired from previous years. And, finally, in section 4, they are evaluated as clearness value evaluators and under geographic conditions.

2. METHODOLOGY

The analysis of the solar radiation has great importance for the evaluations of climate change and global warming, because they arepotentially sensitive indicators of anthropogenic disturbances [15].In order to analyze the behavior of solar radiation, was adopted aninternal factor of the source and another associated with the composition of the atmosphere,then the numbers of spots and cloudiness were chosen.

This study was based on the city of Fortaleza, which is located at $3^o45'$ south latitude and $38^o32'$ west longitude and at 21 meters of altitude.

In cases of scarcity of global radiation data, it is necessary to use linear regression equations. Among those present in the literature, the one which is the most widespread is that of ngstrom-Prescott [16], which shows the relation between the global radiation and the incident at the top of the atmosphere, also known as the clearness index (Kt), and the relation between the daily surface insulation and the photoperiod. The daily clearness index is a general indicator of all scattering and absorption processes in atmosphere due to aerosols, gases and clouds that affect the transmission of radiation through the atmosphere [15], and is given by to Equation 1:

$$\frac{R_g}{R_o} = a + \frac{b \times n}{N} \tag{1}$$

Where: R_g is global radiation; R_o is radiation at the top of the atmosphere; n is number of sunshine hours; N is photoperiod and a, b is coefficients of linear regression.

Literature shows the values of $a = 0.27$ and $b = 0.36$ [16], so these values were adopted in this work.

The values of sunshine and cloudiness were obtained from the Meteorological Database for Teaching and Research of the National Institute of Meteorology (INMET). In order to obtain a greater reliability in the results, we used the data collected from 2005 to 2015, which totals 11 years and is therefore equivalent to a solar cycle.

For each year of the study, we calculated the average monthly and annual cloudiness values and hours of sunshine. We processed the data in *Microsoft Excel* spreadsheets.

To calculate the photoperiod, we used Equation 2:

$$N = 2/15 \times \gamma_s \tag{2}$$

The solar height angle (γ_s) represents the inclination angle between the trajectory of the sun and the horizontal plane. Its value depends on the geographical location of the observer and on the solar declination, and it is calculated according to Equation 3.

$$\gamma_s = \cos^{-1}(\tan\delta \times \tan\theta) \tag{3}$$

where δ is the solar declination and is the local latitude.

The solar declination (δ) is the angle between solar rays and the Equator plane. Such declination is a consequence of the inclination of the Earths axis rotation, and it varies along the year according to the position of the sun. Its value on a particular day is defined by Equation 4.

$$\delta = 23.45 \times \sin(360/365 \times (284 + DJ)) \tag{4}$$

where DJ is the Julian day.

In order to obtain an average value of the photoperiod, we calculated a solar declination on the 15th day of each month. For the study of activity solar influence, which is given by presence of sunspots, we adopted the values acquired by the *International Number of Sunspots*. Such data were obtained from the *Sunspot Index and Long-term Solar Observations* (SILSO).

3. RESULTS

The values of the clearness index for the period 2005-2015 and its comparison with the average annual cloudiness of the same period are shown in Figure 1. A small variation of amplitude can be observed in the values of the clarity index, with a mean value of 0.506 and a standard deviation of 0.015. It is worth noting that in the year 2015, INMET's isolation values for the period from July to December were absent. This period, according to the historical average, presents the highest values of insolation, such that its absence compromised the annual result. Cloudiness showed a greater variability, with an average of 0.561 and a standard deviation of 0.029.

Figure 1 shows the values of the International Number (S_n) during 11 years. From this curve, the behavior of the coefficient of clarity was analyzed in relation to the two mentioned factors.

When comparing Figures 1 and 2, it is possible to observe that the clearness index has a tendency to follow the solar activity curve. In addition, when observing the years 2008 and 2009, it is possible to see that there is one of the smallest solar activities recorded, besides the highest cloudiness, resulting in the lowest index of clarity among the studied years. Although 2014 is the year with the most intense solar activity, the highest record of the clearness index occurred in 2012, in which the lowest cloudiness occurred.

Observing Figure 2, it is verified that between 2013 and 2014 there is a difference when compared. For, although 2013 has less intense solar activity, it presents greater cloudiness when compared to the year 2014 and a greater index of clarity.

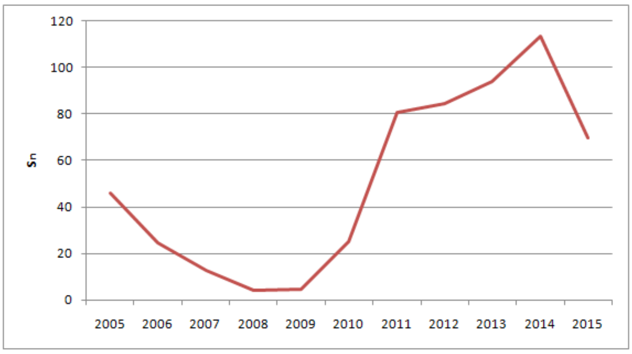


Fig. 1. Cloudiness values and clearness index 2005-2015.

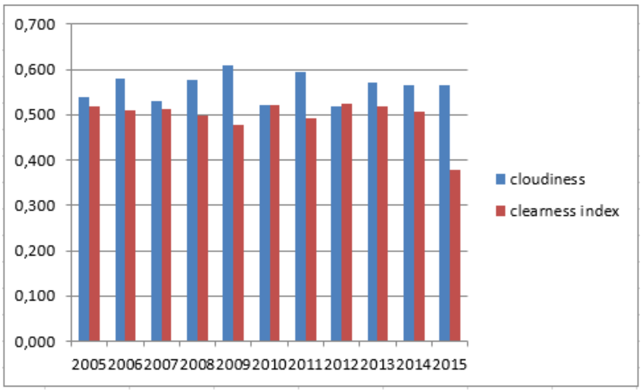


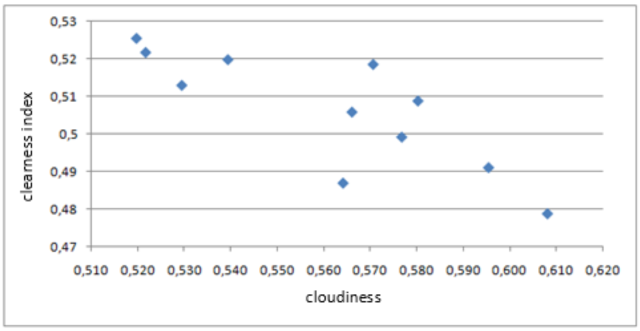
Fig. 2. Annual values of Sn 2005-2015.
Source: The Author, based on data of *Sunspot Index and Long-term Solar Observations* (SILSO).

The years of 2006, 2009 and 2011 were the ones that presented the highest values of cloudiness. In 2006 and 2011, the high values of this variable contributed to attenuate the values of the incident radiation, having generated indices of clearness lower than those indicated by the solar activity trend. The variation between the year with the highest number of spots and the lowest reaches 5.6% for the index of clarity. For cloudiness, this variation reaches 9.7%.

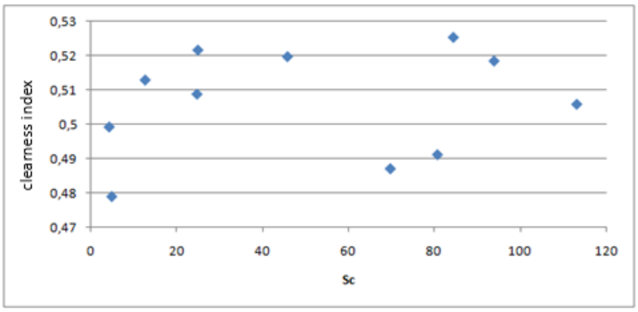
The degree of dependence between cloudiness and clarity indices was calculated from the correlation study, as shown in Figure 3(a), which represents the cloudiness and brightness dispersion diagram. Analyzing these data, it is observed that the variables have a negative correlation due, for example, to the increase in the cloudiness index, there is a reduction in the clarity index.

Figure 3(b) represents the correlation diagram of the number of sunspot variations and the clarity index. When analyzing the data, it was noticed that the increase in the clarity index did not influence much the sunspots, so that the correlation values remained practically straight, except for points 75 and 80.

When calculating the linear correlation coefficient (r), the following values were obtained: $r = -0.808$ for the relation between cloudiness and clarity index and $r = 0,187$ for the relation between the number of points and the index of clarity. Analyzing the value of r in the correlation between the index of cloudiness and the index of clarity, it is observed that this one has a negative value, therefore, it has a negative linear relation. However, when analyzing the value of r in the correlation between the number of spots



(a) Scattering plot of Cloudiness vs. Clearness.



(b) Scatter plot Number of sunspots vs. Clearness.

Fig. 3. Correlation of the variables.

and the index of clarity, it is observed that it has a value very close to zero, causing a linear nonexistence. In order to verify a better relationship, it would be necessary to extend the considered time interval and compare it with factors such as the production of energy by thermal plants, for example.

4. CONCLUSIONS

This work presented an analysis of the influence of internal factors on the Sun and the Earth's atmosphere, given by the number of spots and cloudiness, respectively, in the values of the clarity index, were calculated from the ngstrom-Prescott equation. This work was based on the city of Fortaleza, and data were obtained from INMET and SILSO.

The main results obtained from the analysis of the annual averages were: During the period of the study, the value of the clarity index did not change significantly. However, it was observed that the clarity index shows a tendency of behavior similar to the solar activity. The clarity index showed a significant dependence on cloudiness, with a negative linear correlation of $r = -0.808$. In the years when the highest values of cloudiness (0.610) were present, the reduction of the incident radiation, that is, a decrease in the clarity index, became evident. Already the relation between the sunspots and the index of clarity, that obtained a correlation of $r = 0, 187$, that is, practically a non-existence linear.

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