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GEOSCIENCES

Relationship Between Extreme Rainfall Occurrences and Galactic Cosmic Rays over Natal/RN, Brazil: A Case Study

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Abstract: The increase in Galactic Cosmic Rays (GCR) flux intensity induces the Condensation Nuclei (CN) production, which intensifies rainfall occurrences. Then, the objective of this study was to analyze the rainfall distribution in the NEB and the impact of GCR flux on extreme rainfall events occurred in July 1998 in Natal/RN, Brazil. We used historical rainfall, Sea Surface Temperature (SST) and GCR flux data for Natal/RN. We used R software for statistical analysis. The results indicate that the GCR flux is important for intensifying extremes rainfall occurrences. This fact is observed when analyzing the relationship between rainfall greater than 10 mm and GCR flux above 6,390 counts/min. Pearson correlation coefficient between rainfall and GCR flux was 0.94 (p-value = 0.0005) and SST was -0.76 (p-value = 0.0263), both statistically significant. The rate between GCR flux and rainfall was +2.87 mm/count/min, while the rate between SST and rainfall was -7.91 mm/°C. The variance proportion explained by regression was 94.41%, with relative importance degree corresponding to 62.0% for GCR flux and 32.4% for SST, respectively. The results show that GCR flux had a greater contribution to extreme rainfall occurrence in the metropolitan region of Natal/RN and it is important in climatological studies.

Key words: Modeling, climatic extreme, flood, storm.

INTRODUCTION

The Sun is the main source of energy for the Earth's climate system. The solar irradiance and the intensity of the Sun's magnetic field are aspects of so-called solar activity. An index generally used to measure solar activity is the number of dark spots observed on Sun's surface. When the number of sunspots is maximum (minimum), solar irradiance is maximum (minimum) and the intensity of the solar magnetic field is maximum (minimum). The number of sunspots presents a main cycle of variability with a periodicity of approximately 11 years. During the solar cycle maxima other rapid manifestations of solar activity such as coronal mass ejections and solar flares are more frequent. Every eleven years the Sun's magnetic polarity reverses. The time interval required for the same polarity state to be repeated is approximately 22 years. This 22-year periodicity is called the solar magnetic cycle (Usoskin 2008).

The solar variability has been suggested as a possible cause of climatic variations for a long time (e.g., Herschel 1801, Eddy 1976, Friis-Christensen & Lanssen 1991). Several mechanisms were proposed to explain the connection between the solar variations and the terrestrial climate oscillations (e.g., Gray et al. 2010, Solanki et al. 2013). These mechanisms encompass variations in total solar irradiance, in ultraviolet component of the total solar irradiance, and in the flux of electrically charged particles (Gray et al. 2010). Between the electrically charged particles are the high-energy galactic cosmic rays (GCR) that are mainly protons and are originated out of solar system.

The entrance of GCR particles in the Earth's atmosphere is modulated by the magnetic fields of the Earth and the Sun and varies in different scales of time and space. The flux of the GCR is maximum when the Sun's magnetic field intensity is minimum. The GCR flux is also maximum in geographical locations near the geomagnetic field poles, where the field is almost vertical and is not able to shield the entry of electrically charged particles. On the other hand, the flux of GCR is minimum when Sun's magnetic field intensity is maximum, and in geographical locations near the geomagnetic equator where the Earth's field is horizontal (Frigo et al. 2018). As a consequence of the antiphase relationship between solar activity and GCR variations the last five GCR maxima occurred around 2020, 2009, 1997, 1976 and 1964. Furthermore, as a result of the positive electric charge of de GCR, the maximum flux of these particles in the atmosphere persists for more time during transitions from even to odd solar cycles (Usoskin et al. 2001). The most recent GCR maxima related to this situation occurred around 1964, 1997 and 2020.

The GCR and are the main source of ionization of the low and the middle atmosphere (Dorman 2004). The first work to suggest a possible relation between GCR and the Earth's climate was presented by Ney (1959) after observations that the number of sunspots are correlated with the atmospheric ionization. However, Ney (1959) do not investigated in detail what mechanism would explain the connection between the ionization and the weather. Dickinson (1975) proposed that the GCR-induced ionization would be related to the production of sulphate aerosol which is a very important cloud condensation nuclei (CCN). In other words, the ionization due to GCR would influence cloud cover and consequently the terrestrial climate. This mechanism was tested by Svensmark & Friis-Christensen (1997) using cloud cover satellite data covering almost a complete 11-year solar cycle.

These authors found a positive correlation between GCR and global cloud cover for the period between 1983 and 1990, which corroborates the mechanism suggested by Dickinson (1975). In the following years some authors (e.g., Sun & Bradley 2002, Laut 2003) questioned the results obtained by Svensmark & Friis-Christensen (1997). Svensmark (2007) reassessed the relationship between GCR and clouds, and concluded that this relationship is valid only for low clouds. From the climatic point of view, while high clouds act on the terrestrial energy balance in order to increase the temperature of the region below them, the effect of low clouds is the opposite, that is, they act in a way to decrease the temperature of the region below. Furthermore, there are also evidences that GCR flux, influenced by coronal mass ejections from the Sun, also modulates the cloud cover on a daily time scale (Svensmark et al. 2009).

The scientific debate about the possible influence of galactic cosmic rays on Earth's climate remains intense. Some researchers are investigating whether ionization produced by GCRs in the atmosphere can contribute to cloud formation in ways that generate observationally detectable climate effects (e.g. Enghoff et al. 2011, Pfeifer et al. 2023). Another group of researchers is investigating whether the climate effect of GCR is effective globally or only regionally and whether it is persistent over time (e.g., Voiculescu & Usoskin 2012, Sfîcă et al. 2018). Furthermore, if the modulation of low clouds formation by GCR really occurs and considering that low clouds are extremely important in the terrestrial radiative balance, it is natural to expect that its effects will also be detected in other meteorological variables such as temperature. In this context, there are many works (e.g., Souza Echer et al. 2012, Frigo et al. 2013, 2018) suggesting that GCR flux variations contribute to temperature changes in yearly to multidecadal time scale during the last century.

Another meteorological variable that significantly influences human life is rainfall. Rainfall is one of the most important meteorological elements to characterize the climate of a region. Understanding its space-time variability and its extremes are fundamental for society in several sectors such as economy, agriculture, livestock, tourism, electric power generation, urban supply, among others (Bunhak & Wanderley 2020). The occurrences of extreme rainfall events have great potential to generate major impacts on society. Thus, economic costs of extreme weather events, over the damage caused by droughts and floods, will be intensified by anthropogenic factors due to climate change (Frame et al. 2020). Floods represent about one-third of all-natural disasters. Together with storms they comprise 77% of economic losses caused by extreme weather events in Europe (Lechowska 2018).

Several authors have found typical periodicities of solar activity, and consequently of the GCR, in rainfall time series (e.g., Thomas & Abraham 2022). Some of these results were also obtained for locations in Brazil (King 1975, Gusev et al. 2004, Souza Echer et al. 2008, Rampelotto et al. 2012). These studies that were based on data recorded in south and in northeast Brazil revealed that the 22-year periodicity, typical of the GCR, played an important role in modulating rainfall variability.

In this work we investigate the possible connection between GCR and rainfall in a daily time scale using data registered in Natal (5.8°S, 35.21°W), northeast Brazil. The rainfall data cover the month of July 1998 in which occurred a very intense rainfall event. Furthermore, in the year of 1998 the GCR flux was near the maximum.

The Northeast region of Brazil (NEB) has a historical occurrence of droughts beginning in the 16th century, where more than 20% of the years (from 1583 to 2016) experienced an episode of drought (Marengo et al. 2018). This fact makes the NEB has a great socioeconomic and cultural contrast, which are aggravated due to the desertification process and its impacts in soils (erosion and degradation) in this region (Tomasella et al. 2018).

In addition, NEB also presents floods events, such as the one observed between 20 and 30 May 2017, which was responsible for causing several deaths and leaving thousands homeless. In those days, the accumulated rainfall was greater than 500 mm in some places on the NEB coast, as measured by weather stations (Comin et al. 2021). More recently, an intense flood event occurred in Alagoas and Pernambuco in June 2010 causing serious damage to these states. In Pernambuco, floods were responsible for 20 deaths, 26,797 homeless and 157,124 displaced. About 11,400 houses were damaged or destroyed and 59 cities in Pernambuco were affected, with nine of them declaring a public calamity state and 30 cities declaring an emergency statement. In Alagoas, the homeless exceeded 28 thousand, with 74,515 displaced, 37 dead and 69 missing persons. In Alagoas, 17 cities declared an emergency statement and 15 cities declared to be in public calamity.

Rainfall dynamics in NEB is influenced by meteorological systems such as High Level Cyclonic Vortices, Sea and Land Breezes, East Waves, Intertropical Convergence Zone, Frontal Systems, among others (Riehl 1945, Kousky 1979, 1980, Kousky & Gan 1981, Coelho et al. 2002, 2004, Gomes et al. 2015, 2019). However, Wanderley et al. (2014) observed that statistically significant change in minimum and maximum temperatures and a tendency to reduce rainfall.

Rainfall distribution in NEB is also influenced by the oceans, which are important in atmospheric instability formation as a source of heat, weather and climate regulation due to the occurrence of phenomena such as El Niño-Southern Oscillation, Pacific Decadal Oscillation and Atlantic Dipole (Zhou & Lau 2001, Kayano & Andreoli 2004, Kayano & Andreoli 2007, Cunha et al. 2018, Villamayor et al. 2018, Cunha et al. 2019, Costa et al. 2020).

Another important factor in rainfall formation is the amount of aerosols present in the atmosphere. Aerosols are important CN that help to agglutinate water vapor in the atmosphere. Atmospheric instability is responsible for raising these particles to the upper regions of the troposphere, agglutinating the water vapor and forming clouds and rainfall (Yu 2002, Rosenfeld et al. 2008, Calisto et al. 2011). Studies have shown that the increase in CN concentrations in the atmosphere contributes to the formation of intense rains in several places (Rosenfeld et al. 2008, Spracklen et al. 2008). Singh & Bhargawa (2020) indicates possible solar influences on meteorological and climate parameters such as temperature, thunderstorm frequency, tropopause heights, atmospheric circulation, and occurrences of droughts etc.

Other sources of CN in the troposphere are due to gases ionization present in the earth's atmosphere by galactic cosmic rays (GCR) flux forming the CN and cosmogenic radionuclides (Gosse & Phillips 2001, Calisto et al. 2011, Kirkby et al. 2011). GCR fluxs are strongly attenuated by solar activity and solar magnetic parameters, in a cycle of about 11 years (Solanki et al. 2000, Belov et al. 2002, McCracken 2004, Singh & Bhargawa 2019).

The cosmogenic CNs present in the troposphere depend on several factors such as GCR flux and atmospheric circulation (Staiger et al. 2007). In addition, these contribute to the formation and removal of photoxidants such as NOx, HOx, O_3, and trace gases important for CN production, such as H_2SO_4, HNO_3, NHO_3 (Calisto et al. 2011, Kirkby et al. 2011). The presence of NHO_3 in the atmosphere accelerates the H_2SO_4 particles nucleation by 100 to 1,000 times (Kirkby et al. 2011), where CN concentrations are proportional to H_2SO_4 formation (Spracklen et al. 2008).

The relationship and interaction of GCR flux with gases present in the atmosphere contribute to CN production, serving them as hygroscopic particles, important in clouds and rain formation. Ultrafine particles are important for the formation of clouds and for radiative transfer in the atmosphere (Arnold 1982). The GCR-CN-Troposphere interaction attenuates around 3-4% of the terrestrial cloudiness (Svensmark & Friis-Christensen 1997).

Mavrakis & Lykoudis (2006) showed that rainy and dry periods provide different relationships due to the attenuation of GCR flux. Kniveton & Todd (2001) showed that rainfall varies from 4-7% of the solar cycle to medium and high latitudes. In addition, the relationship between solar activity, GCR flux and climate variables can be used as predictors for rainfall forecasting models (Lucio 2005).

However, this relationship with rainfall distribution in NEB is scarce, especially its relationship with extreme rainfall events. Thus, this article aims to analyze the impact of GCR flux on the extreme rainfall event occurred in July 1998 in Natal/RN, Brazil.

MATERIALS AND METHODS

Dataset

The analysis was performed using a database of accumulated daily rainfall in Natal, station Nº. WMO: 82598 (Latitude -5.91° S, Longitude -35.2° W, Altitude 48.60 m, Rio Grande do Norte/Brazil. Figure 1a shows a map of Brazil with emphasis on the state of Rio Grande do Norte, and in Figure 1b, the map of Rio Grande do Norte stands out. We obtained historical data was from the Meteorological Database for Teaching and Research of the Instituto Nacional de Meteorologia (INMET 2020), from July 1, 1998 to July 31, 1998.

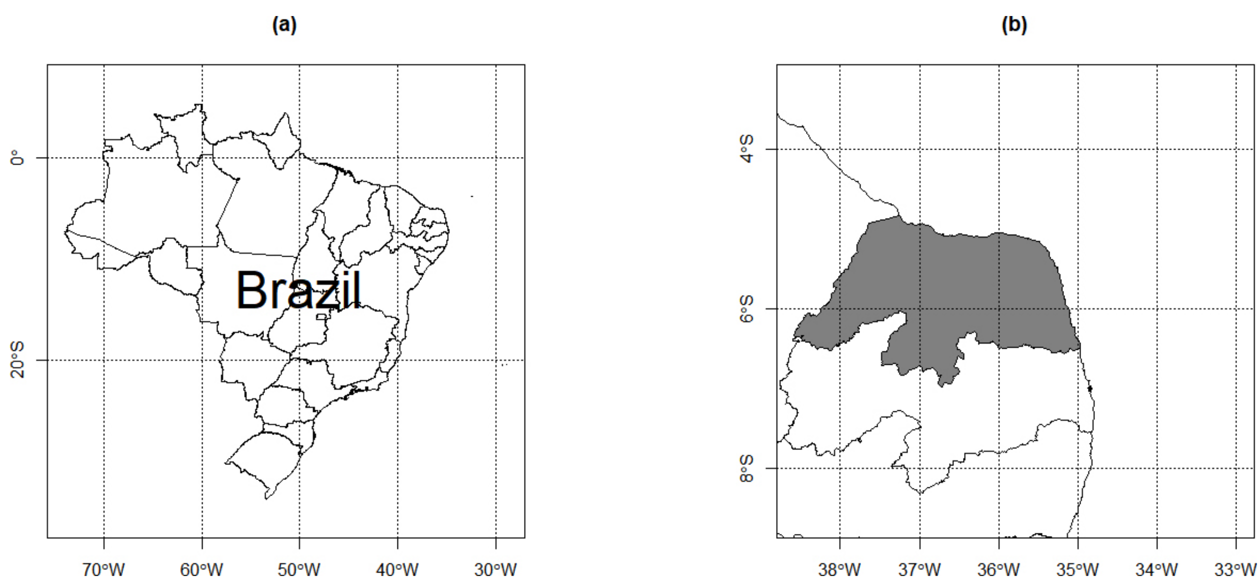

Figure 1. Map of Brazil (a) and highlighted, the state of Rio Grande do Norte and (b) location of rainfall station in Natal/RN, Brazil.

Natal/RN has 167.401 km² of area, with an estimated population of 890,480 inhabitants (2020) and its biome is a mixture of Caatinga and Atlantic Forest. The climate is Tropical (As') with average annual rainfall of 1,721.4 mm (period from 1981 to 2010), and rains are concentrated between April to July. Average temperatures oscillate from 24.7ºC (July) to 27.5ºC (February).

The daily average GCR flux historical series was obtained from the website https://cosmicrays.oulu.fi/, daily average, Oulu Neutron Monitor (Lat .: 65.0544 °, Long .: 25.4681°, Alt .: 15.0 m, Geomagnetic cutoff rigidity = 0.8GV) . We used the NM Oulu historical series to replace the NM station in Huancayo, PER. SST data was obtained from the website https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.highres.html (Reynolds et al. 2007). Both GCR flux and SST were studied between July 1, 1998 to July 31, 1998.

Multiple Linear Regression Model

For this study, the Multiple Linear Regression Model was used to investigate the relationship between the dependent and independent variables. For dependent variable was used the rainfall and for independent variables were used the GCR flux and ASST, according to Eq. (1). The reason for creating a linear regression model is to measure, in percentage, the degree of influence of the explanatory variables on the independent variable. Isse explains how much each variable affects the precipitation extreme under study.

$$Rainf = \beta o + \beta 1.GCR + \beta 2.ASST + \varepsilon i \quad (1)$$

where,
Rainf - accumulated daily rainfall, in mm;
GCR – GCR flux, average daily, in counts/min;
ASST - Sea Surface Temperature Anomaly, average daily, in °C;
εi - random error, assumed to be independent and with normal distribution of the mean, and constant variance βo, β1, and β2 are coefficients of the model adopted.

Model Evaluation Measures

From the results obtained by the Multiple Linear Regression Model, we compared it with the observed data using the "Goodness-of-fit". The "Goodness-of-fit functions for comparison of simulated and observed hydrological time series", is available in the hydroGOF package on R software (Zambrano-Bigiarini 2014) for the Multiple Linear Regression Model performance, between the estimated and observed data. The following items were evaluated:

Mean Absolute Error (MAE) measures the mean magnitude of the estimated data errors in relation to observed data. Closer to zero better is the model's performance (Eq-2)

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|S_i - O_i| \quad (2)$$

where,
S_i – estimated data
O_i – observed data

Normalized Root Mean Square Error (NRMSE) is configured as the standard deviation of the samples of the differences between predicted and observed values, multiplied by 100 and the result in percentage (Eq-3).

$$NRMSE = 100\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_i - O_i)^2}}{nval} \quad (3)$$

where,

$$nval = \begin{Bmatrix} sd(O_i), \ norm = "sd" \\ Omax - Omin, norm = "maxmin" \end{Bmatrix}$$

The Nash-Sutcliffe Efficiency (NSE) coefficient is configured as the relative intensity of the residual variance in relation to the measurement data variance (Nash & Sutcliffe 1970). NSE coefficient can range from negative infinity to 1, with a value of 1 indicating perfect fit (Eq-4):

$$NSE = 1 - \frac{\sum_{i=1}^{N}(S_i - O_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O})^2} \quad (4)$$

The Index of Agreement (d) is a normalized measure of forecast error degree of the model, where, 1 indicates perfect fit and 0 indicates that there is no agreement. This index is extremely sensitive to extreme values, due to squared differences (Willmott 1981, Legates & McCabe 1999) (Eq-5).

$$d = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}\left(|S_i - \overline{O}| + |O_i - \overline{O}|\right)^2} \quad (5)$$

The linear correlation coefficient (r) covariance of Oi and Si, σ_{Oi} and σ_{Si}, (Eq-6) represents the standard deviation of observed and estimated data:

$$R = \frac{\sigma_{Oi,,Si}}{\sigma_{Oi}\sigma_{Si}} \quad (6)$$

The coefficient of determination (R^2) (Eq-7):

$$R^2 = \frac{\sum_{i=1}^{n}(\widehat{S_i} - \overline{O}_i)^2}{\sum_{i=1}^{n}(S_i - \overline{O}_i)^2} \quad (7)$$

Data processing

For data processing, we used the R Core Team (2020), version 4.0. This software was used to read the database and algorithms. The *raster* (Hijmans 2023) and *rasterVis* (Lamigueiro & Hijmans 2018) packages were used to manipulate the nectCDF files. To verify the degree of importance of the linear model, the *relaimpo* package was used (Grömping 2006).

RESULTS AND DISCUSSION

It is observed that every day there was resistance of precipitation in Natal during the studied period (Figure 2a). In figure 2b, it shows the GCR flux during the studied period, it is noted that these are continuous flux with some moments in which there is a reduction and increase of this flux. In relation to Figure 2c, it shows the relationship between rainfall and the GCR flux. It was observed in this period that not every oscillation of the flow of GCR produced precipitation in the study region, given that it does not produce precipitation, but has the possibility of enhancing the systems in favorable atmospheric and oceanographic conditions. Rainfall and GCR flux behavior during July 1998 shows that rains greater than 10 mm is conditioned to GCR flux greater than 6390 counts/min, this threshold being adopted for this study (Figure 2). The highest total rainfall totals are related to GCR flux between 6400-6460 counts/min. Pearson's correlation test was performed between precipitation and GCR flux, resulting in +0.94, being significant at 5%. While for SST with precipitation it was -0.76, being significant at 5%.

The correlation between ASST and GCR flux shows a negative relationship on the east coast of NEB, especially between the coast of Rio Grande do Norte and Pernambuco, where this correlation was greater than -0.60, which is the highest correlation observed (Figure 3). According Badruddin & Aslam (2015) the rainfall and temperature variabilities are inversely related. The greatest correlation is the result of clouds and rainfall formation in the studied period.

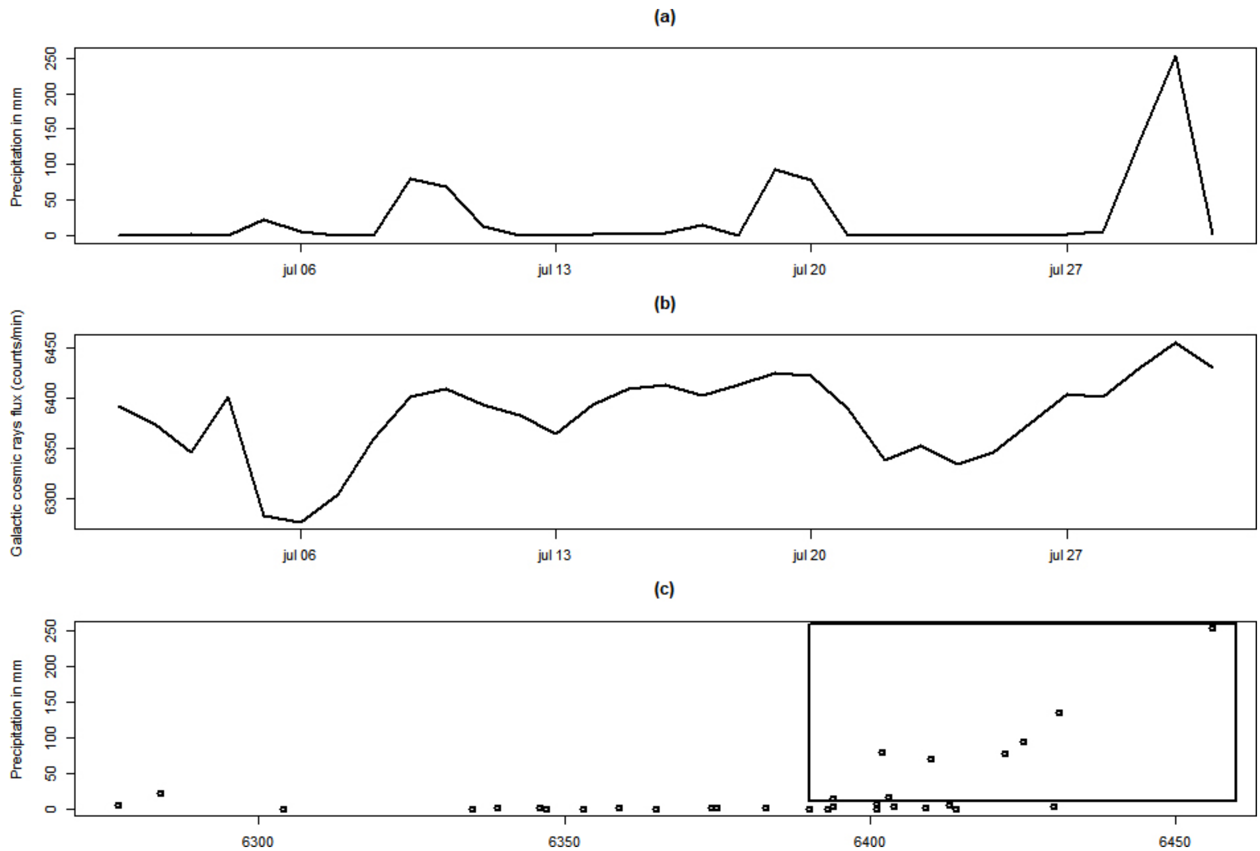

Figure 2. (a) Precipitation in mm, (b) GCR flux in counts/min, and (c) relationship between precipitation and GCR flux, the during July 1998.

Variations in cloud cover can strongly change the fluxes of incoming (shortwave solar radiation) and outgoing (long wave) radiations of the Earth's atmosphere and, thus, affects heavily to the heat balance of the atmosphere. The high/low level clouds contribute to warming/cooling of the atmosphere and a net influx of radiation coming to the Earth's surface during cloudy conditions depends on latitude, season and underlying surface conditions (Veretenenko & Ogurtsov 2018). The largest ASST favors the waters evaporation of the Atlantic Ocean and clouds formation. Clouds are formed by the advection of trade winds from the southeast to the continent where rainfall occurs.

Positive correlations between SST and GCR flux were found in the east coast of Rio Grande do Norte, with the ocean as a source of heat and humidity. Thus, this region was selected according to longitudes (-34.4259° S, -23.9828° S) and latitudes (-9.2236° W, -3.9242° W) coordinates for the construction of a historical series in order to correlate with the rainfall that occurred in July of 1998.

The historical series of daily accumulated rainfall, GCR flux and ASST, selected the days when the daily rainfall was greater than 10 mm and with the GCR flux greater than 6390 counts/min. The total rainfall for July 1998 was 791.8 mm. The rains occurred on that month had a particularity, as it was observed uninterrupted rains for 40 hours, between the 28th and 30th of July, with a total of 380 mm in that period. The impacts, as a result of these rains, were six deaths, 3,000 homeless people and 70 houses destroyed, with the city hall declaring a state of public calamity.

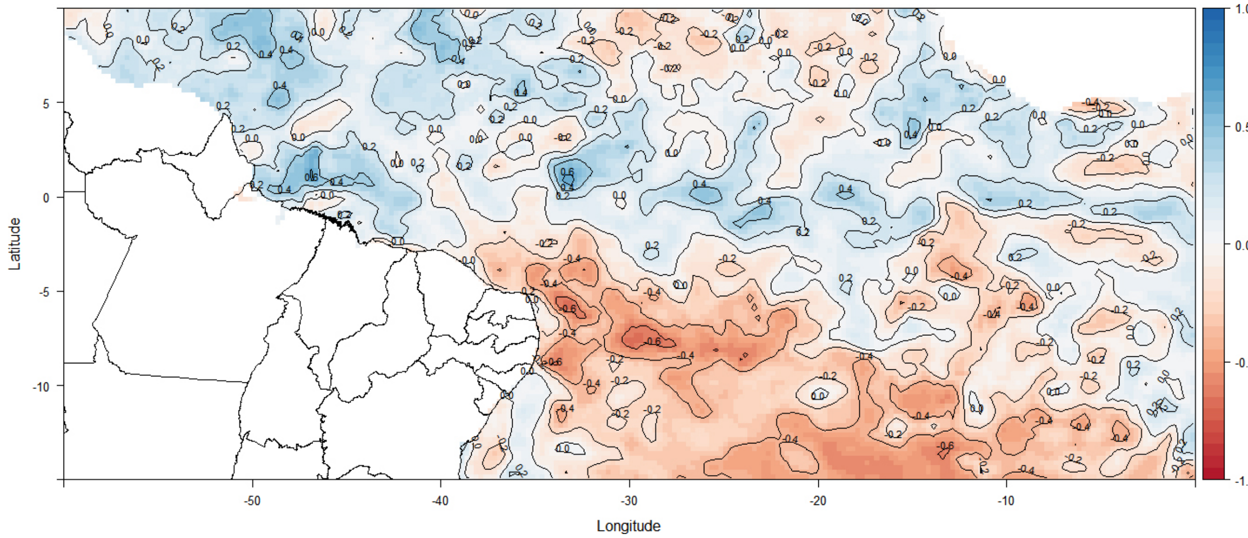

Figure 3. Correlation map of GCR flux with ASST during the period from 01 to 31 July 1998.

The unplanned urbanization especially in developing countries and wide climate changes through global warming increase the risk of natural hazards. Landslide and Floods phenomenon are an important worldwide natural hazard. According to Bradford et al. (2012), the public perception of risk must be in the center of attention, because the authorities' lack of understanding the society is the reason for failure in the politics of flood risk management.

The analysis for July showed that 93% of the rainfall total occurred on the days under analysis, in which the daily rainfall was greater than 10 mm.

The GCR flux oscillates between the 9th and 11th of July 1998, which started to show an increasing trend after that period, reaching its maximum on the 30th of July (Figure 4a). SST showed opposite relation to GCR flux. The increasing trend of positive anomaly in SST was observed from the 9th to the 17th of July, decreasing until the 30th (Figure 4b). The increase in GCR flux after the 17th of July contributes to the reduction of the ASST, where until the 20th the positive ASST is observed.

The increase in GCR flux on the 17th day, associated with the highest positive ASST, caused the daily rainfall to increase to its maximum on the 30th (Figure 4c). Pearson correlation coefficient between GCR flux and rainfall showed a correlation of 0.94, p-value = 0.0005. The correlation between rainfall and SST was -0.76, p-value = 0.0263, both statistically significant.

The increase in GCR flux contributes to the excess of condensation nuclei, which associated with local atmospheric instability, due to the higher SST, which serves as a latent heat and humidity source for the atmosphere. These factors contribute to increase in rainfall from day 17. On July 30, the date when the maximum GCR flux (6,456 counts/min) was obtained, the maximum rainfall was also observed in Natal, with 253.2 mm in 24h. Rains of these magnitudes correspond on average to 50% annual rainfall in some arid and semi-arid regions of NEB (Wanderley et al. 2013).

Rainfalls climatology in Natal shows that the months with rainfall greater than 200 mm occur from March to July. However, for July the climatological normal is 245.4 mm. The rains of the event under analysis, only on the 30th of July was greater than the climatological normal, in one day it exceeded the expected total for the entire month of July.

Climate projections for the rest of the century show continued intensification of daily precipitation extremes. Increases in total and extreme precipitation in dry regions are linearly related to the model-specific global temperature change, so that the spread in projected global warming partly explains the spread in precipitation intensification in these regions by the late twenty-first century. This intensification has implications for the risk of flooding as the climate warms, particularly for the world's dry regions as NEB (Donat et al. 2016).

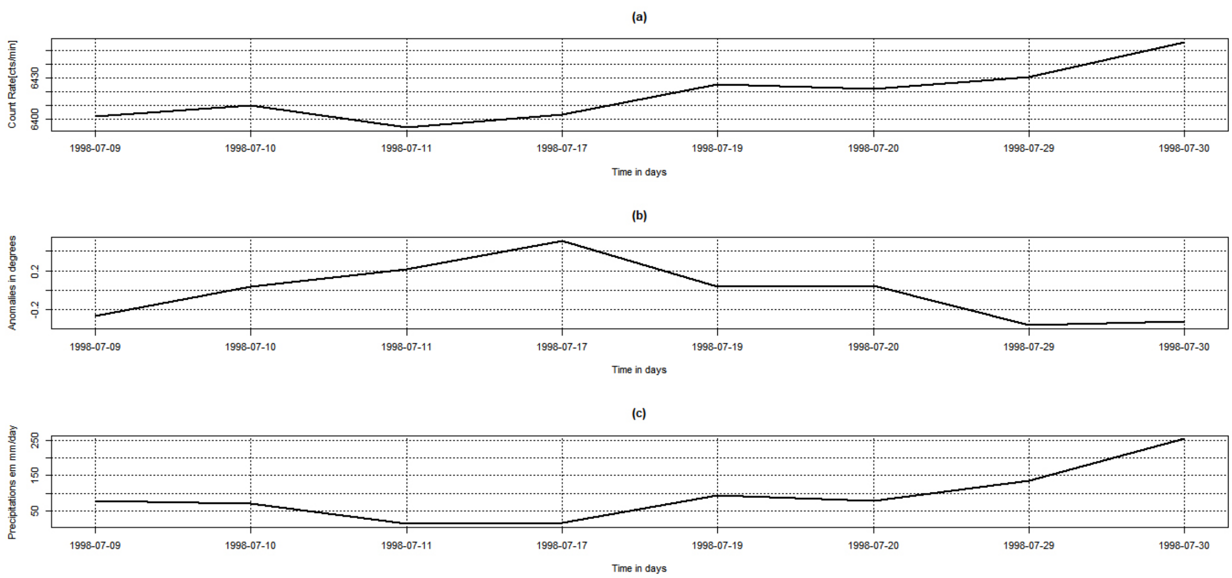

Figure 4. (a) GCR flux, (b) ASST and (c) accumulated daily rainfall for Natal/RN, Brazil, for the respective days.

Given the results obtained in this research, it was necessary to create a linear regression model to measure the impact, in percentage, of each independent variable (GCR, ASST) on the explanatory variable (precipitation). The Multiple Linear Regression Model proposed between rain and GCR flux and ASST variables shows a relationship between GCR flux and positive rain, with a rate of +2.87 mm/count/min. While rainfall rate with ASST was -7.91e + 01 mm/°C. It's observed that the p-value for the proposed model was 0.0007 indicating that the model adopted has statistical significance with a significance level of 5%. Coefficients for Multiple Linear Regression Model can be seen in Table I.

The ANOVA test was applied to the proposed model and it was found that the variable GCR flux, Pr (> F) was 0.0003 and ASST was 0.0702281. Both have statistical significance. The Anderson-Darling test for normality (p-value = 0.3279), Cramer-von Mises (p-value = 0.2988), Lilliefors (Kolmogorov-Smirnov, p-value = 0.3635), Shapiro-Wilk test (p-value = 0.3835) in the Multiple Linear Regression Model residues were used. According to these tests, the residues have approximately normal distribution, with a significance level of 5%. To verify the independence of the data, the Breusch-Godfrey test (p-value = 0.5483) in the Multiple Linear Regression Model was applied, showing that they are independent, with a significance level of 5%.

Rainfall observed series and estimated series according to the model (Prec= (-1.832e+04) + (2.869e+00) * GCR - (7.912e+01) * ATSM), shows that the estimated rainfall was overestimated by 14.92 mm (MAE) in comparison to the observed rainfall, presenting an error of 22.1% (NRMSE) (Figure 5). The predicted and estimated values are well correlated, with a correlation of r = 0.972. The t-test applied to

Table I. Multiple Linear Regression Model coefficients among rainfall, GCR flux and ASST variables for the days 09,10,11,17,19,20, 29 and 30 of July of 1998.

	Estimate	Std. Error	t value	Pr(>|t|)	Sig
Intercept	-1.832e+04	3.266e+03	-5.610	0.00249	*
GCR	2.869e+00	5.089e-01	5.637	0.00244	*
ASST	-7.912e+01	3.448e+01	-2.295	0.07023	
Multiple R-squared: 0.9441	Adjusted R-squared: 0.9217	p-value: 0.0007399			

Signif. codes: '*' 0.01.

the average between observed series and the estimated series by the proposed model did not indicate statistically significant differences between the two series, with a significance level of 5% (p-value = 1). The analysis of variance tested using the Test-F showed that there is no statistically significant difference between its time series, with p-value = 0.9414, at a significance level of 5%. It can be seen in Figure 5 that there was precipitation in relation to the explanatory variables.

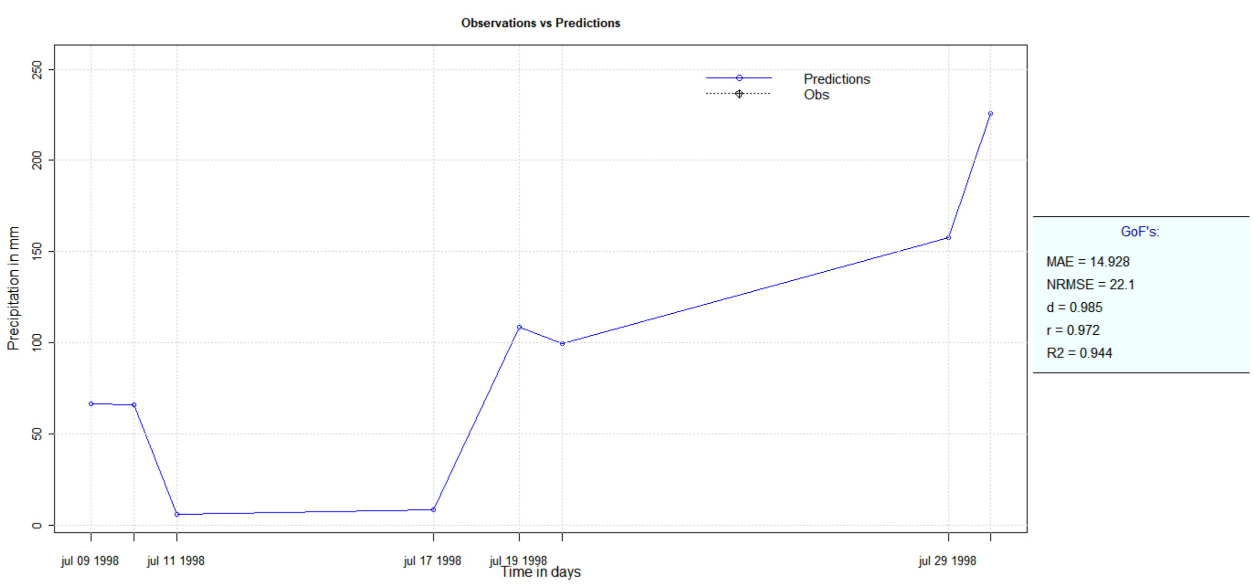

Figure 5. Precipitation observed and estimated by the proposed model and statistics.

The proportion of variance explained by the Multiple Linear Regression Model was 94.41%. The degree of relative importance metrics corresponded to 62.03% for GCR flux and 32.37% for ASST, respectively (Figure 6). The results show that GCR flux had a greater contribution to rainfall in the metropolitan region of Natal-RN. These proportions have a great impact on precipitation, now, with these results, they reveal the great influence of the GCR flux on short scales and such great importance in the formation of extreme precipitation events.

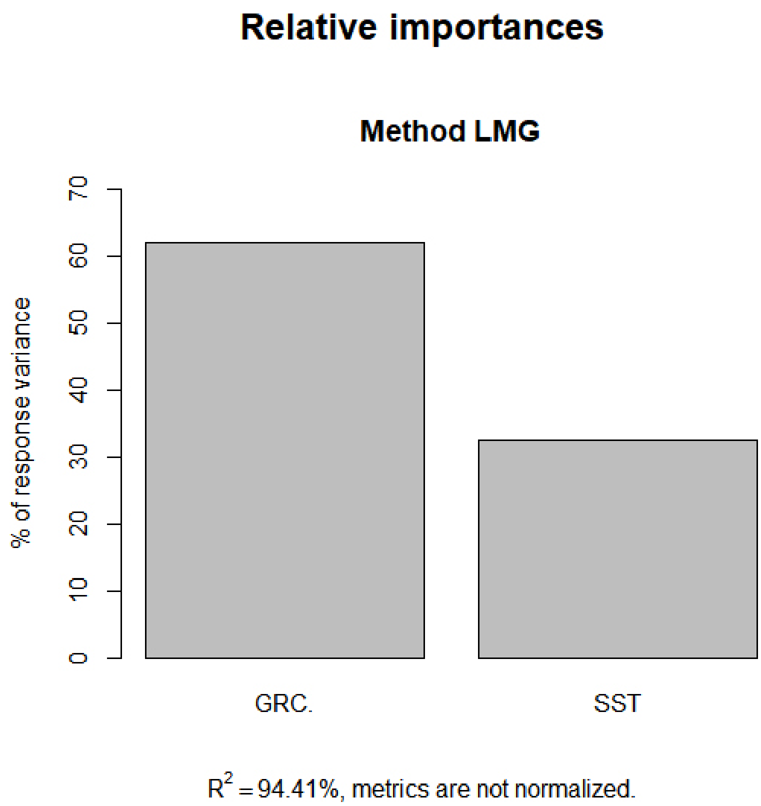

Figure 6. Degree of importance of each variable in the proposed model.

CONCLUSIONS

This research reveals the degree of importance in the GCR flux interaction with rainfall in relation to an extreme event. This variable (GCR) is considered irrelevant in climate sciences studies, among others, however, without an understanding of this interaction, it can sometimes be reduced to facts only. It is worth mentioning that CN attenuation due to the GCR-Atmosphere interaction brings us closer to a climate understanding. Without the insertion of this variable in the present and future time, it can lead to a delay or lack of understanding of this complex system that´s involve the atmosphere and rainfall. In this study, the importance of this variable for rainfall in Natal/RN, Brazil, is about 62%. While studies show that cloudiness varies around 3-4% between the minimum and maximum solar. This work reinforces the need to insert this variable on a smaller scale and how it interacts with the meteorological systems that produce rainfall. Therefore, it is necessary to insert this variable in studies that involve extreme climate and weather events for the present and future time.

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