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TRENDS IN THE HYDROMETEOROLOGICAL REGIME ON AN ISLAND IN THE SOUTH ATLANTIC OCEAN

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ABSTRACT: The aim of this study was to analyze trends in precipitation and temperature on Trindade Island, South Atlantic Ocean. Time series from 1984 to 2008 for precipitation and from 1958 to 2008 for air temperature were analyzed. The regression analysis and Mann-Kendall test were used to test the trend in annual and seasonal scale of precipitation – January, April, July and October, which represents the middle months of summer, autumn, winter and spring, respectively, as well as for maximum and minimum air temperature. Results indicated that for precipitation time series there was no significant trend, while for minimum air temperature there was a significant trend to decay. In addition, no significant trend was found for maximum air temperature.

KEYWORDS: Climatology, Precipitation, Air Temperature.

TENDÊNCIAS NO REGIME HIDROMETEOROLÓGICO EM UMA ILHA OCEÂNICA NO OCEANO ATLÂNTICO SUL

RESUMO: O objetivo desse estudo foi analisar tendências nas séries históricas de precipitação e temperatura na ilha da Trindade, Oceano Atlântico sul. Foi utilizada uma série histórica de 1984 a 2008 para precipitação e de 1958 a 2008 para temperatura do ar. A análise de regressão e o teste de Mann-Kendall foram utilizados para testar a tendência da precipitação nas escalas anual e sazonal, janeiro, abril, julho e outubro, que representam os meses centrais do verão, outono, inverno e primavera, respectivamente, da precipitação máxima diária anual bem como para análise das séries de temperaturas máxima e mínima anual. Os resultados indicaram que para as séries de precipitação não houve tendência significativa de alteração, enquanto que para a série de temperatura mínima, ocorreu tendência significativa de decaimento. Nenhuma tendência significativa foi identificada para as séries de temperatura máxima do ar.

PALAVRAS-CHAVE: Climatologia, Precipitação, Temperatura do Ar.

1. INTRODUCTION

The assessment and understanding of changes in temporal series of weather elements are one of the most important concerns to understand the impacts of human activities on the environment. Normally, the weather elements are assumed as statistically stationary (ALEXANDRE et al., 2010). However, this assumption cannot occur when addressing issues such as change in land cover and use, global climate change and seasonal global climate phenomena, such as La-Niña and El Niño.

Cunha et al. (2013) report that in processes related to land use changes, the climate can be affected. Souza and Oyama (2011), Yanagi and Costa

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

(2011), Oliveira (2008) and Xue et al. (2004) justify this feature because the atmosphere is sensitive to the characteristics of the land surface.

According to Cunha et al. (2013), the impacts of land use changes, such as changes in regional and global climate through biophysical and biogeochemical processes, may be especially noticeable because of the changes related to surface radiative properties (albedo). The energy balance and the exchange of sensible and latent heat between the surface and the atmosphere can be strongly affect by changes in land-use. Some authors show that even small changes in surface albedo can significantly affect the exchange of water and energy between the surface and the atmosphere. Such changes result in alterations in the pattern of air temperature, vapor pressure, atmospheric stability and cloud and rainfall formation (Twine, 2004; Clark et al., 2001).

According to the global climate models presented in the IPCC (Intergovernmental Panel of Climate Change), it is expected an increase in the global temperature between 1.4 and 5.8°C, representing a marked warming in relation to that already is observed in the 20th century (MARCOTT et al. 2013). In this context, Brazil has a high degree of vulnerability to these possible changes in climate, especially if one takes into consideration the current climate change projections (SOLOMON et al., 2007).

It is observed that the application of techniques to study possible changes in weather patterns, mostly relating to precipitation and temperature, notably, average, maximum and minimum value, is of fundamental importance for understanding climate over time. Several techniques can be employed for this purpose, especially climate models of global and regional circulation and application of statistical methods. Regarding the statistical methods, Avila et al. (2014) argue that the Mann Kendall and linear regression modeling are the most commonly used procedures.

This kind study has been widely used in continental areas and oceanic islands in the South Pacific, however, any study is found on the oceanic islands of the Tropical South Atlantic conditions. Thus, it revels the need and the importance of a monitoring program in this environment and the accompanying of the climatic behavior, allowing a better understanding of possible changes in the hydrometeorological regime. In addition, this kind study can also support activities related to the weather forecasting, being important source of data sets available for calibration model process.

Thus, the objective of this work is to perform trend analysis of the precipitation patterns and air temperature behavior on the oceanic Trindade Island, located in the tropical South Atlantic Ocean.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

2. MATERIAL AND METHODS

The study area is the Trindade Island, located in the tropical South Atlantic Ocean (Figure 1).

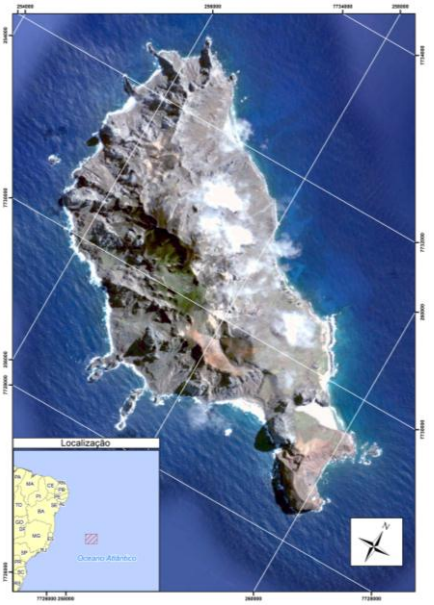


Figure 1. Map of the location of Trindade Island.

The Trindade Island cover an area of 9.2 km², and is located in the South Atlantic Ocean at about the latitude of the city of Vitória, Espírito Santo, far from the coast 1,140 km, at coordinates 20°29-32' S de 29°17-21' W. The submerged part of the island, in the form of an eroded summit, rests on the sea floor about 5,500 m deep (CASTRO and ANTONELLO, 2006), the highest points above sea surface presenting an altitude of approximately 600 meters.

The climate is tropical oceanic, with a mean annual temperature of 25° C, February being the warmest (30° C) and August the coolest (17° C) (MOHR et al., 2009), with an annual average precipitation of 923 mm, but very seasonal (CLEMENTE et al., 2009). Between April and October, the island undergoes effects of periodic cold fronts coming from Antarctica rising through Argentina and southern Brazil and upon arriving in the Southeast region, moves towards the ocean and reaches Trindade, causing abrupt changes in sea conditions.

The weather elements applied to the study (precipitation and air temperature) were extracted from the database of Trindade Island Oceanographic Station (POIT), code 83650, of the 1st Naval District (DN 1) and provided by the Hydrography and Navigation Board (DHN) of the Brazilian Navy, located at 20°31'29" South latitude and 29°19'29" West longitude, covering the period from 1954 to 2008, installed 12 meters above sea level.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

Although there are precipitation records dating from 1925, rainfall data sets from 1974 to 2010 was made available, with gaps observed for the years of 1982 and 1983, therefore, it was decided to use the precipitation time series from 1984 to 2008. Regarding the temperature data (maximum and minimum), it corresponds to the period of 1958-2008, for a total of 50 years of flawless records.

The assessment of the trend in the variation of the maximum and minimum temperature and annual, seasonal, annual maximum daily rainfall and historical series, was conducted on the basis of the non-parametric Mann-Kendall test (MANN, 1945; KENDALL, 1975) and linear regression analysis. For the seasonal scale, it was used the data for the months of January, April, July and September, which represents the core months of summer, autumn, winter and spring seasons, respectively, to study trend in the temperature series (Avila et al., 2014) as well as for rainfall data at this scale. At the annual scale, it was used the extreme values for temperature and total annual values for precipitation.

The Mann-Kendall (MK) test was firstly proposed by Sneyers (1975). Back et al. (2012) emphasize that this test has been frequently used to identify trends in time series of the climate variables. According to Goossens and Berger (1986), the MK test is considered the most appropriate to analyze trend changes in climate data, since it allows the detection and approximate location of the starting point of a particular trend. This test considers the hypothesis that the sequence of values in a time series occurs independently and its probability distribution remains the same (simple random number). The null hypothesis is rejected when there is a significant trend in the time series at a given significance level (usually 5%, which returns a Z absolute value of 1.96). Thus, positive values of the MK coefficient indicate a growth trend for the variable analyzed, while negative values indicate a decrease of this variable. Thus, if the MK test statistic is greater than |1.96|, the null hypothesis is rejected and the alternative hypothesis, that there is a significant trend in the number of evaluated data, is accepted.

The MK test, as presented by Silva et al. (2010), is calculated by:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \quad (1)$$

Where x_j is the estimated data of the sequence of values, n the length of the time series and the sign (x_i-x_j) is equal to -1 for (x_i-x_j) < 0; 0 for (x_i-x_j) = 0 and 1 for (x_i-x_j) > 0.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

Kendall (1975) demonstrated that *S* is normally distributed with mean E (*S*) null and variance Var(*S*). In a situation where there can be equal values of x, E (*S*) and Var (*S*) are calculated by the equations:

$$E[S] = 0 \quad (2)$$

$$Var[S] = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (3)$$

Where t_p is the number of data with equal values in a certain group (*pth*) and *q* is the number of groups containing equal values in the data series in a certain group *p*. The second term represents an adjustment for censored data.

The parametric statistic of the test (Z_{MK}) is calculated by the following equation:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; se \; S > 0 \\ 0 \; se \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \; se \; S < 0 \end{cases} \quad (4)$$

Complementarily, linear regression analysis was conducted, checking the slope of the line adjusted to the data series that showed trends by the MK test. Furthermore, regression analysis allows the estimation of the rate of minimum and maximum temperature increase or decrease in the decadal trends, as proposed by Back et al. (2012). For this test, it was adopted a significance level of 5%, having applied Student's t test for comparison with the critical value, considering n-2 degrees of freedom (WILKS, 1995).

3. RESULTS AND DISCUSSION

Figure 2 shows the rainfall behavior of the Trindade Island in terms of monthly average and standard deviation values.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

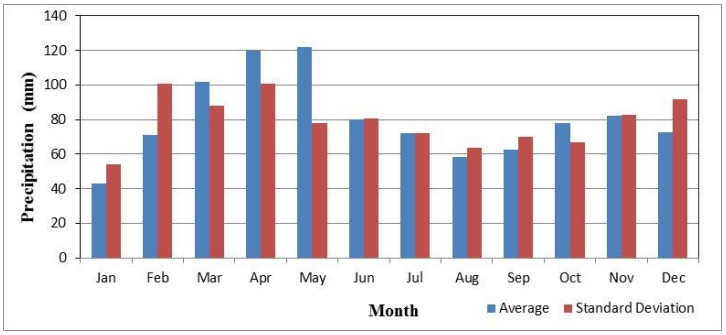


Figure 2. Mean and standard deviation of monthly rainfall for the historical time series from 1984 to 2008.

From the analysis of the annual precipitation time series, a maximum value of 2,578 mm was found, that occurred in 2008, and a minimum value of 479.1 mm in 2006, while the average rainfall was 963.5 mm. According to the results presented in Figure 2 and considering the seasonal series, the rainiest seasons, in terms of average values, are the autumn and spring, being the summer, the driest. This behavior can be associated to, according to Reboita et al. (2010), the oceanic climate which is conducive to the formation of rain clouds, unlike what happens over the continent, which is under the influence of areas of high atmospheric pressure and atmospheric blockages in the tropical latitude ranges, especially in winter.

In Figure 2, a high standard deviation can also be noted, which represents a high dispersion of data around the average for all months of the year. This behavior can be explained by climate characteristics associated with greater availability of steam water to form rain clouds under ocean conditions, especially cumulonimbus and convective rainfall events.

Considering the time series of monthly average maximum and minimum temperatures from 1958 to 2008, it is observed that the highest average maximum temperature values occur between January and April, while the lowest values for minimum temperatures between July and October (Figure 3). However, no differences between summer and winter months are observed. The average maximum and minimum temperatures were 27.5°C and 24.6°C respectively. Considering the pattern of monthly series of maximum and minimum temperature, shown in Figure 3 offset values, there was little variation, in average terms, in the two time series.

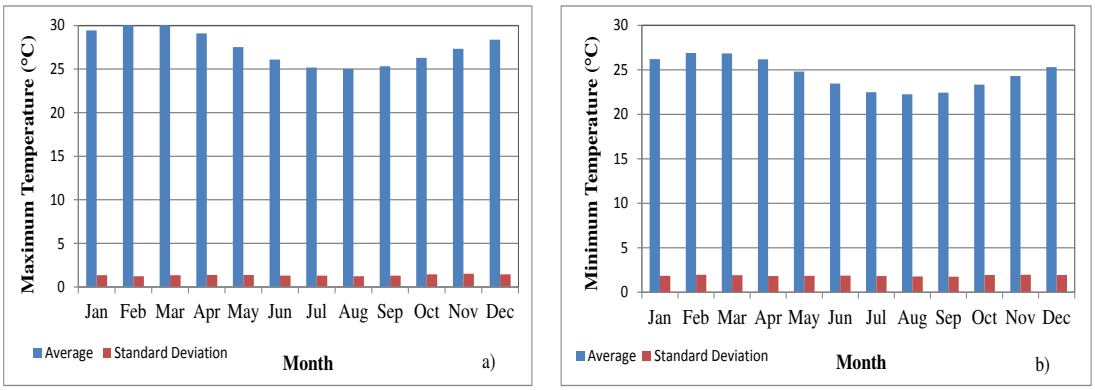


Figure 3. Basic descriptive statistics regarding the average and dispersion of maximum (a) and minimum (b) temperatures in the Trindade Island, South Atlantic.

Extreme rainfall events have received special attention in the literature in the fields of climatology and hydrology due to their potential to cause soil water saturation, runoff, flooding and soil erosion (BLAIN, 2013). As Trindade Island has undergone a strong process of degradation and suppression of native vegetation and nowadays there is an advanced stage of degradation (CLEMENTE et al., 2011), in order to an environmental recovery process to take place, studies of the behavior of these extreme events makes an important contribution to decision-making and soil erosion control practices.

Furthermore, on the process of deforestation, Yanagi (2006) conducted a study considering different levels of deforestation of tropical forests (25, 50 and 75%), through the substitution of different types of vegetation cover and showed that there is a considerable effect on the radiative processes and consequently the formation of rain. The results of this study showed that changes in precipitation are linearly related to the anomalies of net surface radiation and the change in precipitation due to radiative mechanisms. The basic mechanism proposed for the reduction of rainfall after tropical deforestation begins with the decrease in net surface radiation due to increased albedo after deforestation.

Considering non-radiative effects of the deforestation processes in the Amazon region, such as decreasing the roughness length, leaf area index and root depth, causes a decrease in latent heat flow and consequently an increase in surface temperature, leading to atmospheric instability, cloudiness and precipitation. On the other hand, the radiative effects caused mainly by the increase of the surface albedo, causes a reduction in heat flow from the surface, resulting in a loss of energy by radiation from the surface of the Amazon, with consequent reduction in convection, cloudiness and precipitation (YANAGI, 2006). However, it was not possible to observe these non-radiative effects in the rainfall time series in this study, because the rain is predominantly regulated in function of the ocean evaporation processes and Cumulus type cloud formation.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

After observing these historical series, statistical analysis was conducted to detect possible trends in these series, using the Mann-Kendall test and the presence of a trend was not detected (Table 1). Since the null hypothesis was accepted, the linear regression test was not performed.

Table 1. Results of the statistical series for precipitation tests.

Precipitation	S	Z_{MK}	t-Student
Total Annual	-36	-0,817	0,45
Maximum Annual Daily	-6	-0,117	0,523
January (Summer)	-22	-0,49	1,06
April (Autumn)	-4	-0,07	0,274
July (Winter)	-46	-1,051	0,194
September (Spring)	-48	-1,098	-0,279

Alexandre et al. (2010) conducted a study on trends in rainfall patterns over the metropolitan region of Belo Horizonte, Minas Gerais state, Brazil, and according to the results there was a possible trend of increased rainfall during the dry season (April to September), in contrast to a declining trend of rainfall in the rainy season (October to March). These authors call attention to such studies, for which care must be when pointing to climate changes as the cause of natural disasters currently observed, given the complexity of the dissociation of these changes from natural climate variations.

In terms of annual maximum daily precipitation, relevant for extreme event behavior studies, we observed a maximum value of 187 mm, averaging 96 mm for the period. Similarly, the presence of a trend in time series was not detected.

Blain et al. (2009) studied the sampling variability of the monthly series of rainfall in two regions of Brazil (Pelotas - RS and Campinas - SP). The authors found no indications of any kind of trend (increase or decrease) in rainfall by applying the likelihood ratio test.

Analyzing the trend of monthly and annual precipitation in the Brígida river basin in Pernambuco, Fechine and Galvíncio (2009) concluded that the series analyzed showed no trends in precipitation, reinforcing that these series have high climatological consistency.

The temporal distribution of rainfall, on annual and seasonal scales, as well as the annual maximum values are displayed in Figure 4.

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

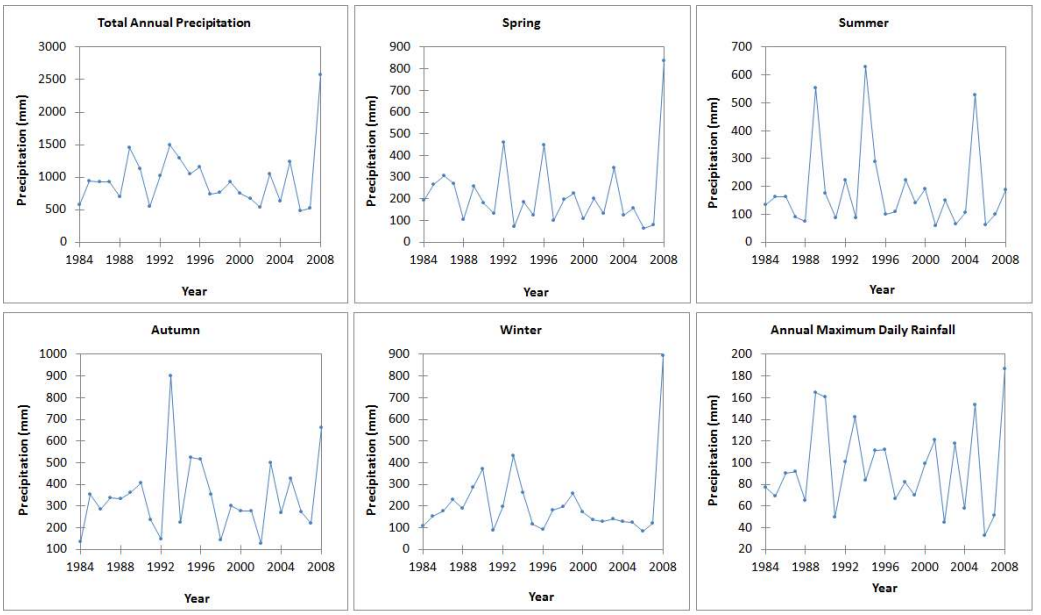


Figure 4. Temporal distribution of rainfall on Trindade Island, tropical South Atlantic Ocean.

For the series of the maximum and minimum air temperature, analyzes were conducted on the annual and seasonal scales (Figure 5), with the results of the statistics for the selected series presented in Table 2, for the series with presence of trend.

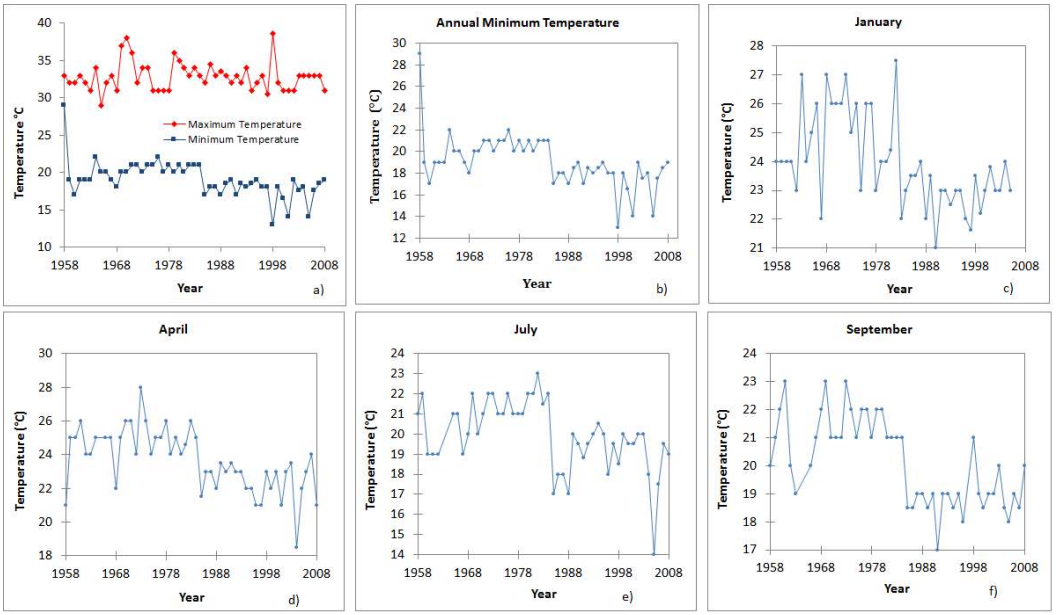


Figure 5. Behavior of the annual maximum and minimum temperature (a); minimal annual (b); and minimum for the central months of the seasons of the year (c, d, e, f).

ISSN: 1980-055x (Impressa) 2237-8642 (Eletrônica)

Table 2. Results of statistical tests for minimum temperatures.

Temperature	S	Z_{MK}	t-Student	Regression model
Annual Average	-454	-3,68	4,73	y = -0.0887x + 194.92
January (Summer)	-397	-3,52	3,08	y = -0.0539x + 131.01
April (Autumn)	-536	-4,47	4,25	y = -0.0714x + 165.22
July (Winter)	-340	-2,92	3,58	y = -0.054x + 126.5
September (Spring)	-479	-4,25	4,15	y = -0.0664x + 151.77

From the results shown in Figure 5 it was possible to observed a tendency in the series, both on the annual scale, as well as on the seasonal scale, simultaneously with the Mann-Kendall test and by regression analysis. For the month of January (summer), a significant downward trend in minimum temperature was evident, with a rate of -0.53°C per decade. The minimum temperature in April (autumn), July (winter) and September (spring) also tended to decrease, with a rate of -0.71°C, -0.54° C and -0.66°C per decade, respectively, for the months of April, July and September. On the other hand, there was no trend for maximum temperatures by both tests. For the annual series, there was a minimum temperature reduction trend at a rate of -0.88°C per decade, and for the maximum temperatures, any trend was not found.

This behavior for minimum temperature for Trindade Island contradict those found in other regions of the world where there is a predominance of the increase in maximum and minimum temperatures. The study by Jones and Moberg (2003) concluded that the average air temperature increased by 0.7° C in the twentieth century and that of Jones et al. (2001) showed that warming occurred in two periods, the first from 1910 to 1945 and the other at the end of the 1970s until the late XX century.

According Molion (2005), the observed warming in recent decades can be attributed to changes of Pacific Ocean anomalies from negative to positive in the mid-1970s, suggesting the influence of phenomena on a planetary scale. However, Collins et al. (2009) argue that the changes verified over the South American continent is not primarily a response to variations in the ENSO (El Niño Southern Oscillation), but a function of some other kind of climate variability as well as human activity.

Also in this context, Chung and Yoon (2000) pointed out that from 1974 to 1997 in South Korea, the average annual temperature in large urban centers increased by about 1.5°C, while at marine stations and those located in rural areas, the increase was lower, about 0.58°C, thus demonstrating the effect of albedo on temperature. However, what was observed for Trindade Island was a decreasing trend in minimum temperature, which may be due to the sea

breezes that operate on the Island, however, it does not explain the fact of a change in the temperature patterns occurring from 1985, since deforestation dates from the late eighteenth century (SERAFINI et al., 2010).

Considering the oceanic environment in which Trindade Island is inserted, Safeeq et al. (2013) analyzed the temporal and spatial pattern of rain on the island of Oahu in Hawaii and observed a significant warming on both an annual and seasonal scales. In this study, the authors found an increase of 0.17°C per decade in the minimum temperatures, considering the period 1969-2007, while for the maximum temperature series, there was no detection of variation in the pattern of the series.

On the other hand, Malamud et al. (2011) conducted a study to assess the hourly temperature patterns in Mauna Loa, also in Hawaii. For the night period, they found uniform temperature increase at a rate of 0.04°C per year, however, for the daytime, a mild cooling at a rate of -0.014°C per year was observed.

According to Minuzzi et al. (2011), on the regional scale, these changes are very divergent and do not always accompany the global trend, mainly the temperature, which for the Trindade Island, can explain this decreasing pattern of the minimum temperature. In this regard, the results of this study demonstrate the importance of analyzing the climate behavior under different conditions, especially oceanic islands, which are under different conditions from those observed for the continent, since there is a very relevant aspect in the latter, which is the increase of urbanized areas and their effects on local climate. This situation does not occur in environments like oceanic islands, hundreds of miles from the coast, demonstrating that this work brings unprecedented contributions to the understanding of global climate conditions.

4. CONCLUSIONS

The results found for the temperature time series on Trindade Island showed that there is a trend towards a decrease of minimum temperatures;

In terms of precipitation, no trend in the rainfall pattern, both on the annual scale as well as seasonal, was observed;

The absence of forest type vegetation revealed no change in the weather patterns of the island, nor in the rain formation process.

5. ACKNOWLEDGMENT

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