

Trend analysis of the reference evapotranspiration for the southwestern Amazon, Brazil

Helder J. F. da Silva^{*}, Paulo S. Lucio^{**}, Irving F. Brown^{***}

^{*}Meteorologista, doctoral student in Climate Sciences, Federal University of Rio Grande do Norte, Natal, Rio Grande do Norte, Campus Academical, s/n, CEP: 59072-970, Natal, Brazil.

^{**}Coordenador of the Graduate Program in Climate Sciences, Associate Professor of Statistics Department, Federal University Rio Grande do Norte, Campus Academical, s/n, CEP: 59072-970, Natal, Rio Grande do Norte, Brazil.

^{***}Docente the course of Master in Ecology and Natural Resource Management, Federal University of Acre, Campus Universitário - BR 364, Km 04 - Distrito industrial - CEP: 69.920-900, Rio Branco, Brazil.

Abstract

The changes in climatic conditions can affect demand of water in regions because the evapotranspiration is affected by changes weather elements. The goal of this study was to identify possible trends in the reference evapotranspiration (ET_o) to Acre State, with study units to Rio Branco locations (Acre's capital), Tarauacá and Cruzeiro do Sul considering a period of 30 years, using monthly meteorological stations data. The methodology was adopted to achieve meteorological consistency data, in this way was made the gap filling in the time series by means of multivariate techniques. The trend analysis was performed using the Mann-Kendall nonparametric and your magnitude through the Theil-Sen test. The indirect method of Penmann-Montheith was used to calculate the ET_o. It was found that there is upward trend in ET_o at the autumn, winter and spring seasons and that became a significant through the years 1990, 1996 and 2001 to cities of Cruzeiro do Sul Tarauacá and Rio Branco, respectively. The average temperature datasets, minimum temperature, solar radiation and global solar radiation showed upward trend at 5% significance for all that three locations. These being the main responsible for the increase in ET_o in these locations.

Keywords: Climate variability, Penman-Monteith, Mann-Kendall test.

1. Introduction

The Evapotranspiration (ET) is the combined loss of water from the soil by evaporation (E) and plant transpiration (T). It is the joint transfer of water from the liquid or solid state to the vapor state and stomatic transpiration of the vegetables by means of sheets (Ometto, 1981; Sentelhas and Silva, 2013). Pereira et al. (1997) define the ET as a fundamental element of weather, which is the opposite of rain process and is also expressed in millimeters. It is estimated that, by ET, 60-80% of the precipitate volume returns to the atmosphere in tropical forest areas, a fact which gives it the status of

primary regulator of water, surface and groundwater availability, as well as the most diverse activities human, for example, agriculture (Victoria, 1998).

Currently, it is essential to understand how changes in meteorological elements are changing the climate regime in a region. One way to check this change would observe the existence of trends. According Some'e et al. (2012) the tendency can be understood as a continuous and systematic changing observed in a time series, which reflects the degree of increase or decrease in the values of the variable. The presence of trends in time series (each and every set of time ordered data) may show

evidence of how the observed data are reflecting the effect of climate change, whether natural or not.

According to Allen et al. (1998) the reference evapotranspiration (ET_o) is set to a reference surface that describes the atmospheric evaporative demand regardless of the culture, stage of development and form of management. Alencar et al. (2014) point out that in recent years studies have been conducted using prediction models on climate change in order to examine the impact of these on the ET_o, where results showed that ET_o to increase in coming years, whenever there temperature increase (Espadafor et al., 2011). In Brazil growing trends in ET_o were detected in the Northeast (Silva, 2004), Uberaba-MG (Alencar et al., 2012) and Catalan in Goiás (Alencar et al., 2014). However, downward trends have been observed in some parts of America (Hobbins et al., 2004), Europe (Mcvicar et al., 2012) and Asia (Xu et al., 2006; Yin et al., 2010). In Brazil we were also detected declining trends in Viçosa, Minas Gerais (Alencar et al., 2011) and Rio Grande do Sul (Cordeiro, 2010).

Technological advances and population growth coupled with urbanization, pollution, deforestation, among other things, require the need for various natural resources often involving the depletion of same. This entails the modification of the biotic and not biotic natural elements of a region, damaging different climatic elements (Alencar et al., 2014). The ET_o is conditioned especially by the air temperature, wind and solar radiation, and other weather elements [Allen et al., 1998]. Thus, variations in these elements may change the ET_o through the time. However, identifying such modifications is not an easy task to accomplish. Once ET_o is complex function, non-linear, many meteorological parameters, the changes in one of them may modify another parameter; thus, the effect of such changes on ET_o is difficult to understand (Dinpashoh et al., 2011).

Brazilian tropical biomes, the Amazon in particularly, have been the focus of the world attention due to its high biological diversity, and the deforestation effects, land using and occupation on a large scale may be causing in climate, hydrology and biogeochemical cycles in regional and global scales (Cavalcante et al., 2013). Climate trends studies in the Amazon,

mostly have been focused on variables such as rainfall, flow and temperature (Fisch et al., 1998; Gash et al., 1996; Marengo, 1992; Marengo, 2008). But many of these research results are generalized to the entire Amazon.

Other studies also have been dealing with climatological meteorological and hydrological variables, using statistical tests such as the Mann-Kendall test, linear regression and Sen slope estimator to characterize and identify trends in environmental variables (Ferrari et al., 2012; Fontolan et al., 2012; Santos and Silva, 2013). We have not been observed works that have used observational data to detect trends specifically in ET_o of Amazon biome and therefore it is necessary to fill this gap.

The studies found in the literature focused on Acre the state, southwestern Amazon, as concern the ET_o studies have been done focusing to evaluate performance of the simplest methods to ET_o estimate and compare it with the Penman-Monteith (Ferraz, 2008 and Souza, 2009). Recently, Silva et al. (2015b) characterized ET_o for the state of Acre. However, there are no published studies that have explored the trend existence and ET_o distribution in a seasonal space-time and interannual scales for southeastern Amazon region.

Considering this, and the aims to fill the gap, it is clear the importance of analyzing the existence of climate change in the Amazon biome order determining their approximate dates of occurrences and their statistical significance. Therefore, this study aims to investigate the existence of trend in the distribution space-time reference evapotranspiration and weather elements that condition to the Acre state for a period of 30 years, with the research units of the Rio Branco municipalities (east of Acre), Tarauacá (midwest of Acre) and Cruzeiro do Sul (west of Acre). This information is critical to environmental risk management, water resources management, hydrological modeling, agro-meteorological and climate studies related to atmospheric phenomena and climate change, among other applications.

2. Materials and Methods

2.1 Study Area

The study area corresponds to the state of

Acre which is located in the extreme southwest of the Brazilian Amazon, between latitudes 07° 07' S and 11°08' S and longitude 66°30' W and 74° W. It presents a land area of 164,221.36 square kilometers, accounting for 4% of the Brazilian Amazon, and 2% of the country. It has a territorial extension of 445 km in north-south direction and 809 km east-west between its extremes. The state makes international border with Peru and Bolivia and has state lines with the

states of Amazonas and Rondônia (Figure 1). The state's population is ~733,559.000 hab, with a current concentration of 66% is in urban areas (ACRE, 2010; IBGE, 2014).

The five most populous cities in the state are: Rio Branco, the capital, the Cruzeiro do Sul, Sena Madureira, Tarauacá and Feijó (Table 1). These regions are accessible by land by BR 364 (ACRE, 2010).

Table 1 - Most populated municipalities of the state of Acre, in bold towns object of study.

Rank	Cities	Population	Areas (Km ²)
1°	Rio Branco (AC)	336.038,00	8.835,541
2°	Cruzeiro do Sul (AC)	78.507,00	8.779,391
3°	Sena Madureira (AC)	38.029,00	23.751,494
4°	Tarauacá (AC)	35.590,00	20.171,053
5°	Feijó (AC)	32.412,00	27.974,890

Source: IBGE (2014)

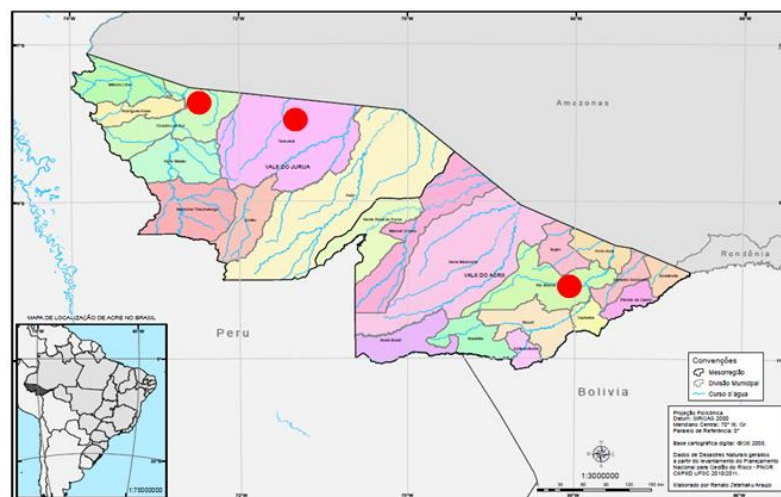


Figure 1 - Acre state located in South America and Brazil and location of municipalities used in the study (red circles). Source: ZEE (ACRE1010100 k

The eastern region of the state, where is capital, is most favored in terms of administrative infrastructure, health services and other sectors that polarize life in the region and throughout the state. This region has many agrarian reform settlements and cattle ranches and human occupation is denser. Occurs in the area a network of branch lines and highways that support economic activities between the municipalities of the region, with significantly amended in your own original vegetation (ACRE, 2010). The extractive activity and agriculture stand out on the basis of Acre's economy, which revolves around commodities,

although it has a modest degree of industrialization. Rubber, also called white gold, stood out as flagship on the agenda of Acre exports until the 1970s (PROSER, 2012).

The state of Acre climate is basically equatorial humid, towards the south and east, and super humid at north and west facing the state. In the first region, there is little or moderate water stress, while in the second there is virtually no mineral absence. The average annual rainfall is around 2,000 mm. During May-September rainfall decrease due to increased atmospheric stability, and the more pronounced dry season occurs from July to

August (ACRE, 2010). The average temperatures are in the range of 22°C to 25°C, although occasionally suffer state penetrations polar Antarctic anticyclone causing the "chill" phenomenon as it known. In these periods, the minimum temperatures go below 10°C. The air relative humidity average varies monthly of 77.6% (August) to 87.6% (February), with an annual average of 84.3% (Duarte, 2006).

Meteorological monthly data were extracted from database of National Institute of

Meteorology (Instituto Nacional de Meteorologia - INMET) through the Bank of Meteorological Data for Education and Research (Banco de Dados Meteorológicos para Ensino e Pesquisa - BDMEP) for period January 1985 to December 2014 (30 years), measured in conventional weather stations installed in Cruzeiro do Sul, Tarauacá and Rio Branco cities, as Table 2 is showing. This period is justified by present consistent values and less failures in the data set.

Table 2 - Meteorological station information.

Municipalities	Lat.	Lon.	Altitude (m)
Cruzeiro do Sul (AC)	7°38'48'' S	72°40'12'' W	170
Tarauacá (AC)	8°10'36'' S	71°46'12'' W	190
Rio Branco (AC)	9°58'36'' S	67°52'12'' W	160

Source: INMET (2014)

2.2 Data and procedures

The meteorological variables used in the state are listed below along with their acronyms (abbreviations) and their respective units of measure: average temperature compensated (Tmed, °C), mean maximum temperature (Tmax, °C), minimum temperature (Tmin, °C), relative humidity (RH, %), insolation (n, hours), atmospheric pressure at station level (Pres. hPa), the mean wind speed (u_2 , m s⁻¹), global solar radiation (Rad., W m⁻²) and pluvial precipitation (prp, mm).

Data solar radiation incident are not available in the INMET database, so were estimated based on the monthly isolation time through the formula of Angstrom (1924), according to the estimates summarized in Ometo (1981) and Silva et al. (2015a).

For gap filling in meteorological data, was used in this study the MTSDI (Multivariate Time Series Data imputation) which is an algorithm to fill missing data series multivariate normal time, based on the Expectation

Maximization (EM) algorithm, proposed by Junger and Leon (2012). In the correlation structure between the stations considered in the covariance matrix of data, the method also considers the temporal correlation by means of independent modeling of time series at each station.

Silva et al. (2015a) describes the method featuring the missing data you want to complete by "NA", and used the number of imputations multiple standard version 2.15 of *mtsd* statistical software package R (R, 2013). The original variable weather series failed is placed side by side from the nearest stations of locality as an array. As predictor variables, have been used meteorological variables series time by Air Force Command of the Meteorological Network (REDEMET, 2014), available at Generation System and Availability of Climatological information (Table 3). Table 3 shows the geographical location of stations and their source.

Table 3 - Information on weather stations used as an aid in completing missing data (predictors)

Cities	Acronyme	Source	Lat. – Lon.	Altitude (m)
Plácido de Castro (AC)	rbr-rede	REDEMET	09°58' S - 67°48' W	136
Cruzeiro do Sul (AC)	crz-rede	REDEMET	07°36' S - 72°46' W	191
Porto Velho (RO)	rond-rede	REDEMET	08°42' S - 63°54' W	88

Following were estimated reference evapotranspiration series (ET_o) by Penman-Monteith-FAO, parameterized and recommended as standard by the Food and Agriculture Organization (FAO) for present itself consistently to estimate the ET_o in different locations and weather in addition to considering all the parameters that govern the energy exchanges and the latent heat flux (Allen et al., 1998).

The Penman-Monteith-FAO is given below:

$$ET_o = \frac{0,408 \Delta (4n - G) + \gamma \left(\frac{900u_2}{T_{med} + 273} \right) (e_s - e_a)}{\Delta + \gamma(1 + 0,34u_2)} \quad (1)$$

where, ET_o is the reference evapotranspiration (mm d⁻¹), R_n is the net radiation culture surface (MJ m⁻² day⁻¹), G is the ground heat flux (MJ m⁻² day⁻¹), T_{med} is the average daily air temperature measured 2 meters tall (°C), u₂ is the wind speed measured at 2 meters tall (m s⁻¹), e_s is the saturation vapor pressure (kPa), e_a is current steam pressure (kPa), Δ is the slope of the vapor pressure curve (kPa °C⁻¹) and γ is the psychrometric constant (kPa °C⁻¹).

The details and standard equations for calculating all parameters of equation (1) were performed as shown in Allen et al. (1998) and described in Fernandes et al. (2010).

Trend analysis of time series was performed using the Mann-Kendall test (Back, 2001). This non-parametric test is suggested by World Meteorological Organization (WMO) for trend evaluation of environmental data sets (Yue and Hashino, 2003). This is a test result of enhanced first studied by Mann (1945) and then repeated by Kendall and Stuart (1967). This is a test that compares each value of a time series with the other remaining values, always in sequential order (Silva et al., 2007). However, it should be emphasized that the presence of temporal persistence (auto-correlation) and possible seasonality in time series, affects the sensitivity of this method nonparametric (Bayazit and Onoz, 2007). In order to adapt the Mann-Kendall test (MK) to this a series with potential seasonality, Hirsch et. al (1982) and Hirsch and Slack (1984) proposed a method known as Mann-Kendall Seasonal (SMK).

Alencar et al. (2011) and Santos e Silva (2013) describe the adapted method (SMK) considering the observations X₁, X₂, ..., X_n of a time series. One can apply SMK test for trend only if the series is independent serially. So we want to test whether the observations of the series are independent and identically distributed, that is, we want to test the hypothesis:

H₀ = “The series observations are independent and identically distributed”;

H₁ = “The series observations have monotonic trend over time”.

Therefore, under H₀ of the statistic test is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sing}(X_j - X_i), \quad (2)$$

wherein,

$$\text{sing}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases}$$

It can be shown that S presents a normal distribution with zero mean E(S) and variance Var(S), in other words, a distribution normally is given by:

$$E(S) = 0 \quad (3)$$

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^P t_j(t_j-1)(2t_j+5)}{18} \quad (4)$$

where, n is the number of observations, and considering the case where the series may have groups with equal observations, P is the number of groups with equal observations and t_j is equal to the number of observations in group j.

If observations number is greater than 30, the test statistic is calculated by:

$$Z = \begin{cases} \frac{(S-1)}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{(S+1)}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

Even for a less observations number than 30, is possible use the Z statistic for testing. Z is Based on statistical analysis, the final decision to reject or not reject H₀ is made, ie, it can confirm

the hypothesis stability data or reject it in favor of the alternative hypothesis, i.e., the existence of trend in the data. The Z statistic signal indicates whether the trend is growing ($Z > 0$) or descending ($Z < 0$). Adopting the $\alpha = 0,05$ significance level, H_0 will not be rejected where $-1,96 < Z < 1,96$. The calculations and results of SMK test were obtained using the *SeasonalMannKendall()* command from the *kendall* package of the statistical program R.

The Mann-Kendall test is able to detect significant trends statistically, but does not provide estimated as the slope of the trend (magnitude) or the exact point of change in a time series. For this reason, their application was complemented by a nonparametric statistical estimator, called the Theil-Sen trend estimator or Sen method, which is a better alternative to using a linear regression for this purpose, as the Linear Regression suffers significant influence points away (outliers) the main trend.

The estimator Theil-Sen trend, Equation (6), t proposed first by Theil (1950) and later expanded by Sen (1968) and described by Hirsch et al. (1982). This method selects, among all of inclination lines formed by each pair of sample points, one corresponding to the median slope.

$$S_e = \text{median} \left[\frac{X_k - X_i}{K - i} \right] \text{ for } i < j \text{ e } X_i \neq X_j \quad (6)$$

The Theil-Sen test helps to identify if there was or not change in series trend and magnitude being a widely technique used to verify the magnitude (Deo et al, 2007). The significance level used in the test application was $\alpha = 5\%$. In R the command used to obtain the value Sen estimator of equation (6) is *zyp.sen()* of the package *zyp*.

Regarding the determination of turning points (break), statistically significant, in the time series. We used the Change Point Model algorithm (CPM) of the R program, introduced. For example, if the observations are assumed to be Gaussian (normal), then it would be appropriate to use the Student t test for two samples to detect a significant deviation. If there is no information about the assumptions of the sample distribution, non-parametric test can be used as the Mann-Whitney test for changes of location.

3. Results and discussion

For a better understanding and discussion space-temporal trends in ETo of the study area, were built graphs and tables showing the average annual, seasonal, the linear regression line, estimated by Thiel-Sen estimator in order to show if there are trends linear with time, and the magnitude, sign (positive or negative), statistical significance using the Mann-Kendall test (statistic Z) and approximate date of start of trend (change point).

Image 2a represents the ETo for Acre region, which was obtained by the arithmetic mean of the ETo of the three locations, which will be called from now ETo Regional or Acre. Figures 3b, c and d represent the Rio Branco locations Tarauacá and the Cruzeiro do Sul which in turn represent the regions East, Midwest and West Acre, respectively.

By regression analysis and the statistical value of the Mann-Kendall test ($Z = 5.34$), it is observed in Figure 3a that regionally, there is significant upward trend in the annual ETo of 0.11 mm decade⁻¹ for the period 1985-2014 (dashed red line), which became significant from 2000 (blue vertical line). However, during 1985-1992 (blue line) this trend was the order of 0.20 mm decade⁻¹. After 1992 the trend of ETo persisted with a positive sign, but with lower slope (green line), and after this period is configured with sign of decline in the range 2005-2014 (orange line).

When analyzed by regions (Figure 3b, c and d), it appears that, in general, present trends similar to Figure 2a configuration, differing only in intensity, duration and start them. The East Acre (Figure 2b) and Western (Figure 2d), for example, showed the greatest inclinations (magnitude) of inclination of the order of 0.15 to 0.11 mm⁻¹ for the decade from 1985 to 2014, respectively, while the Midwest region (Figure 2c) showed the smallest increase (0.06 mm decade⁻¹). Correlation the beginning of the trend dates, statistically significant, also differed in the West began from 1990, while for the Midwest and East occurred in 1996 and 2001 respectively. Another distinctive aspect was related to the observed decline after 2005, which was not observed in the eastern region, as maintained a positive sign, but with lower intensity (slope).

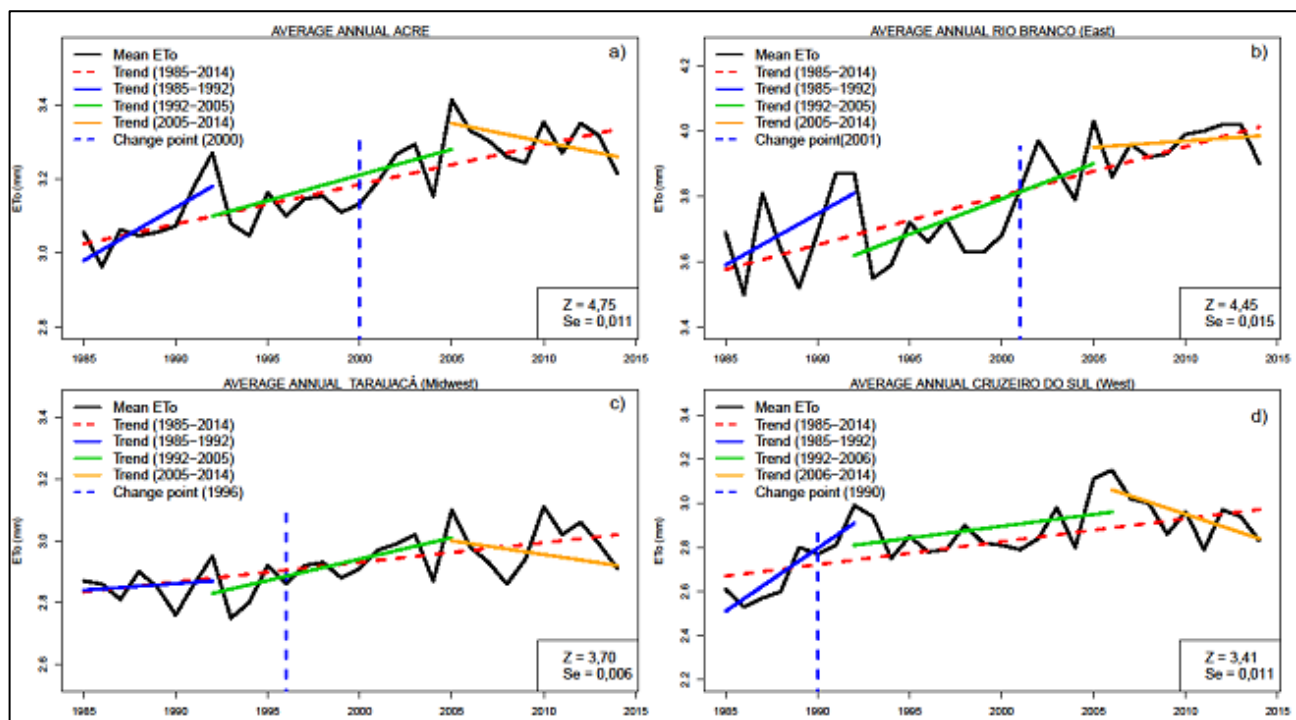


Figure 2 - Annual ETo series time (mm day year^{-1}) observed on the Acre (a) and on the eastern regions (b), Midwest (c) and West (d) with their linear trends, inclinations and turning point for the period 1985-2014.

The variability and trends through Figure 2 in the annual values of ETo the study area can be explained as a result of atmospheric anomalous ocean conditions on the North Atlantic following a cycle known as Multidecadal Oscillation Atlantic – AMO (Dijkstra et al, 2006), as observed by Silva et al. (2015a) and also by Borma and Nobre (2009) analyzing the rain for the whole Amazon. These authors point out that despite the AMO be considered a natural cycle, some studies indicate that the anomalous heating may be related to global climate change (Cox et al, 2004). However, local effects such as urbanization and deforestation can contribute to the intensification of the magnitude of the regional trend, especially in East and West regions, where the two localities more populated and developed state: Rio Branco and Cruzeiro do Sul (Table 1).

The table 4 is a summary about trend analysis for three locations in Acre state. It was found in that table that when applied the trend test for ETo at study region, statistical Z always showed values greater than zero in seasonal scale confirming the positive trend, except for summer which did not show a trend for three cities. The increase in winter ETo was more pronounced than observed in other seasons. Sen slope

estimator of ETo, considering two decimal places, showed values ranging from 0.01 to 0.02 mm yr^{-1} day or 0.10 to 0.20 mm per decade for autumn seasons, winter and spring, with an average increase of 0.10 mm per decade. Based on results, it can be concluded that, except for the summer, annual and seasonal series ETo in study area showed temporal elevation trends in their values. This significant increase (0.11 mm per decade) is mainly related to winter and spring seasons, as had the highest Z values (> 3).

Alencar et al. (2014) observed, studying the temporal variation of reference evapotranspiration in Catalan, Goiás, from 1961 to 2011, increasing trend of 1.4 mm year^{-1} , 5% level of significance in study region. Silva (2004) found, to the northeast of Brazil, a statistically significant upward trend in the ETo in 8 weather stations. Cordeiro (2010) observed, analyzing ETo between the years 1950-2009, for state of Rio Grande do Sul, an annual reduction of approximately 4.4 mm to 1% significance.

After confirmed the trend assumption in ETo in the study region through graphical inspection and statistical tests. Was solved in this way, to do the same analysis in meteorological elements (ME) which determine the ETo, a time which is a complex function, not linear, many

MS, and changes in a can modify other and

consequently ETo.

Table 4 - Statistical tests of Mann-kendall (Z) and the estimator of Sen's (magnitude) applied to annual and seasonal time of ETo series for Rio Branco, Tarauacá and Cruzeiro do Sul considering the 5% level of significance (p-value <0.05) for the period 1985-2014.

Var.	Series	RIO BRANCO			TARAUACÁ			CRUZEIRO DO SUL		
		Z	Trend $\alpha \leq 0,05$	Se	Z	Trend $\alpha \leq 0,05$	Se	Z	Trend $\alpha \leq 0,05$	Se
ETo	Summer	1,55	NS	0,005	0,46	NS	0,001	1,36	NS	0,004
	Autumn	2,69	S+	0,012	2,77	S+	0,006	2,48	S+	0,010
	Winter	4,02	S+	0,023	3,02	S+	0,010	3,43	S+	0,014
	Spring	3,73	S+	0,019	3,30	S+	0,010	3,38	S+	0,013
	Annual	4,45	S+	0,015	3,70	S+	0,006	3,41	S+	0,011

NS = no significant trend; S+ = significant positive trend at 5%; S- = significant negative trend at 5%.

The ME analyzed were: Maximum temperature (Tmax), medium temperature (Tmed), minimum temperature (Tmin), relative humidity (RH), wind speed (u2), global solar radiation (Rad.), pressure deficit steam (DPV) rainfall (prp) and insolation (n).

In table 5, 6 and 7 are shown a summary about results of the statistical tests of Mann-Kendall (Z), Sen estimator (Sen) and sign of the trend (trend) for each weather element in seasonal and annual scale for three locations.

The results of Mann-Kendall test and Sen estimator for annual and seasonal series of meteorological variables average temperatures, maximum and minimum (Tmed, Tmax and Tmin) are presented in Table 5.

Whereas the annual scale, it was found that in locations lifting trends were detected in values of Tmed and according to Sen test was of order of 0.2 ° C to 0.3 ° C per decade. It was found in the seasonal scale, these changes are fundamentally related to summer, winter and spring to Cruzeiro do Sul. To Rio Branco summer and spring and Tarauacá the winter and spring test were significant only.

For Tmax, the annual scale, trend test demonstrated high for three locations, but without statistical significance. The seasonal scale, winter statistically significant trend for Rio Branco and Cruzeiro do Sul. In summer there was downward trend for three locations, but without statistical significance.

With respect to annual both Tmin and seasonal scale (table 5), it was found that Z values were always higher than zero and above the critical value (1.96), except for winter

Tarauacá. Confirming Tmin lifting tendency at study area with an average increase of approximately 0.5°C to 0.7°C per decade for Branco and Tarauacá and 0.7°C per decade for Cruzeiro do Sul.

Significant increases in average temperatures, maximum and minimum have been observed in several studies in Brazil. Victoria et. al (1998) detected a warming in the Amazon region that reached + 0.63°C/100 years, while the heating rate found by Marengo (2003) reached + 0.85/100 years. Silva (2004) and Lima et al. (2010) found, studying the air temperature behavior in northeastern Brazil, statistically significant upward trend in the annual maximum temperature with average increases of 0.50°C per decade.

In Table 6 are shown the results for the meteorological variables: relative humidity (RH), wind speed (u2) and insolation (n).

It is observed that regionally the UR at the annual scale, increased by trend with average increases of 2.2% per decade, with statistically significant to only Cruzeiro do Sul town. Winter was down trend, but it was not statistically significant for three localities, while in summer and autumn in Rio Branco and Cruzeiro do Sul was detected positive trend. Cruzeiro do Sul presented upward trend also on spring.

Increased UR at the annual scale observed in localities generally can be associated with significant declines in average temperature, maximum and pluvial precipitation recorded from 2000, checked in INMET database. These decreases contributed to decrease of vapor pressure deficit during this period increasing

relative humidity. Different behavior were observed by Alencar et al. (2012), on Southeast, and Silva (2004) on Northeast, the authors found marked reduction relative humidity annual

average, associated with an increased set of minimum temperature and maximum temperature.

Table 5 - Statistical tests of Mann-kendall (Z) and the estimator of Sen's (magnitude) applied to annual and seasonal time series in average temperatures, maximum and minimum for Rio Branco, Tarauacá and Cruzeiro do Sul for the period 1985-2014.

Var.	Series	RIO BRANCO			TARAUACÁ			CRUZEIRO DO SUL		
		Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen
Tmed	Summer	1,99	S+	0,017	1,02	NS	0,010	2,16	S+	0,031
	Autumn	0,45	NS	0,012	1,32	NS	0,016	1,86	NS	0,030
	Winter	1,48	NS	0,027	2,20	S+	0,026	2,84	S+	0,036
	Spring	3,52	S+	0,024	3,49	S+	0,021	2,39	S+	0,029
	Annual	3,16	S+	0,023	3,14	S+	0,019	2,62	S+	0,025
Tmax	Summer	-1,20	NS	-0,015	-0,01	NS	0,000	-0,16	NS	-0,001
	Autumn	0,00	NS	0,000	0,46	NS	0,007	1,32	NS	0,022
	Winter	2,08	S+	0,038	1,66	NS	0,030	1,96	S+	0,040
	Spring	1,23	NS	0,010	1,07	NS	0,012	0,25	NS	0,002
	Annual	1,43	NS	0,011	1,61	NS	0,014	1,32	NS	0,016
Tmin	Summer	3,60	S+	0,039	2,88	S+	0,033	4,16	S+	0,087
	Autumn	3,22	S+	0,060	1,97	S+	0,035	4,51	S+	0,086
	Winter	3,21	S+	0,071	1,66	NS	0,027	3,50	S+	0,082
	Spring	4,16	S+	0,043	3,59	S+	0,057	4,46	S+	0,078
	Annual	4,56	S+	0,051	3,46	S+	0,041	5,66	S+	0,072

NS = no significant trend; S+ = significant positive trend at 5%; S- = significant negative trend at 5%.

In the wind speed analysis data series (u_2), Table 6, it was observed that the town of Rio Branco and Cruzeiro do Sul presented upward trend in summer with average rate of increase from 0.04 to 0.12 m s⁻¹ per decade, respectively. To Rio Branco and Tarauacá was a trend for spring and autumn season for Tarauacá. Alencar et al. (2012) and Santos e Silva (2013) conducted studies of this variable to southeast (Uberada-MG) and Northeast Brazil region, respectively. To the southeast was observed increasing trend in wind speed, while the Northeast was observed declining trend.

Data analysis shows that regionally, heat stroke showed a significant upward trend in annual scale (Table 6). It is observed statistically significant increase trend (p-value <0.05), for the winter of the three locations for fall Rio Branco and Tarauacá and the spring of the Cruzeiro do Sul. These results suggest that the number of hours of sunshine in the region has increased over time, especially plants in autumn, winter and spring which is indicative of fewer clouds in this region. Involving direct incidence of solar radiation which in turn contribute to increasing

temperature and decreasing precipitation in these periods.

Different results were found by Alencar et al. (2014), Alencar et al. (2011) and Cordeiro (2010) that consisted significant trend of decreased insolation for the Catalão region (GO), Viçosa (MG) and for the state of Rio Grande do Sul, respectively.

When analyzing the meteorological parameter global solar radiation (Rad.) Through Table 7, it appears that results regarding the trend of the signal to the Rio Branco locations Tarauacá and Cruzeiro do Sul at the annual scale was upward trend with an increase rate of ~0.50 MJ m⁻² decade⁻¹. The seasonal scale all locations showed a significant upward trend of 5%, except for the summer and spring in White and Tarauacá River and in the summer and autumn of Cruzeiro do Sul. These results are associated with the trend observed in insolation who presented the same pattern configuration in the region, since this variable was used to calculate the solar radiation by means of the equation Angstrom.

Table 6 - Statistical tests of Mann-kendall (Z) and the estimator of Sen's (magnitude) applied to annual and seasonal time series relative humidity, wind speed and insolation to Rio Branco, Tarauacá and Cruzeiro do Sul for the period 1985-2014.

Var.	Série	RIO BRANCO			TARAUACÁ			CRUZEIRO DO SUL		
		Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen
UR	Summer	2,29	S+	0,110	1,33	NS	0,049	3,57	S+	0,211
	Autumn	2,48	S+	0,119	0,78	NS	0,029	3,39	S+	0,229
	Winter	-0,71	NS	-0,062	-0,34	NS	-0,017	1,75	NS	0,155
	Spring	0,62	NS	0,029	-0,09	NS	-0,006	4,08	S+	0,333
	Annual	1,70	NS	0,050	0,18	NS	0,008	3,39	S+	0,219
u ₂	Summer	2,05	S+	0,004	0,59	NS	0,001	2,29	S+	0,012
	Autumn	0,46	NS	0,002	1,91	S+	0,004	0,99	NS	0,005
	Winter	-0,70	NS	-0,003	0,41	NS	0,001	0,46	NS	0,003
	Spring	3,32	S+	0,008	2,07	S+	0,005	1,37	NS	0,011
	Annual	1,51	NS	0,002	1,49	NS	0,002	1,39	NS	0,007
n	Summer	1,16	NS	0,015	0,34	NS	0,000	1,72	NS	0,014
	Autumn	3,22	S+	0,068	2,33	S+	0,033	0,81	NS	0,013
	Winter	4,61	S+	0,111	3,81	S+	0,060	4,09	S+	0,068
	Spring	1,60	NS	0,019	0,97	NS	0,011	2,60	S+	0,030
	Annual	4,64	S+	0,050	3,21	S+	0,025	3,68	S+	0,029

NS = no significant trend; S+ = significant positive trend at 5%; S- = significant negative trend at 5%.

Table 7 - Statistical tests of Mann-kendall (Z) and the estimator of Sen's (magnitude) applied to annual and seasonal temporal humidity series of solar radiation, vapor pressure deficit and pluvial precipitation to Rio Branco, Tarauacá and Cruzeiro do Sul to the period 1985-2014.

Var.	Series	RIO BRANCO			TARAUACÁ			CRUZEIRO DO SUL		
		Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen	Z	Trend $\alpha \leq 0,05$	Sen
Rad.	Summer	1,33	NS	0,032	0,39	NS	0,007	1,68	NS	0,018
	Autumn	3,17	S+	0,095	2,52	S+	0,039	0,91	NS	0,015
	Winter	4,50	S+	0,160	3,89	S+	0,066	4,19	S+	0,076
	Spring	1,50	NS	0,033	0,89	NS	0,012	2,71	S+	0,037
	Annual	4,65	S+	0,074	3,21	S+	0,029	3,64	S+	0,034
DPV	Summer	-1,65	NS	-0,002	-0,04	NS	0,000	-0,27	NS	-0,001
	Autumn	0,30	NS	0,000	-0,02	NS	0,000	0,37	NS	0,001
	Winter	2,83	S+	0,008	1,39	NS	0,004	0,90	NS	0,005
	Spring	1,45	NS	0,002	1,50	NS	0,003	-1,66	NS	-0,005
	Annual	1,23	NS	0,002	1,25	NS	0,002	-0,04	NS	0,000
PRP	Summer	-0,11	NS	-0,191	1,48	NS	6,806	-0,20	NS	-0,550
	Autumn	-0,28	NS	-1,160	1,12	NS	3,064	0,30	NS	1,044
	Winter	0,35	NS	0,747	-0,09	NS	-0,148	0,48	NS	1,026
	Spring	-0,87	NS	-2,576	0,09	NS	0,133	-0,07	NS	-0,258
	Annual	-0,13	NS	-1,879	1,77	NS	8,128	-0,09	NS	-0,870

NS = no significant trend; S+ = significant positive trend at 5%; S- = significant negative trend at 5%.

For the DPV (Table 7) at the annual scale it was found that in Rio Branco and Tarauacá showed upward trend, unlike Cruzeiro do Sul which showed decline. However, these trends were not significant at the 5%, except for the Rio Branco winter statistically significant. Note that summer, the three locations, is featured with trend I decline and fall of Tarauacá and the spring of Cruzeiro do Sul but without statistical

significance. These associated with the increasing trend of temperatures in the region checked in Table (5).

The annual pluvial precipitation (Table 7) to Rio Branco and Cruzeiro do Sul showed declining trend signal in the range of -1.87 mm and -0.87 mm year, respectively. By contrast, Tarauacá tended to rise in the order of 8.13 mm year, but all without statistical significance using

the Mann-Kendall test. Rio Branco to this decline was observed for the summer season, autumn and spring for winter the trend signal was increased. To Tarauacá the trend signals were inverse to the Rio Branco. In Cruzeiro do Sul increasing trends in rainfall were detected in autumn and winter and decline in summer and spring. It is emphasized that these seasonal trend signals were not statistically significant at the 5% significance.

These results on the trend of precipitation corroborate studies and findings of Paiva and Clake (1995), analyzing rainfall trends in the Amazon for 48 rainfall stations, with over 15 years of record and Duarte (2005) to Rio Branco location during 1970-2000. The authors concluded that negative trends (frequently the western Amazon) are more common than positive (more occurred in Amazon east) and the associated decrease in rainfall in deforestation western region. Moreover, Cavalcante et al. (2009) reported that recent research about climate and hydro-meteorological trends have not shown one-way large-scale trends in precipitation or in rivers flows in Amazon region, showing different trends, often conflicting, or by techniques used in the analysis, either by short series rain information.

According to the results and analysis above the increase in water demand associated with ETo in the state of Acre region proved to be distributed homogeneously as this increase was observed in all localities objects of study of this work.

The increase in average temperature, minimum temperature and solar radiation and consequently ETo in recent years, in the state of Acre region, can increase water demand and impact the addition, the development and productivity of regional agriculture. And the increase in extreme events as occurrences of droughts prolonged like those that occurred in 2005 and 2010 (Brow et al, 2011; Saatchi et al., 2013) and historical floods as 2012 and 2014 (River Madeira) and more recently, 2015 in Acre River (Brown et al., 2015).

Several authors (Alencar et al., 2014; Lima et al., 2010; Cavalcante et al, 2009) point out that the observed trends in weather variables for Brazil in general, climate change can be assigned and also the origin and quality of information (data from weather stations or grid

point), and the analyzed time period or local urbanization effects, which can add heat, but not as a direct result of natural or anthropogenic global warming.

In the case of this study region, trends in observed meteorological parameters can be related in part to natural climate variability, it is associated with warmer water occurrences in the northern basin of the Atlantic Ocean, which vary according to the signal index AMO (North Atlantic Multidecadal Oscillation), as noted and discussed in Silva (2015a). On the other hand urbanization local effects associated with the growth of cities have the potential to interfere directly in the dynamics of local environment, primarily the atmosphere. Thus contributing to intensification of changes in meteorological parameters.

Acknowledgments

We appreciate the financial support and encouragement of research at the Federal University of Rio Grande do Norte (UFRN) through the Program of Graduate Studies in Climate Sciences (Programa de Pós-Graduação em Ciências Climáticas - PPGCC) and the Higher Education Personnel Training Coordination (Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior - CAPES).

References

- ACRE. Governo do Estado do Acre, 2010. Zoneamento Ecológico-Econômico do Estado do Acre, Fase II (Escala 1:250.000): Documento Síntese. 2. Ed. Rio Branco, SEMA. Available: http://www.mma.gov.br/port/conama/processos/CD194D39/ZEE-Acre-faseII_Parte1-baixareol.pdf. Access: mar.,10, 2014.
- Alencar, L.P., Mantovani, E.C., Bufon, V.B., Sedyama, G.C, Silva, T.G.F., 2014. Variação temporal dos elementos climáticos e da ETo em Catalão, Goiás, no período de 1961-2011. *Revista Brasileira de Engenharia Agrícola e Ambiental* 18, 826-832.
- Alencar, L.P., Sedyama, G.C., Mantovani, E.C., Martinez, M.A, 2011. Tendências recentes nos elementos do clima e suas implicações na evapotranspiração da cultura do milho em Viçosa – MG. *Revista de Engenharia Agrícola*, Jaboticabal 31, 631-642.

- Alencar, L.P., Sedyama, H.C., Wanderley, H.S., Almeida, T.S., Delgado, R.C., Vieira, G.H.S., 2012. Evolução temporal da evapotranspiração de referencia e sua sensibilidade para os principais elementos climáticos na cidade de Uberaba – MG. *Revista Brasileira de Ciências Agrárias* 7, 159-166.
- Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO, Rome. (Irrigation and Drainage Paper 56).
- Allen, R.G., Smith, M., Perrier, A., 1994. An update for the definition of reference evapotranspiration. *Irid Bulletin* 43, 1-34.
- Back, A.J., 2001. Aplicação de análise estatística para identificação de tendências climáticas. *Pesquisa Agropecuária Brasileira* 36, 717-726.
- Bayazit, M., Onoz, B., 2007. To prewhiten or not prewhiten in trend analysis? *Hidrologic Science Journal* 52, 611-624.
- Borma, L.S., Nobre, C., 2013. Secas na Amazônia: Causas e Conseqüências. Oficina de Textos, São Paulo.
- Brown, F., Santos, G.P., Pires, F.F., Costa, C.B.da, 2011. Brazil: Drought and Fire Response in the Amazon. *World Resources Report* [on line] 1. Available: <http://www.worldresourcesreport.org/>. Access: apr., 14, 2014.
- Brown, I.F., 2015. Somo responsáveis pelos eventos extremos de inundações e secas?. Rio Branco, 30 jun. 2015. *Jornal Agazeta do Acre.com*. Available: <http://agazetadoacre.com/noticias/somos-responsaveis-pelos-eventos-extremos-de-inundacoes-e-secas/>. Access: jul., 13, 2015.
- Cavalcante, I.F.A., Ferreira, N.J., Silva, M.G.A.J., Dias, M.A.F.S. (Orgs.), 2009. Tempo e Clima no Brasil. Oficina de Textos, São Paulo.
- Cordeiro, A.P.R.A., 2010, Tendências climáticas das variáveis meteorológicas originais, estimadas e das derivadas do balanço hídrico seriado do Rio Grande do Sul: Rio Grande do Sul, Brasil. Thesis (Master). Porto Alegre, UFRGS.
- Cox, P.M., Betts, R.A., Collins, M., Harris, P.P., Huntingford, C., Jones, C.D., 2004. Amazonian forest dieback under climate-carbon cycle projections for the 21st century. *Theoretical and Applied Climatology* 78, 137-156.
- Deo, R.C., McAlpine, C.A., Syktus, J., McGowan, H.A., Phinn, S., 2007. On Australian heat waves: Time series analysis of extreme temperature events in Australia, 1950-2005. MODSIM 2007 International Congress on Modeling and Simulation, 626-635. Available: http://www.mssanz.org.au/MODSIM07/papers/10_s61/OnAustralianHeat_s61_Deo_.pdf. Access: jul., 19, 2015.
- Dijkstra, H.A., RAA, L., Schmeits, M., Gerrits, J., 2006. On the physics of the Atlantic Multidecadal Oscillation. *Ocean Dynamics* 56, 36-50.
- Dinpashoh, Y., Jhajharia, D., Fakheri-Fard, A., Singh, V.P., Kahya, E., 2011. Trends in reference crop evapotranspiration over Iran. *Journal of Hydrology* 399, 422-433.
- Duarte, A.F., 2006. Aspectos da climatologia do Acre, Brasil, com base no intervalo 1971 – 2000. *Revista Brasileira de Meteorologia* 21, 308-317.
- Duarte, A.F., 2005. Variabilidade e tendência das chuvas em Rio Branco, Acre, Brasil. *Revista Brasileira de Meteorologia* 20, 37-42.
- Espadafor, M., Lorite, I.J., Gavilán, P., Berengena, J., 2011. An analysis of the tendency of reference evapotranspiration estimates and other climate variables during the last 45 years in Southern Spain. *Agricultural Water Management* 98, 1045-1061.
- Fernandes, D.S., Heinemann, A.B., Amorim, A.O., 2010. Evapotranspiração – Uma Revisão sobre os Métodos Empíricos. Embrapa Arroz e Feijão, Santo Antônio de Goiás. (Documentos, 263).
- Ferrari, A.L., Vecchia, F.A.S., Colabone, R.O., 2012. Tendência e variabilidade anuais da temperatura e da pluviosidade em Pirassununga-SP. *Revista Brasileira de Climatologia* 8, 30-46.
- Ferraz, P.A., 2008. Estimativa da Evapotranspiração de referência (ET_o) para a região de Rio Branco – ACRE. Acre, Brasil: Thesis (Master). Rio Branco, UFAC.
- Fisch, G., Marengo, J.A., Nobre, C.A., 1998. Uma revisão geral sobre o clima da Amazônia. *Acta Amazônica* 28, 101-126.

- Fontolan, M.R., Ferreira, D.H.L., Penereiro, J.C., 2012. Comportamento climático ao longo do rio Tietê: aplicações envolvendo testes estatísticos. *Revista Geonorte* 2, 466-475.
- Gash, J.H.C., Nobre, C.A., Roberts, J.M., Victoria, R.L. (organizers), 1996. *Amazonian deforestation and climate*. Published by John Wiley & Sons, Chichester.
- Hawkins, D.M., Qiu, P.H., Kang, C.W., 2003. The Changepoint Model for Statistical Process Control. *Journal of Quality Technology* 35, 355-366.
- Hawkins, D.M., Zamba, K.D., 2005. A Change-Point Model for a Shift in Variance. *Journal of Quality Technology* 37, 21-31.
- Hirsch, R.M., Slack, J.R., 1984. A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research* 20, 727-732.
- Hirsch, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of trend analysis for monthly water quality data. *Water Resources Research* 18, 107-121.
- Hobbins, M.T., Ramirez, J.A., Brown, T.C., 2004. Trends in pan evaporation and actual evapotranspiration across the conterminous US.: Paradoxical or complementary? *Geophysical Research Letters* 31, 1-5.
- IBGE. Instituto Brasileiro de Geografia e Estatística, 2010. *Cidades*. Rio Branco. Available: <http://ibge.gov.br/cidadesat>. Access: feb., 14, 2014.
- Junger, W., Leon, A.P., 2012. mtsdi: Multivariate time series data imputation. R package 0.3.3.
- Lima, R.A.F.A., Menezes, H.E.A., Brito, J.I.B., 2010. Diagnóstico de tendência de mudanças na temperatura do ar no nordeste setentrional. *Revista Caatinga* 23, 117- 124.
- Marengo, J.A., 2003. Condições climáticas e recursos hídricos no Norte do Brasil, in: *Clima e Recursos Hídricos* 9. Associação Brasileira de Recursos Hídricos/FBMC-ANA, Porto Alegre, pp. 117-156.
- Marengo, J.A., 1992. Interannual variability of surfasse climate in the Amazona basin. *International Journal of Climatoloy* 12, 853-863.
- Marengo, J.A., Nobre, C.A., Tomasella, J., Oyama, M.D., Oliveira, G.S., Oliveira, R., Camargo, H., Alves, L.M., Brown, I.F., 2008. The drought of Amazonia in 2005. *Journal of Climate* 21, 495-516.
- Mcvicar, T.R., Roderick, M.L., Donohue, R.J., Li, L.T., Niel, T.G.V., Thomas, A., Grieser, J., Jhajharia, D. Himri, Y., Mahowald, N.M., Mescherskaya, A.V., Kruger, A.C., Rehman, S., Dinpashoh, Y., 2012. Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation. *Journal of Hydrology* 416-417, 182-205.
- Ometto, J.C., 1981. *Bioclimatologia vegetal*. Agronômica Ceres, São Paulo.
- Paiva, E.M.C.D., Clake, R.T., 1995. Análise de Tendência de Precipitação da Amazônia. *Revista Brasileira de Meteorologia* 10, 37-41.
- Pereira, A.R., Villa Nova, N.A., Sediya, G.C., 1997. *Evapotranspiração*. FEALQ. Piracicaba.
- PROSER, Programa de Saneamento Ambiental Integrado e Inclusão Socioeconômica do Acre, 2012. *Avaliação Ambiental – AA: Financiamento Adicional*, Rio Branco-AC. Available: [http://www.ac.gov.br/wps/wcm/connect/3bb9a90044ada50eaefbfff6d5b2b192/Avaliac%CC%A7a%CC%83o%2BAmbiental%2B-%2BProser+\(Atualizado!\).pdf?MOD=AJPERES](http://www.ac.gov.br/wps/wcm/connect/3bb9a90044ada50eaefbfff6d5b2b192/Avaliac%CC%A7a%CC%83o%2BAmbiental%2B-%2BProser+(Atualizado!).pdf?MOD=AJPERES). Access: jul., 10, 2014.
- R Core Team, 2013. *A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Available: <http://www.R-project.org/>. Access: mar., 14, 2014.
- REDEMETS. Rede de Meteorologia da Aeronáutica, 2014. Homepage oficial do Comando Aéreo da Aeronáutica. Available: <http://clima.icea.gov.br/clima/>. Access: mar., 14, 2014.
- Saatchi, S., Asefi-Najafabady, S., Malhi, Y., Aragão, L.E.O.C., Anderson, L.O., Myneni, R.B., Neman, R., 2013. Persistent effects of a severe drought on Amazonian forest canopy. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* 110, 565-570.
- Santos, A.T.S., Silva, C.M.S., 2013. Seasonality, Interannual Variability, and Linear Tendency of Wind Speeds in the Northeast Brazil from 1986 to 2011. *The Scientific World Journal* 2013, 1-10.