



Detecting trends in 10-day rainfall amounts at five sites in the state of São Paulo, Brazil

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ABSTRACT. The temporal distribution of the rainfall events within a crop growing season plays a crucial role on the crop yield. In this way, the main goal of this study was to evaluate the presence of climate trends in the 10-day rainfall totals obtained from five weather stations in the State of São Paulo, Brazil (1951-2012). The autocorrelation function, the Run test and the Durbin-Watson test indicated a lack of significant serial correlation in these series. The wavelet analysis revealed no conclusive evidence of periodicities in the temporal variability of this variable. According to the Mann-Kendall test, most of the 10-day rainfall amounts obtained from the five weather stations shows no significant trends. However, for the locations of States Campinas, Pindorama and Ribeirão Preto, the significant decreasing trends observed during the 2nd and 3rd ten days of October suggests a possible change in the climatic patterns of these locations, which may be linked to a delay in the return of the rainy season.

Keywords: Mann-Kendall, climate change, rainy season.

Detecção de tendências em series decendias de precipitação pluvial em cinco localidades do Estado de São Paulo, Brasil

RESUMO. A distribuição temporal dos eventos de precipitação pluvial (PRE) em cada ano agrícola desempenha papel determinante sobre o rendimento das culturas. Com isso, o objetivo do trabalho foi avaliar a presença de tendências climáticas nos totais decendiais desse elemento meteorológico em cinco localidades do Estado de São Paulo (1951-2012). A função auto-correlação e os testes Run e Durbin-Watson indicaram inexistência de significativas correlações seriais nas séries do estudo. A análise de ondaleta não permitiu indicação conclusiva de periodicidades na variabilidade temporal da PRE. De acordo com o teste de Mann-Kendall a maioria das séries decendiais, obtidas a partir dos cinco postos meteorológicos, não demonstram tendências significativas em seus dados. Entretanto, as tendências significativas de diminuição nos totais decendiais desse elemento meteorológico, observadas nas localidades dos Estados de Campinas, Pindorama e Ribeirão Preto durante o segundo e terceiro decêndio do mês de outubro, indicam uma possível mudança nos padrões climáticos dessas regiões que podem estar associadas a um atraso na retomada da estação chuvosa regional.

Palavras-chave: Mann-Kendall, mudança climática, estação chuvosa.

Introduction

It is well known that the agricultural productivity is not only affected by the rainfall amounts observed during the crop growing season. The temporal distribution of the rainfall events, among many other factors, also plays a crucial role on the crop yields. As pointed out by Ramos and Casasnovas-Martínes (2006), changes in the patterns and amounts of rainfall are one of the most important factors affecting agricultural areas. In this perspective, a detailed analysis of historical rainfall series is important for improving the assessment of climate risks associated with a certain human activity (GEMMER et al., 2004). In addition, according to

Hayhoe (2007), investigation of climate trends at the regional scale is an essential step for understanding the potential impacts associated with the current global climate change. Finally, MacDonald and Phillips (2006) indicate that the analysis of historical rainfall records provides an opportunity for improving the knowledge of the process that controls this meteorological element. Also, according to MacDonald and Phillips (2006), this analysis places recent observations in a longer historical context.

Considering all these statements, Blain (2009, 2010) evaluated several features of historical rainfall records of the State of São Paulo. The results found in these studies indicate that the

most remarkable feature of this meteorological element, observed in this State, is its great variability over the space-time domain. Nevertheless, by comparing the number of cases in which decreasing and increasing trends were detected, the studies of Blain (2009, 2010) also seem to reveal a predominance of increasing trends in the annual and monthly rainfall amounts observed during the period of 1948-2007. Afterwards, Haylock et al. (2006) have evaluated rainfall indices, calculated annually from January to December (1960-2000), they also observed a change to wetter conditions in regions of South America, where the State of São Paulo is situated.

However, one can point out that studies carried out at annual and monthly scales may stand far from the agricultural interests. As previously described the temporal distribution of the rainfall events within a year or even within a month is also a key factor for agricultural activities. Based on this assumption, Blain (2011) evaluated the presence of temporal persistence, periodic components, and trends in the 10-day rainfall totals (PRE), obtained from the weather station of Campinas (1890-2009; State of São Paulo). The results of this latter study suggest a possible change in climatic patterns of this location, which can impact the agricultural management. According to this author, it was observed an unexpected high number of decreasing trends from the 1st ten days of August to the 1st ten day of November. These results may be linked to a delay in the return of the local rainy season (BLAIN, 2011). In addition, it is worth mentioning that among the results indicated by Dufek and Ambrizzi (2008), it can be verified increasing trends in the number of consecutive dry days observed at an annual scale over the State of São Paulo. Based on rainfall series of the Department of Water and Electric Energy (DAEE, 1950-1999), Dufek and Ambrizzi (2008) indicated that these trends have begun after 1985.

These last results have encouraged us to test the hypothesis that the delay detected by Blain (2011) in the location of Campinas (and considering 10-day rainfall totals) can also be observed in other regions of the State of São Paulo. Thus, the main goal of this study was to evaluate the presence of trends in the 10-day rainfall totals obtained from the weather stations

of Campinas, Jundiaí, Mococa, Pindorama and Ribeirão Preto. As a secondary goal, the presence of other non-random components, such as periodicities and temporal persistence (serial correlation) were also evaluated. It is expected that this study will provide insights into the temporal rainfall variability observed at these sites.

Material and methods

The 10-day rainfall data used in the study (Figure 1) were obtained from the Agronomic Institute (IAC/APTA/SAA-SP). The length of records of these series is 62 years (1951-2012; encompassing, approximately, two 30-year periods). The selected series do not have missing data and their consistencies have already been assessed by Blain (2009).

According to Blain (2009), even at a particular location of the State of São Paulo it can be observed strongly skewed rainfall distributions (similar to those observed in arid climates) during the winter months. However, during the summer months the shape of these monthly distributions becomes similar to the bell shape of the Gaussian distribution (frequently observed in equatorial climates). The region of Campinas is one of the most important technological centers of Brazil, with more than 1 million inhabitants. The weather station of Jundiaí is situated in an important fruit-producing region known as "Circuito das Frutas". The region of Ribeirão Preto is regarded as one of the richest farming land in Brazil. Ribeirão Preto and Pindorama are also known for their sugar cane production. The weather station of Mococa is situated in an important coffee-producing region of the State of São Paulo.

The auto-correlation function (acf) was used in order to evaluate the presence of temporal persistence in the PRE series. The null hypothesis (H_0) adopted by this method assumes that the dataset is free from serial correlation. The coefficients of the acf were estimated as described in Wilks (2011) from lags 1 to 35. Although the number of lags (#lags) is always an arbitrary choice, the upper limit $\#lags \leq N/4$ (N being the number of data records of the series) was respected.

The Run (Z) and the Durbin-Watson (DW) tests, described in several studies such as Sansigolo and Kayano (2010), Blain (2011) and Blain and Kayano (2011) were also applied to each one of the thirty six 10-day datasets obtained from each weather station.

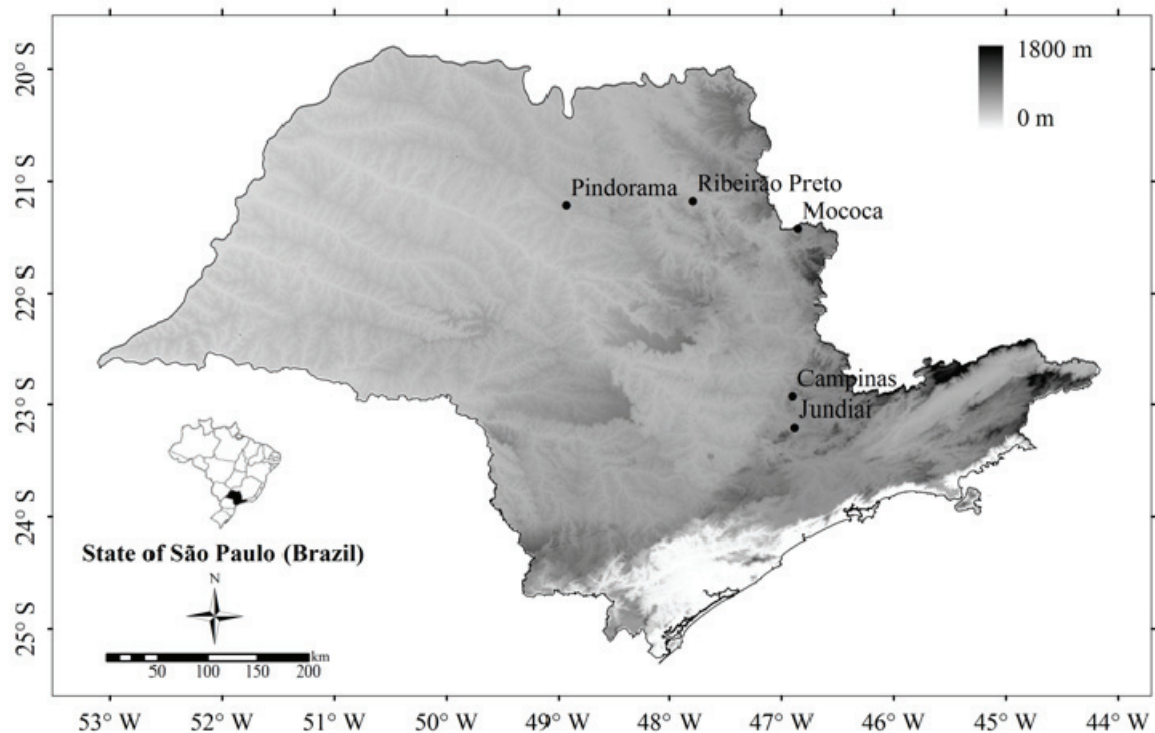


Figure 1. Five weather stations in the State of São Paulo, Brazil.

In this last case, the time span between two subsequent values within each dataset is one year. By not rejecting the H_0 associated with these two tests, one may assume that the dataset under evaluation is free from significant serial correlations. The acf function, Z and DW tests were performed at the 5% significance level.

The wavelet analysis was used to decompose the Preabs time series into time-frequency space (TORRENCE; COMPO, 1998). This sort of spectral analysis allowed us to evaluate the variance peaks in the frequency domain as well as to verify how these peaks varied over time. Further information regarding this method for signal processing, including its statistical significance testing, performed at the 5% significance level, can be found in several studies including Torrence and Compo (1998). By following several studies such as Souza-Echer et al. (2008), Pezzi and Kayano (2009), Blain (2009, 2011) and Beecham and Chowdhury (2010), the wavelet function (mother wavelet) used in the present study was the Morlet wavelet. The computational algorithm used to calculate this method is available at <http://paos.colorado.edu/research/wavelets> (WAVELETS, 2012). The wavelet analysis was applied to the PRE'_i series for each ten-day period.

$$PRE'_i = [PRE_i - \text{mean}(PRE_i)] / \text{Std}(PRE_i) \quad (1)$$

Std is the standard deviation of the i ten-day period.

The nonparametric procedure called Mann-Kendall (MK) test (KENDALL; STUART, 1967) was used to evaluate the presence of trends in the PRE series. This non parametric test is widely used to evaluate the presence of trends in meteorological time series (ÖNÖZ; BAYAZIT, 2011). Positive MK statistics are obtained in the presence of increasing trends, while negative MK values are observed in the presence of decreasing trends. The H_0 associated with this test assumes that the dataset under evaluation is free from trends. The absence of significant serial correlation is also assumed. Further information regarding the MK as well as the influence of serial correlations on this trend test can be found in several studies including Yue et al. (2002) and Chandler and Scott (2011).

At this point, it is worth emphasizing that, according to Radziejewski and Kundzewicz (2004), performing a trend analysis in series in which 'the natural variability is considerable' is not a trivial task. These authors indicated that even if a trend has not been properly detected by a statistical test, this cannot be taken as a demonstration of absence of any change. Thus we decided to adopt two critical levels for performing

the MK test (5 and 10%). Regarding the 5 and 10% significance levels, a non-significant MK value should remain, respectively, within the $[-1.96;1.96]$ and $[-1.64;1.64]$ intervals.

Results and discussion

Almost all the Z values were associated with p-values far from the adopted 5% significance level. In fact, among the 180 datasets, this critical level was reached only three times (2nd ten days of February in Ribeirão Preto, 3rd ten days of August in Pindorama and, 1st ten days of September in Jundiaí). The DW test also indicated the absence of significant serial correlation in almost all datasets. Considering this latter test, the 5% critical level was reached only twice in the location of Ribeirão Preto (1st ten days of April and 3rd ten days of September) and only twice in the location of Jundiaí (2nd ten days of April and 1st ten days of October). This lack of significant serial correlation was also observed even when the rainfall data were classified into its natural chronological order (acf; Figure 2). Practically all the acf coefficients fell into the white noise range. Thus, we were able to assume that the MK test will not be significantly affected by the presence of serial correlations in the datasets under evaluation (BLAIN, 2011; CHANDLER; SCOTT, 2011; ÖNÖZ; BAYAZIT, 2011; SANSIGOLO; KAYANO, 2010; YUE et al., 2002, and, among others).

Blain (2011) applied the wavelet analysis to the ten-day rainfall totals of the weather station of Campinas (1890-2009). By considering only the frequency domain (global wavelet; GWP) this author identified two significant variance peaks at the frequencies of 0.5 and 0.25 year⁻¹. As expected, a similar feature was observed (Figure 3). By analyzing the GWP of Campinas (Figure 3b), one may observe a significant variance peak between the frequencies of 0.5 and 0.25 year⁻¹. By considering the time-frequency domain (wavelet power spectrum, Figure 3a) this aforementioned variance peak was mainly the result of significant wavelet energy concentrated during the years of 1965-1972, 1976-1990 and 2000's.

For the weather station of Jundiaí, the GWP (Figure 3d) described a significant variance peak between the frequencies of 0.25 and 0.125 years⁻¹. However, by analyzing Figure 3c, one may verify that the wavelet energy that has resulted in this significant variance peak was concentrated

between the years of 1960 and 1990. There was no significant power after this period (Figure 3c). For the other three weather stations (Figure 3f, g and h), it was observed no significant variance peak or periodicity in the GWP. The difference among the wavelet energy observed for the five locations of the study (Figure 3) is consistent with the large spatio-temporal variability of the rainfall totals observed in the State of São Paulo by other studies, such as Blain (2009). The results of Figure 3 also agree with the idea that topography, land use and other regional features may produce particular patterns of local climatic variability (BEECHAM; CHOWDHURY, 2010). Finally, the sparse temporal distribution of the variance peaks observed from the wavelet power spectrum (time-frequency domain) did not indicate a conclusive presence of a periodical component in the series of the study.

Before evaluating the presence of a possible delay in the return of the rainy season (Table 1) it has to be emphasized that the overwhelming majority of the ten-day series showed no sign of climate trends. In fact, only 4.4 and 11.1% of the MK values have met, respectively, the 5 and 10% significance level. By considering the 5% significance level, 5 MK values described increasing trends and 3 MK values described decreasing trends. By considering the 10% significance level, 14 MK values were associated with increasing trends and 6 were associated with decreasing trends.

This predominance of non-significant results, obtained by applying the MK test to the rainfall totals of these five weather stations (Table 1) corroborates the studies of Blain (2009, 2010) and Blain and Kayano (2011). Nevertheless, concerning only the significant values, it is worth emphasizing that there was a greater number of increasing trends as shown in Table 1. This last feature is also similar to the findings of Blain (2009, 2010). Despite the above-mentioned results, for the weather stations of Campinas and Pindorama, the MK test, performed at the 5% level, indicated the presence of significant decreasing trends during the 3rd and 2nd ten days of October, respectively (Table 1).

For the weather station of Ribeirão Preto a significant decreasing trend (at 10% significance level) was observed during the 2nd ten days of October.

To the author's interpretation, these significant MK results, associated with the other non-significant decreasing trend observed between the

2nd ten days of October and the 1st ten days of November (Table 1), seem to be consistent with a possible delay in the return of the local rainy season.

By considering this last period, one may note that 14 out of the 15 ten-day series showed negative MK values.

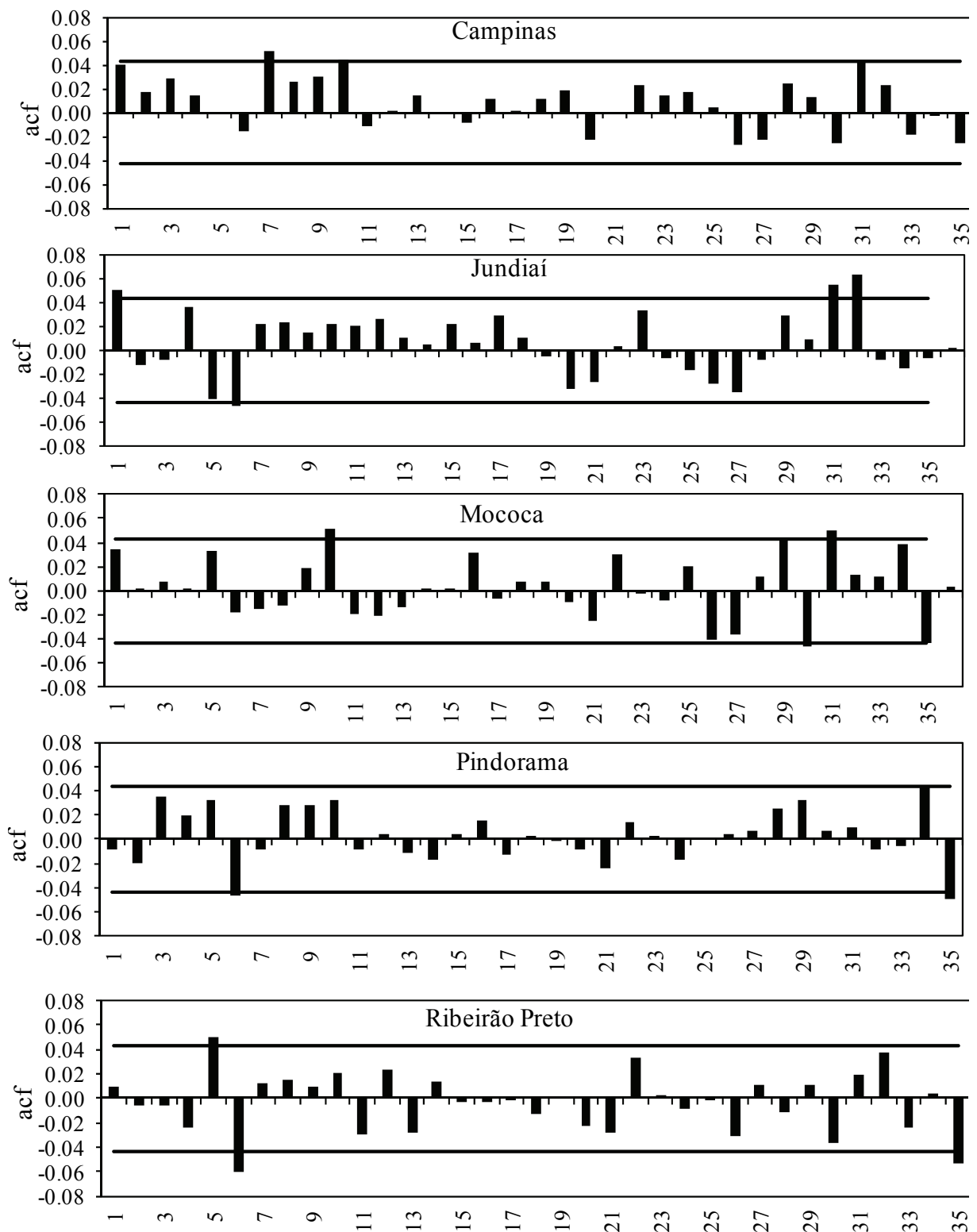


Figure 2. Autocorrelation function obtained at five locations in the State of São Paulo, Brazil.

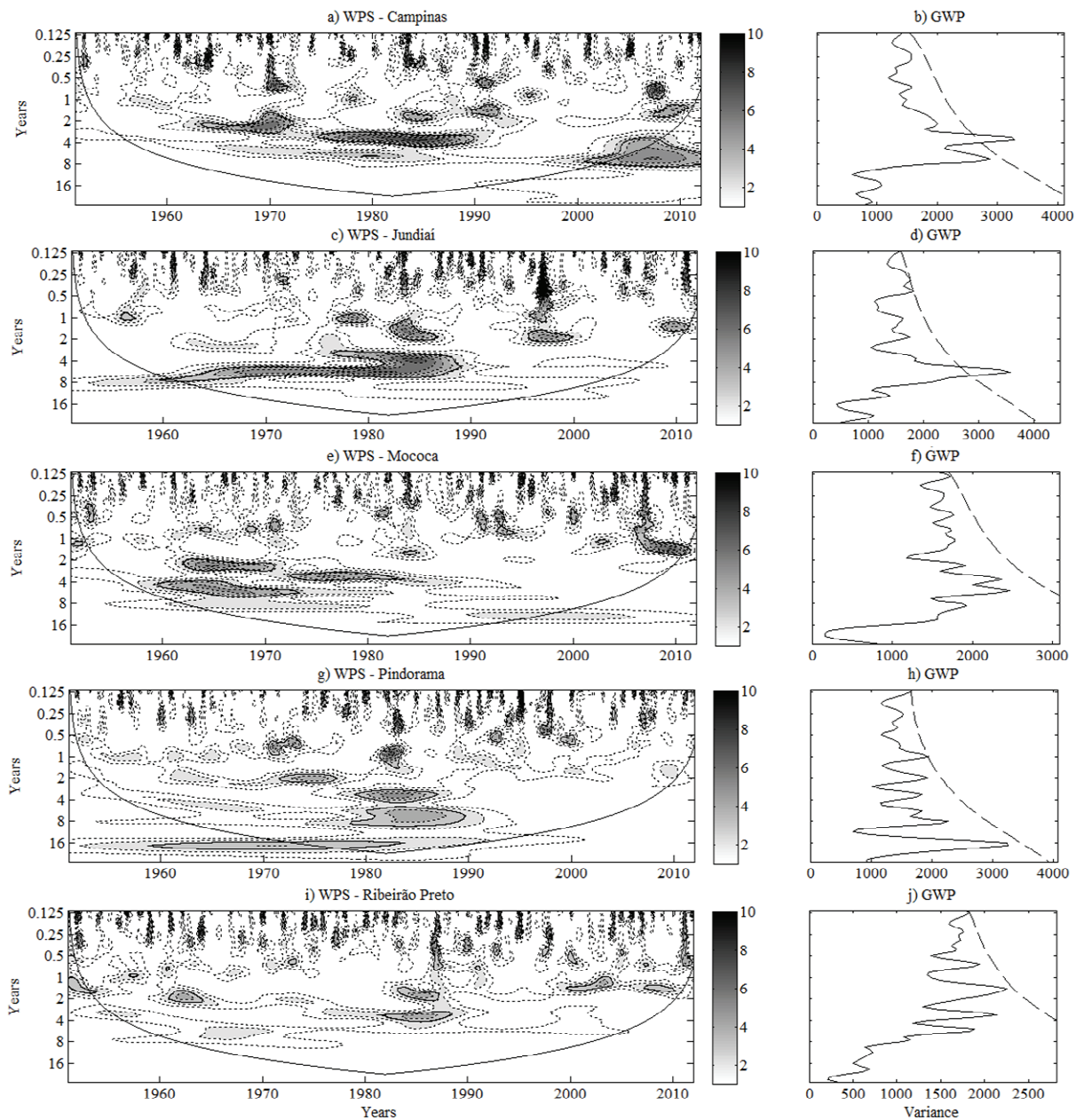


Figure 3. Wavelet power spectrum (WPS) and Global Power Spectrum (GWP) - in variance units - of the ten-day rainfall series of five location in the State of São Paulo, Brazil. The wavelet analysis was applied to standardized rainfall values as described in equation 1.

Table 1. Mann-Kendall test (MK) applied to 10-day rainfall totals. State of São Paulo, Brazil.

Month	Campinas	Jundiaí	Mococa	Pindorama	Ribeirão Preto
Jan	-0.28	1.85*	2.01**	2.20**	1.40
Jan	0.36	-0.12	-0.99	-0.75	-0.98
Jan	1.03	1.74*	2.08**	1.09	0.26
Feb	-0.98	-0.76	-1.25	-0.96	-0.72
Feb	0.33	0.91	0.16	0.63	0.16
Feb	-0.67	0.32	-1.76*	-0.84	-1.17
Mar	0.20	0.42	-0.76	-0.16	-0.95
Mar	-0.49	1.43	1.04	1.73*	0.45
Mar	0.52	-1.20	-2.33*	-0.95	0.44
Apr	-0.34	-0.20	-0.47	-0.12	-1.10
Apr	0.71	1.99**	1.45	1.41	0.29
Apr	0.36	0.81	-0.03	-0.05	-0.31
May	1.29	0.89	-0.40	-1.25	-0.10

Continue...

...continuation.

Month	Campinas	Jundiaí	Mococa	Pindorama	Ribeirão Preto
May	0.43	0.73	0.81	1.41	1.35
May	1.05	1.42	0.86	0.60	0.14
Jun	-0.62	-0.33	-0.53	-1.05	-0.93
Jun	-0.88	-0.29	-0.89	-0.84	-0.58
Jun	1.78*	1.90*	0.08	0.77	1.19
Jul	-1.74*	-0.12	-1.09	-1.05	-0.60
Jul	1.47	1.70*	0.55	0.84	1.32
Jul	0.69	1.64*	-0.13	1.53	0.52
Aug	-0.18	0.32	-0.87	0.33	-0.36
Aug	-1.37	-0.94	-0.43	-0.65	-0.22
Aug	-0.63	-0.17	0.64	0.20	0.41
Sep	-0.15	0.65	-0.01	0.46	0.32
Sep	0.97	0.51	1.17	1.38	1.15
Sep	0.18	0.60	1.82*	0.11	1.40
Oct	1.58	0.96	0.60	0.83	-0.53
Oct	-1.08	-0.27	-0.13	-1.97**	-1.78*
Oct	-2.96**	-1.14	-0.08	-0.27	-1.36
Nov	-0.35	0.07	-0.91	-0.18	-0.73
Nov	0.03	1.38	1.18	0.60	1.99**
Nov	0.75	1.73*	1.52	1.20	1.08
Dec	-0.02	-0.18	0.43	-0.29	-0.47
Dec	0.82	1.43	0.51	0.04	-0.18
Dec	0.01	0.11	0.58	1.12	-0.22

*Significant at the 10% level. **Significant at the 5% level.

Regarding this last interpretation, we pointed out that these significant decreasing trends may be the result of an unfavorable temporal distribution of the rainfall events observed at the beginning of the crop growing seasons. Blain (2012) found similar results when evaluated the presence of trends in four Standardized Precipitation Index (SPI) series of the State of São Paulo. According to Blain (2012), the great concentration of negative MK values obtained from these SPI series during the months of October cannot be seen as the result of a purely random process.

Conclusion

Most of the 10-day rainfall amounts obtained from the weather stations of Campinas, Mococa, Jundiaí, Pindorama and, Ribeirão Preto show no sign of significant trends. However, for the locations of Campinas, Pindorama and Ribeirão Preto, the significant decreasing trends observed during the 2nd and 3rd ten days of October suggest a possible change in the climatic patterns of these locations, which may be linked to a delay in the return of the rainy season.

All series of the study show no significant serial correlation and no conclusive evidence of periodicities.

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Received on April 15, 2013.

Accepted on February 25, 2014.

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