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Variability of rainfall and temperature (1912–2008) parameters measured from Santa Maria (29°41′S, 53°48′W) and their connections with ENSO and solar activity

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Abstract

In this work, we analyze the long term variability of rainfall and temperature (1912–2008) of Santa Maria (29°S, 53°W) and its possible connection with natural influences such as solar activity and ENSO. Temperature and rainfall present similar frequencies as revealed by spectral analyses. This analysis shows a large number of short periods between 2–8 years and periods of 11.8–12.3, 19.1–21.0, and 64.3–82.5 years. The cross correlation for rainfall and temperature versus Southern Oscillation Index (SOI) have higher cross-power around 2–8 yr. Rainfall and temperature versus sunspot number (Rz) showed higher cross-power around the 11-yr solar cycle period. A high and continuous cross correlation was observed for Rz-22 yr versus rainfall and temperature. Furthermore, the power between 22-yr solar cycle and meteorological parameters was higher than that obtained with the 11-yr solar cycle, suggesting that the effect of Hale cycle on climate may be stronger than the Schwabe cycle effect. These results indicate that the variability of rainfall and temperature is closely related to the variation of the Southern Oscillation Index and solar activity, and that the El Nino Southern Oscillation and solar activity probably play an important role in the climate system over Southern Brazil.

Highlights

► Temperature and rainfall present similar frequencies as revealed by spectral analyses. ► In low frequencies, the Hale cycle is an important factor in the climate modulation. ► The effect of the Schwabe cycle is also statistically significant. ► In high frequencies ENSO is the main influence on climate variability.

Introduction

Both natural and anthropogenic influences caused twentieth century climate change, but their relative roles and regional impacts are still under intense debate (Haigh, 2007, Joseph and Nigam, 2006, Lean and Rind, 2009, Pittock, 2009, Gray et al., 2011). In this context, it is fundamental to study the long term variability of climate in order to understand, which factors cause such variability. The climate of the Earth at a given time may be primarily characterized by its surface temperature and rainfall variations. To identify the causes of past change, thereby rendering forecasts for future decades, it is necessary to isolate and quantify the specific changes arising from both natural and anthropogenic influences (Benestad, 2003, Lean and Rind, 2008). The most cited natural phenomena affecting the long term variability of climate has been the El Niño.

Southern Oscillation and solar activity (Wang et al., 2000, Nuzhdina, 2002, Haigh, 2003, Raspopov et al., 2004, Souza Echer et al., 2008, Souza Echer et al., 2009, Courtillot et al., 2010, Le Mouël et al., 2010).

The El Niño Southern Oscillation (ENSO) phenomenon is a result of complex interaction between the atmosphere and the hydrosphere in the tropical Pacific (Cane, 2005). The Southern Oscillation Index (SOI) is an index used to represent the ENSO phenomena (Petroni and Ausloos, 2008). This is a standardized index based in observations of sea level pressure between Darwin (12°27′S, 130°50′E) and Tahiti (17°37′S, 149°26′W). Negative values of the SOI indicate El Niño episodes and positive values are associated with La Niña episodes (Ausloos and Ivanova, 2001). El Niño, or warm phase of ENSO, is caused by the heating of water from the East Pacific (Andreoli and Kayano, 2005). On the other hand, at La Niña, or cold phase of ENSO, an anomalous cooling of superficial water has been observed at the Equator and in the Eastern Pacific Ocean. ENSO, which has its origin at the tropical Pacific Ocean, can cause climatic anomalies in different regions of the world (Dai and Wigley, 2000, Alexander et al., 2002, Barnett et al., 2002).

Southern Brazil is one of the extra-tropical regions most affected by El Niño and La Niña events (Grimm et al., 2000). Many observations suggested that the precipitation and temperature are the meteorological parameters most associated to ENSO (Alexander and Barnett, 1998). Positive rainfall anomalies are observed in El Niño years, and negative anomalies prevail in La Niña years (Prieto, 2007). Another study suggests that the temperature amplitude in Northern Uruguay is reduced in El Niño years, and the mean temperatures throughout the whole country have a tendency to be lower in La Niña years (Bidegain and Krecl, 1999).

Solar activity is related to the Sun's output, which varies on a wide range of time scales. Sunspot number is the longest directly measured solar activity index available and is representative of the general state of solar activity (Hoyt and Schatten, 1997). Analysis of sunspot number time series allowed the identification of the two main characteristic periodic variations of the solar activity: the 11-year sunspot cycle (Schwabe cycle) and the 22-year solar magnetic cycle (Hale cycle) (Lang, 2001, Usoskin and Mursula, 2003). While the Schwabe cycle is mainly related to the irradiance variations (Fröhlich, 2011) the Hale cycle is mainly related to the modulation of galactic cosmic rays (Singh et al., 2011). Changes in solar irradiance and in galactic cosmic ray flux are suggested to be the triggers of the mechanisms that relate solar activity and Earth's climate (Kirkby, 2008; Gray et al., 2011; Kilifarska, 2011, Singh et al., 2011). Several studies have indicated that solar activity may affect climate variations (Rind, 2002, Bard and Frank, 2006). The search for possible influences of solar activity on the different meteorological or climatological parameters is one key element that has been widely used to prove the Sun–climate connection. The literature contains an extensive history of this issue (Rigozo et al., 2004, Valev, 2006, Kilcik et al., 2008, Dobrica et al., 2009, Souza Echer et al., 2009, Le Mouël et al., 2010). Despite the scientific works supporting the view that meteorological phenomena must respond to variations of solar activity, this subject is far from being settled (Tsiropoula, 2003, Lockwood and Frohlich, 2007). Several analyses of these records are fraught with problems in the methods, have biased data selection, or have questionable statistical significance of the reported correlations. Quality research indicates that the relationship between solar activity and climate is very complicated and varies with time and probably also with geographic position (Kilcik et al., 2009). On the global scale, the correlation between sunspot number and meteorological parameters may be positive, negative, or even zero (Zhao et al., 2004). However, for South America, few studies on this issue have been reported (Rigozo et al., 2004; Gusev et al., 2004; Rampelotto et al., 2008).

In this work spectral analysis was applied to centennial time series data of Santa Maria, Southern Brazil, in order to identify the main periodicities in rainfall and surface air temperature from historical records. These time series were also cross-correlated with possible natural factors that may influence the climate in this region.

Section snippets

Datasets

The monthly rainfall and temperature from historical records were obtained for Santa Maria—RS (29°41′S, 53°48′W, 151 m a.s.l.), Southern Brazil from 1912 to 2008. We also used the Southern Oscillation Index (SOI) time series obtained from the United States National Geophysical Data Center (http://www.ngdc.noaa.gov↗). Rz is the longest solar activity index of sunspot number (Rz), which was first compiled by R. Wolf in the XIX century and is available as annual averages since 1700 (Eddy, 1976; Hoyt…

Results and discussion

Fig. 1 shows the annual temperature (a) and rainfall (b) series data collected at Santa Maria from 1912 to 2008. At this location temperature varies seasonally with the higher values for January (30.6±0.9)°C and the lower for June (19.2±1.8)°C (Fig. 2a). Precipitation has a constant profile throughout the year with a mean of 144.7±11.4mm (Fig. 2b).

Fig. 3 shows the ARIST spectra variability for the (a) temperature and (b) rainfall time series. For annual temperature, the significant periods are: …

Conclusion

The Earth's climate is affected by several factors acting in different temporal and spatial scales. In this work, we analyzed the long term variability of rainfall and temperature (1912–2008) from Santa Maria (29°S, 53°W) and its possible connection with natural influences such as solar activity and ENSO. Temperature and rainfall time series present similar frequencies as revealed by spectral analyses. Our results indicate that in low frequencies, the 22-yr solar cycle is an important factor in …

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> …Using wavelet analysis, Scafetta and West (2005) found the solar signature on global surface temperatures using the ACRIM total solar irradiance satellite composite of Willson and Mordvinov (2003). Also, Rampelotto et al. (2012) used the cross wavelet between rainfall and temperature versus the ENSO and reported periodicities of 2–8 years; the cross wavelet of rainfall and temperature versus sunspot number allowed them to find the periodicity of the solar cycle (11 years). By applying the wavelet analysis of the total annual precipitation falling on Pelotas in southern Brazil, Souza Echer et al. (2008) reported periodicities of around 2–6 years.…

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> …Georgieva et al. (2012) established the different effects of two types of solar activity (sunspot number/geomagnetic activity indices) on atmospheric circulation, and their influence is opposite to the changes in North Atlantic Oscillation. Rampelotto et al. (2012) indicated that temperature and rainfall time series show similar frequencies; at low frequencies, the 22-year solar cycle is an important factor in climate modulation during the analysed period. The relationship between the Indian temperature anomalies and the solar activity (SSN) provides evidence in favor of the mechanism that depends not only on the level of sunspot activity, but also on the solar polarity (Aslam et al., 2014).…

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