The effect of the Tropical Southern Atlantic index in the monthly number of thunderstorm days in Rio de Janeiro from 1951 to 2009

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ABSTRACT: The goal of this study was to investigate if the variability of the annual number of thunderstorm days (TD) of Rio de Janeiro from 1951 to 2009 is related to any large scale weather phenomena. Wavelet, cross-wavelet and wavelet coherence analyses, as well as associated statistical significance tests, were used to investigate the frequency structure of TD as well as the Tropical Southern Atlantic Index (TSA), Southern Oscillation Index (SOI), the Pacific decadal oscillation (PDO) and the International Sunspot Number (ISN). Wavelet analyses indicated that the variability of Rio de Janeiro's TD can be primarily explained by two distinct significant ($p<0.05$) peaks of periodicity of 1 year and 12 years. The 1 year periodicity in TD is well established, being associated to the difference in temperature from summer to winter. Our results suggest that the 12 years periodicity in TD is mainly caused by fluctuations in the TSA. The cross-wavelet spectrum of the TD and TSA indicated a significant peak at 12 years. Furthermore, wavelet coherence demonstrated that the intensity of the 12 years periodicity of the TD and TSA were significantly positively correlated through time. The study concludes that TSA contributes significantly to the variability of the TD in Rio de Janeiro indicating it may be potentially used in TD forecasting.

1. INTRODUCTION

The identification and understanding of long-term periodicities in meteorological variables is a vital component of explaining the variability of natural phenomena. Furthermore, the understanding of the long-term fluctuations within a meteorological time series may aid in the construction of precise forecasting methods.

Although some natural phenomena have well-established long-term fluctuations in the order of decades (e.g. 11 year period in solar activity), thunderstorm occurrence have only been associated, for most part, to semiannual and annual cycles (Williams, 2009). A better understanding of thunderstorm day monthly data (TD) variability is crucial considering the economical relevance of this phenomenon. Some estimates indicate that the economical losses caused by lightning to electric power systems reach approximately 20 billion dollars in United States and one billion dollars in Brazil (Pinto et al., 2011). In order to minimize these problems, a reliable

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forecast of the thunderstorm activity in the summer period would be of great importance. A better understanding of long-term fluctuations and possible causes for such fluctuations in TD data is important for building such reliable forecasting methods.

TD data can be deeply influenced by the location where data is collected. TD data changes significantly with changes of latitude, altitude, proximity of the ocean, mountains and etc… As such, it is most likely that the causes for long term fluctuations in TD and possible forecasting methods may be different for different cities. In this study, our only concern is with the TD data collected from Rio de Janeiro, Brazil, an Atlantic coastal city of latitude 22º 55´S.

Assuming there is one or more significant long-term cycles in the TD data of Rio de Janeiro, we investigated the frequency structure of several climate indices during the same time period to find a possible explanation for such cycles. The Climate index related to the El Niño Southern Oscillation (ENSO) employed here was the Southern Oscillation Index (SOI). The SOI index is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin and sustained negative values of the SOI often indicate El Niño episodes. We also investigated a possible association between the TD and the temperature anomalies of the southern Atlantic Ocean using the Tropical Southern Atlantic (TSA) index. The TSA index represents the sea surface temperature anomalies (SSTA) in the Eq-20S and 10E-30W region. Additionally, we also investigated a possible indirect effect of changes in the Pacific Ocean surface temperature in the TD of Rio de Janeiro using the Pacific Decadal Oscillation (PDO). The PDO index is defined as the leading principal component of North Pacific monthly sea surface temperature variability. Finally, we investigate the possibility that solar activity may cause long term cycles in the TD of Rio de Janeiro using the international sunspot number (ISN) index. The ISN index stands for a visual sunspot counts as a measure of solar activity.

In order to determine possible linear associations between significant cycles in the TD and meteorological indices we used a mathematical tool known as wavelet coherence. This tool was needed since we were interested in the correlation of variations during the years of the intensity of a specific frequency of the time-series analyzed. This feat would certainly not be possible without using a time-frequency representation which in our study was attained with the wavelet transform.

The main goal of this study was to identify long term cycles that can partially explain the variability of thunderstorm day monthly data obtained in the city of Rio de Janeiro from 1951 to 2009, Brazil. Furthermore, by investigating the time-frequency representation of several global climate indices for the same period, we aim to find what may be causing long term periodicities in TD.

2. METHODS

Thunderstorm day monthly data in the city of Rio de Janeiro from 1951 to 2009 were used in this study. They are compared with data of the following large scale phenomena: El Niño Southern Oscillation - ENSO, characterized by the Southern Oscillation Index – SOI, the South Atlantic Ocean surface temperature, characterized by the TSA index, the South Pacific Ocean surface temperature, characterized by the Pacific Decadal Oscillation (PDO) as a proxy of the South Pacific Ocean surface temperature and the solar activity characterized by the International Sunspot Number (ISN). All data were provided by NCAR and NOAA.

2.1 Wavelet Analyses

To study the frequency content of the TD, SOI, TSA, PDO and ISN time series we used the *Morlet* wavelet transform (Equation 1). To investigate possible association between periodicities of the TD and the other meteorological indices we used the cross-wavelet and wavelet coherence methods. Wavelet, cross-wavelet, and wavelet coherence spectra were generated using Matlab functions developed by several research groups (Grinsted et. al, 2004; Neto et al., 2010; Torrence and Compo, 1998).

2.2 Statistics

Hundreds of surrogate data sets were constructed using Gaussian noise and first order autoregressive (AR1) processes. Significance levels (with α =0.05) were calculated separately for each scale and for wavelet, cross-wavelet and wavelet coherence estimations.

3. RESULTS

Wavelet analyses indicated that the variability of Rio de Janeiro's TD can be primarily explained by two distinct significant ($p<0.05$) peaks of periodicity of 1 year and 12 years (Figure 1). The 1 year periodicity in TD is well established, being associated to the difference in temperature from summer to winter.

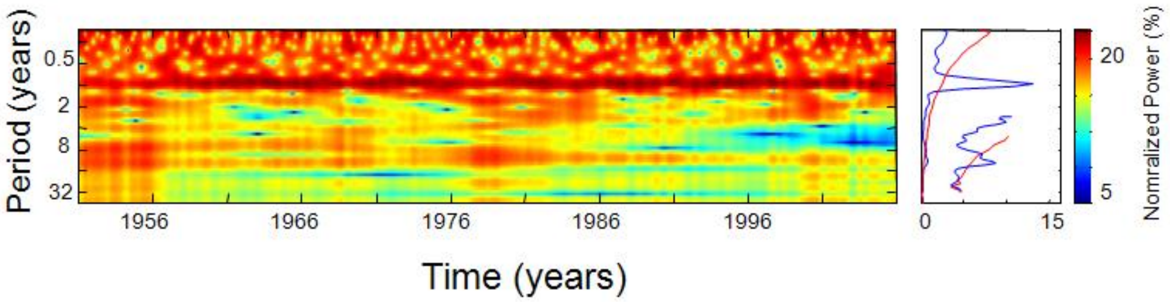

Figure 1 – Normalized wavelet spectrum of Rio de Janeiro's thunderstorm day monthly data from 1951 to 2009. The spectrum shows two significant cycles in the time series of 1 year and 12 years.

Cross-wavelet analyses indicated two significant common peaks at 1 year and 12 years between TD and TSA (Figure 2). This result indicated a possible association between the cycles contained in the TD and TSA.

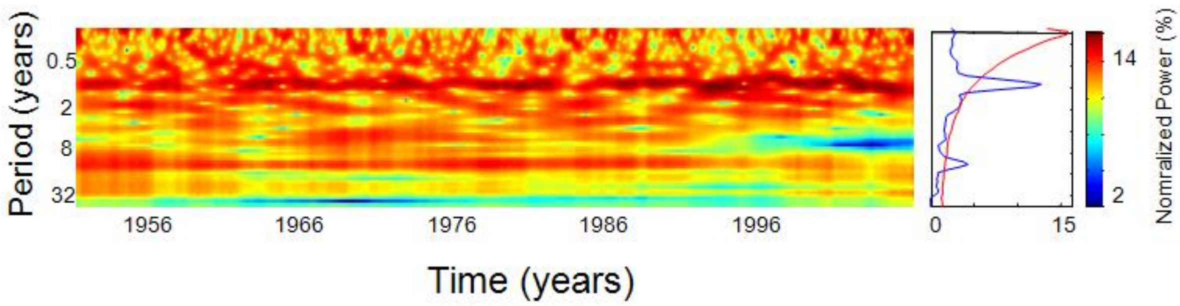

Figure 2 – Normalized cross-wavelet spectrum of Rio de Janeiro's thunderstorm day monthly data and the Tropical Southern Atlantic index from 1951 to 2009. The spectrum shows two significant peaks at 1 year and 12 years.

Wavelet coherence analyses indicated that only the 12 year period found for both the TD and TSA are significantly associated though time (Figure 3). This result suggest that the cause of long-term cycle in the thunderstorm activity in Rio de Janeiro may be caused by long term changes in the southern Atlantic Ocean sea surface temperature.

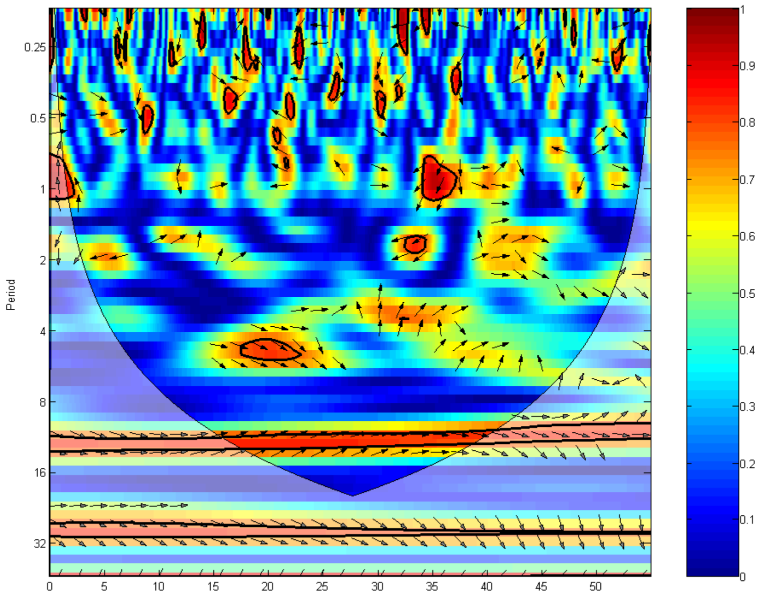

Figure 3 – Wavelet Coherence spectrum of Rio de Janeiro's thunderstorm day monthly data and the Tropical Southern Atlantic index from 1951 to 2009. The spectrum shows a significant correlation between the 12 year periodicity of the TD of Rio de Janeiro and the TSA index.

The same analysis was applied to the other parameters without significant results.

4. CONCLUSIONS

Our results suggest that there is a significant 12 years periodicity in the TD of Rio de Janeiro, most likely caused by fluctuations in the TSA. In other words, the study concludes that TSA contributes significantly to the variability of the TD in Rio de Janeiro indicating it may be potentially used in TD forecasting.

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