Detecting low frequency cycles in rainfall series from Colombian coffee-growing area
by using descriptive methods

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ABSTRACT

Descriptive statistical methods were used for improving climatic variability scenarios regarding rainfall using time series from five representative pluviometric stations (Miguel Valencia, Naranjal, Cenicafé, La Bella and Paraguaicito); such scenarios are used to make decisions regarding coffee-growing. The purpose was to find signs of cyclic behaviour besides those associated with El Niño Southern Oscillation (ENSO) which happens every 3.5 to 4.5 years. Signals were found of decadal to interdecadal cycle (10 to 30 years), modulating known ENSO effects related to periodic changes in the Pacific Ocean and solar activity.

Introduction

Climate cycle detection is an ancient topic; our ancestors thought that our life was governed by the seasons' rhythms; it would thus be logical to think that it would be the same in the long-term (Burroughs, 2004). One can now speak about climate cycles being associated with changes in the sun (climate engine) and other cycles related to the ocean (climatic regulator).

The most studied cycles from the former group are the 11-year cycle associated with sunspots and the 22-year cycle related to changes in the sun's magnetic field (Burroughs, 2004). The most important cycle in the second group is the 3- to 4-year cycle related to El Niño Southern Oscillation (ENSO). Mesa et al., (1997) found that hydrology and rainfall in Colombia are usually affected by cycles related to changes in the tropical Pacific Ocean's surface temperature than by any other cycle. ENSO's local climatic effects have a defined pattern; rainy years are associated with La Niña (negative phase) and dry years with El Niño (positive phase), as described by Guzmán & Baldión (1997 and 1999). Nevertheless, some very dry or rainy years do not correspond to La Niña or El Niño, i.e. dryness or wetness intensity are not associated with Oceanic Niño Index (ONI) intensity (Figure 1).

Some authors have found that cycles having longer periods than ENSO could modulate this phenomenon's effect on climate; several authors have found cycles having a 10-40 year rainfall series period since the earliest part of the 20th century. The most important work in Colombia has shown 16-year (Peña, 1982) and 35-year (Poveda et al., 2002; Poveda, 2004) related to special phases in solar motion (Landscheidt, 2001) and Pacific Decadal Oscillation (PDO) peaks which could be affecting ENSO's effects on climate (Verdon & Franks, 2006). The purpose of this paper was therefore to assess rainfall time series at five locations having an annual dataset going back more than 46 years in the Colombian coffee-growing area (a rain-fed crop system) to detect other cycles, apart from ENSO, which could be used as predictable patterns for annual rainfall forecasting.
Simple methodological approximations based on moving averages and semivariograms were used as an alternative to periodograms, which have been shown to have problems when used for determining the presence of cycles and oscillations (Hernandez, 1999), and the autocorrelation function whose results would not have been appropriate in exploratory analysis because correlation level significance would not have been high and the aim was to identify signals not to quantify them. Moving averages with Burroughs filter (eq.1) were used as in the mathematical expression shown for (eq.2).

Using running means or moving averages was common practice in climatology; although this was a powerful tool for reducing short-term fluctuations in meteorological time series, it became unused because unweighted moving averages could be inappropriate for explaining periodicity (Lewis, 1960). Therefore, Burroughs (1978) proposed moving averages with filters to improve the smoothness of meteorological series. Function (eq.1) is known as a seven-year triangular filter and its great advantage lies in effectively suppressing high frequency elements. Kutzbach & Bryson (1974) explained the importance of non-high frequency components in a climatological time series. Weighted moving averages can show cyclical time series' behaviour. However, the semivariance function was also used here for improving results. This function was thus estimated with the experimental semivariogram calculated according to Wackernagel (1995), as shown in (eq.3).

Data and Methodology

Five rain gauges were chosen having historical annual data sets going back a long way; they formed part of the Colombian Federation of Coffee Growers' meteorological network. The rain gauges were located in the coffee-growing area (C.G. Zone), between 4°24’ N (Paraguaicito Station) and 5°36’ N (Miguel Valencia Station) at different heights above sea level (in meters, masl) (Figure 2).
where $Z(x)$ is the value in $x$ time, $Z(x+h)$ is a value separated by $h$ time from the previous value and $n$ is the pair’s number separated by this time (and it is not constant). Semivariograms were drawn using a semivariance/sample variance ratio on the $y$-axis to have the same scale at all locations. As opposed to a geostatistical approach, where the aim is to fit a model to the experimental semivariogram to be interpolated, semivariograms were used in this work to detect signs of cyclical behaviour, i.e. it was used as a descriptive tool. Semivariance function could thus be inversely interpreted regarding the correlation function; when there is high semivariance there is a negative correlation, when semivariance is close to one there is no correlation, whereas there is positive correlation if there is low semivariance. Thus when there is cyclical behaviour, a semivariogram having high to low semivariance oscillations is expected when distance (time, in this case) becomes increased.
Figure 5. Hypothetical time series generated with the experimental semivariogram illustrated in Figure 4 (left-hand column). The right-hand column gives an experimental semivariogram for each series. 11-year period signal (a), 21-year period signal (b), 33-year period signal (c) and reconstructed series representing mean annual rainfall pattern in the area (d).
Figure 3 shows the annual rainfall's cyclic pattern recorded at five stations. Consecutive wet years alternated with consecutive dry years; the wettest periods in the area were 1971-1977 and 1996-2002 and the driest periods were 1977-1983 and 1989-1995. There was an exceptional period having greater annual rainfall in the longer time series: 1951-1957.

Overall, 12 to 18 years between crests (rainy years) were noticed in weighted time series. In spite of the fact that there were more “La Niña” months (and more intense cooling in the Pacific Ocean) between 1971 and 1977 than between 1996 and 2002, the latter period was rainier regarding 1971–1977. It was not related to ENSO effects, at least not completely because when “La Niña” occurred there was greater rainfall in the area (Guzman & Baldión, 1999). Similar results were obtained when the driest periods were analyzed; there were less “El Niño” months between 1977 and 1983 than between 1989 and 1995; however, the dry period was longer after 1977.

Figure 4 shows signs of periodical variability in annual rainfall time series. Three signals (decadal, bi-decadal and interdecadal) occurred at almost all stations which other authors have associated with sunspots (Burroughs, 2004; Hiremath, 2006), solar magnetic cycles (Almeida, 2004) and ocean phenomena such as PDO and North Atlantic Oscillation (NAO) (Poveda, 2004; Tourre et al., 2001). Three hypothetical time series (n=65) were calculated for each signal (11, 21 and 33 years), having values between -1 and 1 to obtain a reconstructed series by summing representing mean annual rainfall pattern in the area (Figure 5).

The reconstructed series representing mean annual rainfall pattern (Figure 5d) was compared to the smoothed time series (running means with Burroughs filter) for La Bella and Cenicafé locations. A relationship was found between running mean series and bit-lagged reconstructed series (Figure 6).

The results showed that signs of low frequency cycles could be detected in annual rainfall series by using simple statistical methods related to a description of variability and that there were relevant cycles in rainfall
series which could have been modulating ENSO effects. This occurred because sea surface temperature time series’ semivariance function (Equatorial Pacific Ocean) was related to ENSO phenomenon, showing signs of cycles having one- and three-decade periods as rainfall series (Figure 7), whereas a two-decade cycle would mostly be related to an 18.5 year cycle associated with the PDO’s moon-tidal cycle (Currie, 1991; Yasuda, 2009).

References


