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POWER LAWS GOVERNING THE RELATIONSHIP BETWEEN THE EL NIÑO SOUTHERN OSCILLATION AND VECTOR BORNE DISEASES

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Abstract: - The el Niño Southern Oscillation (ENSO) exerts a marked effect over the propagation of vector borne diseases in Colombia, In particular for Malaria and yellow fever. We found that for malaria the correlation with SOI is negative with r=-0.76. Also, for Yellow Fever, we found a negative correlation with SOI of -0.54. Our results indicate that Public Health programs in Colombia must take into account climatic events in order to prevent future outbreaks of these diseases because of the power law dependence between them and ENSO.

Key-Words: - El Niño, Power-laws, Fractals, Malaria, Yellow Fever.

1 Introduction

The El Niño Southern oscillation (ENSO) is an oceanic-atmospheric phenomenon which exerts a very marked effect in precipitation, humidity and temperature all around the world, leading to catastrophic climatological changes in extensive regions in the five continents. Usually, ENSO is measured by the Southern Oscillation Index (SOI), the normalized atmospheric pressure difference between Darwin in Australia and Tahiti in the South Pacific. ENSO has two opposite extremes, recurring over a 2 to 7 years cycle. At one extreme of the cycle (El Niño), the SOI is negative and both temperature and rainfall are below average in the west pacific, and above average in central and eastern areas. At the other side (La Niña) , the SOI is positive and the opposite climate patterns occurs. This outmost behavior provides an opportunity to study the impact of strong climate variations on the spreading of vector borne diseases. In accordance with, Epstein et.al.(1), suggest that extreme climatological events, like abnormal warm and wet weather, can create conditions conducive to multiple disease outbreaks, especially of vector-borne ones, by enhancing mosquito breeding, biting and pathogen replication.

Several studies have reported a relationship between the SOI and vector-borne diseases spreading. Nicholls (2) related ENSO to patterns of viral encephalitides. Bouma et.al.(3), established a consistent correlation between ENSO and the historic malaria epidemics in India and Sri Lanka, also Cuevas et.al.(4) describe a correlation between the SOI and malaria in Colombia. Hales, Weinstein and Woodward (5) found a positive correlation between the SOI and dengue fever epidemics in the South Pacific.

As many other natural phenomena, the climate behavior posses a nonlinear dynamics i.e. proportionality between causes and effect does not hold, small changes can have striking and unanticipated effects (6). Thus, there are no obvious discernible patterns to the dynamics, the system returns again and again to the same steps, but never in a regular fashion, describing what is known as a self-similar behavior. Statistical approaches to the study of non-linear systems have showed that, under different increments of time, their statistical characteristics remains, which means that nonlinear systems are governed by fractal processes (7). Fractal processes are organized following scaling or power laws (a real number raised to a power) which emerge from the spatio-temporal extended interaction of the different components of the system (8,9). An important feature of those systems driven by power laws is their complex structure, they are the result of deterministic as well as random events leading to an apparently noisy time series distribution. Regarding the nonlinear nature of epidemics, temporal changes in the incidence of measles virus infection within large urban communities in the developed world have been the focus of much discussion in the context of the identification of nonlinear and chaotic patterns in biological time series (10). Moreover, Rhodes and Anderson (11), described how power laws are governing epidemics in isolated populations, and Woolhouse et.al.(12) showed that a power law, the 20/80 rule, generates heterogenities in the transmission of a variety of infectious agents, including vector-borne diseases like malaria, leishmaniasis and schistosomiasis and also in HIV and bacterial STDs. These results indicates the preponderal role that power laws can exert over some disease systems.

In this paper we established that ENSO is governed by a power law with scaling exponent $b \approx 1.31$, indicating that ENSO like other natural phenomena v.gr. earthquakes, occurs following scaling or fractal distributions. Also, we applied fractal analysis to malaria and yellow-fever time series in Colombia, establishing that not only these diseases are ruled by power laws, but there exist a significative inverse correlation between SOI and malaria ($r = -0.76$) and between the SOI and yellow-fever ($r = -0.54$).

Our results suggest the existence of scaling laws controlling ENSO events and also power laws governing malaria and yellow-fever epidemics. This places the dynamics of these complex systems in the same class as other spatially extended nonlinear dynamical systems.

2 Statistical methods

Data concerning a time series of fifty years of the SOI were obtained from climatological data bank of the Colombian Pacific coast, and were kindly provided by Dr. Daniel Pabón of Instituto de Metereología y Estudios Ambientales (IDEAM) of Colombia. From **figure 1A** it is appearent that there is no obvious discernible pattern to the dynamics; clearly, there is a wide variation in both the duration and size of ENSO events, like the sort of dynamics observed in the study of earthquakes, mass extinctions (13) and capital markets (14). In these cases a power law acts as an organizing principle connecting the frequency and magnitude of larger and smaller events. Performing this kind of statistical analysis here, we counted the number (N) of the SOI of size > s, there is a power or scaling law dependence of the form $\log N (> s) = a - b \cdot \log (s)$. Thus, the number of the SOI of size s scales as $N(s) \propto s^{-1-b}$, where b is the scaling exponent that connects the frequency and magnitude of the larger and smaller SOI events.

On the other hand, time series of malaria and yellow-fever epidemic events were obtained from Grupo de Parasitología del Instituto Nacional de Salud of Colombia. In this case we counted the number (N) of epidemic events of size > s, and studied the functional relation between the log N (> s) and log (s) in order to determine the scaling exponents of the malaria and yellow-fever outbreaks.

To study the SOI-malaria and the SOI-yellow fever relationships, and following the same strategy succesfully employed in the study of mass extinctions and also in econometric analysis, we choose the preponderal events, the greater and lower indices in ENSO (mean ± 2 SD) and the greater epidemics outbreaks of both diseases (mean ± 2 SD). Finally, we plotted these preponderal events in the same cartesian plane,and the correlation coefficients (r) between these plots was estimated employing standard statistical methods.

As we pointed out before, an important feature of nonlinear systems driven by scaling laws is their complex structure, they are the result of the combination of deterministic as well as random events producing an apparently noisy time series distribution. Thus, the preponderal events corresponds with the deterministic features of the system.

3 Results

The results suggest that a power law acts as an organizing principle connecting the frequency and the magnitude of ENSO events. As is shown in **figure 1A**, the SOI follows a power law with b ≈1.31 indicating that there exist heterogenities in the ENSO dynamics, with small short events ocurring more often than large long events, but these large oscillations corresponds to a few particularly pronounced El Niño years. Thus, the scaling behavior of ENSO indicates a long range correlation between the successive ‘warm’ and ‘cold’ events i.e. a particularly strong El Niño event could exert its anomalous effect over other climatological phenomena after several years of its occurrence. Also, **figures 1B and 1C** showed that both, malaria and yellow-fever are governed by power laws with scaling indices b ≈ 1.32 and b ≈ 1.22 respectively. In these cases, small short epidemic events occur more often than large long events.

As is shown in **figures 2A and 2B** respectively, a very significative inverse correlation between the SOI and malaria was observed, presenting a correlation coefficient of -0.76. Also an negative correlation was observed between the SOI and yellow-fever with a coefficient of -0.54.

4 Discussion

In the present study we have found that ENSO is governed by scaling laws i.e. ENSO dynamics is ruled by a fractal statistical distribution. This result is consistent with a nonlinear, self-similar behavior of this climatic phenomenon. The origin of scale-free dynamics in natural systems remains obscure, although the idea that fluctuations over all timescales and power laws are a direct consequence of autoorganizative processes, in accordance with a model kown as Self-Organized Criticality (SOC) (9), which remains actually as a possible explanation of the observed self-similarity in a broad range of natural phenomena. In SOC models, the heterogeneity in the interaction between the different components of the system naturally lead to the autoorganization of that system.

Our result also indicates that malaria and yellow-fever epidemics in Colombia are also governed by power laws, suggesting that the connectedness of the spatial distribution of the population in affected areas plays a central role in the transmission dynamics of the studied epidemics. As Rhodes and Anderson pointed out (11), scaling behavior of epidemics reflects the active social interaction between individual hosts i.e., scalarity is based on the dynamics of the social networks inside of the communities. On the other hand, Woolhouse et.al.(12) suggest that heterogeneous contact is likely to be an important determinant of the epidemiology of vector-borne diseases. They found that different host-parasite associations are governed by a 20/80 rule (a power law) regarding the relative magnitude of the transmission potential (over 80 %) made by a small fraction (20 %) of the host population. This fact has as consequence the observed aggregated distributions of infection and disease within the host population such that a few host are rapidly and heavily infected, while the majority evade infection or suffer light infections. Thus, the active social network inside the communities living in malaria and yellow-fever zones in Colombia, usually relatively isolated populations, and the heterogeneity in transmission rates contribute to the nonlinear spreading of this vector-borne diseases.

We found a very significant negative correlation between the SOI and malaria (r = - 0.76) and negative correlation (r = - 0.54) between the SOI and yellow-fever. This result indicates that when the SOI presents its lower values the malarial events experiment a vertiginous increment, a similar behavior is observed for the relationship between the SOI and yellow-fever.

It is important to note, that lower values of the SOI has as consequence a rainfall reduction which causes rivers to pool, creating abundant breeding sites, enhancing vector longevity and population density. Under these conditions, the likelihood that an infected vector will survive long enough to be infective, feed on susceptible hosts, and transmits disease is very high, increasing in an abnormal way, the levels of parasite and viral burdens among exposed hosts, creating and probably enhancing, the above described highly infective group among those populations exposed to vectors.

Given that ENSO is also governed by scaling laws, its coupling with power laws ruled diseases will lead to extremely severe epidemic events, especially concentrated in strong ENSO years, leading to the widely acknowledged global emergence, resurgence and redistribution of infectious diseases.

Fractal analyses demonstrates that the impact of ENSO over vector-borne diseases may be higher than usually has been assessed. For example, Cuevas et.al. (4) described a correlation coefficient r = - 0.51 between malaria and the SOI. In contrast, in our survey we found a coefficient r = - 0.76 between malaria and ENSO. We would like to emphasize that in the first study, conventional statistical analyses were employed, whereas in our study, fractal statistics was applied. The difference in results may be attributed to the employment of fractal methods to analyze systems ruled by scaling laws. Probably higher correlations could be detected between ENSO and other vector-borne diseases when the nonlinear nature of both systems is taken into account.

In practice, our analysis facilitates a form of prediction in which we can estimate the frequency of occurrence of ENSO of a given size and duration. In the same way, prediction concerning the frequency of occurrence of malaria and yellow-fever epidemics of a given size and duration could be assessed employing scaling analysis.

Our finding that ENSO is governed by power laws, and the possibility that ENSO can exert stronger effects over infectious diseases propagation than usually is expected, must lead meteorologists, environmentalists and public health officers to develop appropiate measures of surveillance and control of vector-borne diseases.

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Figures:

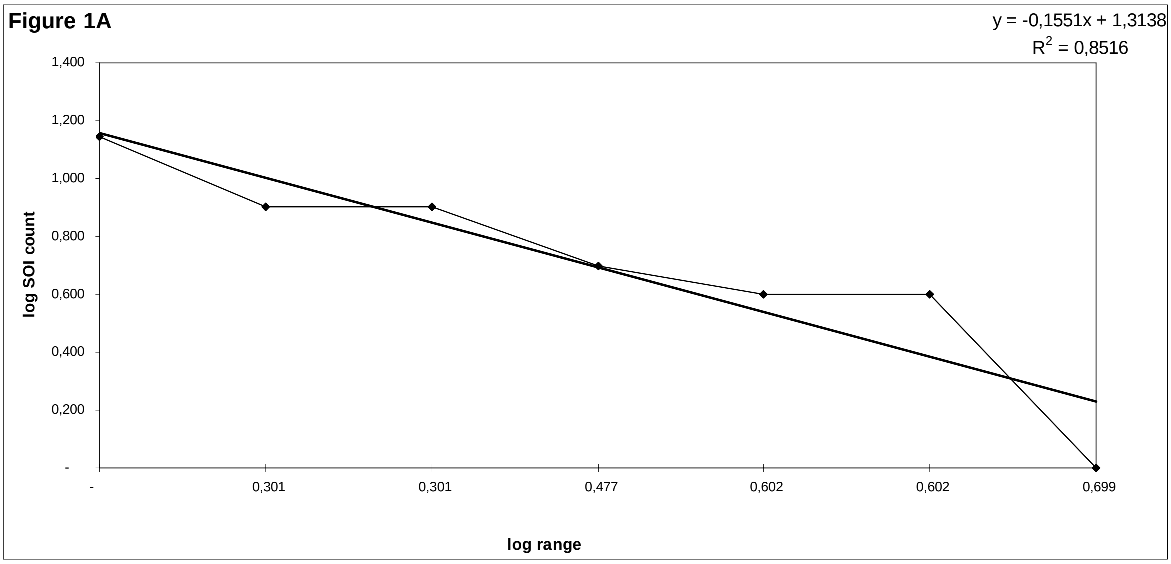

Figure 1 A: Bilogarithmic Analysis for the SOI.

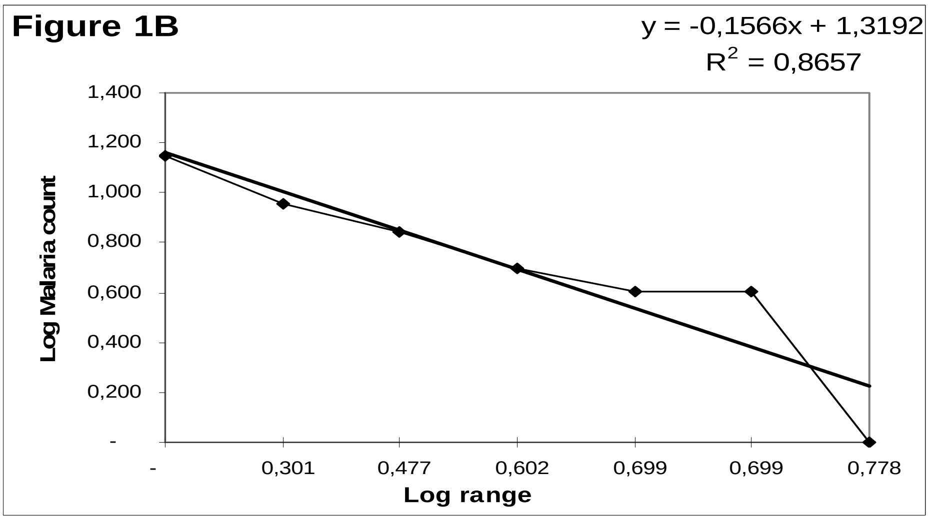

Figure 1 B: Bilogarithmic Analysis for Malaria Cases in Colombia Since 1950.

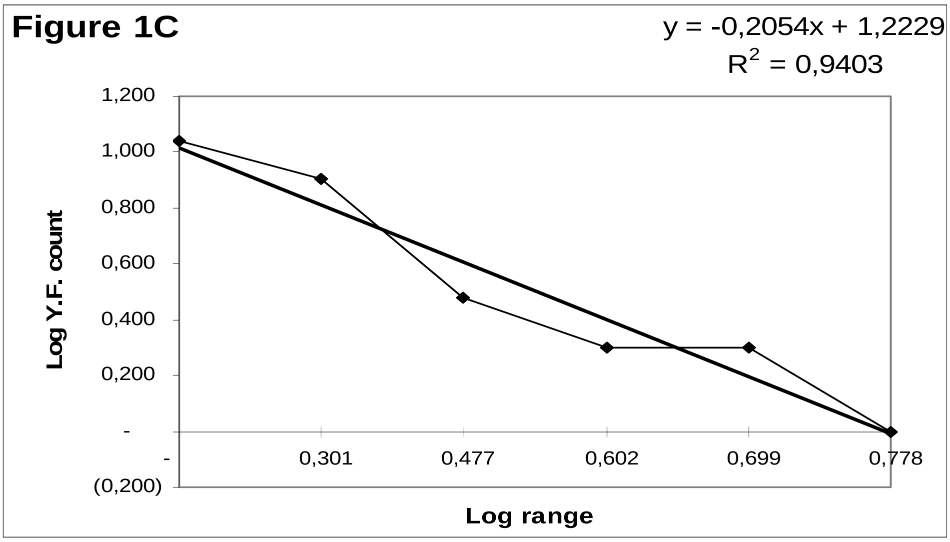

Figure 1 C: Bilogarithmic Analysis for Yellow Fever Cases in Colombia Since 1970.

Figure 2 A: Correlation Analysis (r= -0.76) for Standard Pressure and Malaria Cases in Colombia

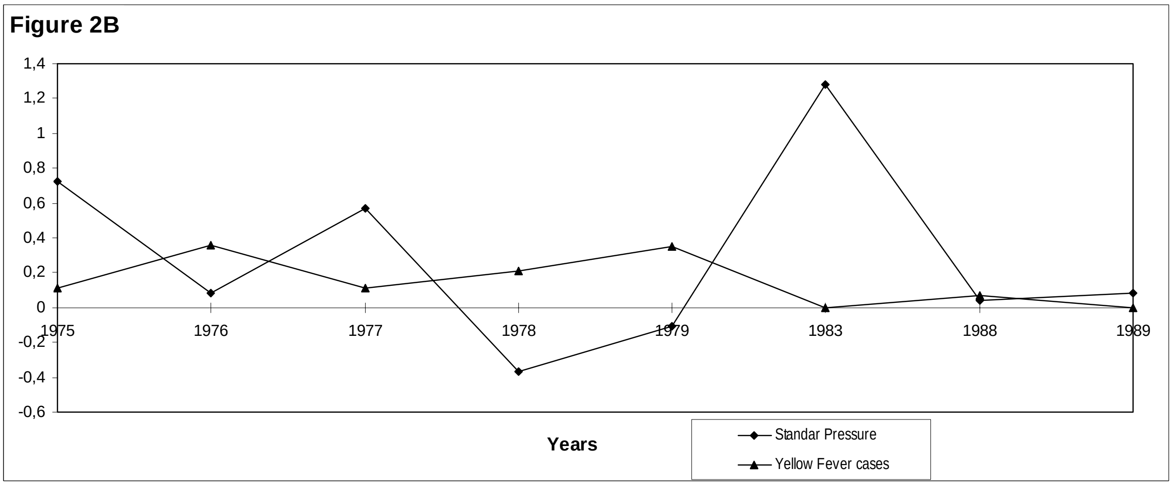

Figure 2 B: Correlation Analysis (r= -0.54) for Standard Pressure and Yellow Fever Cases in Colombia