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Critical Phenomena of Rainfall in Ecuador

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Abstract: Self-organized criticality (SOC) is characterized by a power law behavior over complex systems like earthquakes and avalanches. We study rainfall using data of one day, 3 hours and 10 min temporal resolution from INAMHI (Instituto Nacional de Meteorología e Hidrología) station at Izobamba, DMQ (Metropolitan District of Quito), satellite data over Ecuador from Tropical Rainfall Measure Mission (TRMM,) and REMMAQ (Red Metropolitana de Monitoreo Atmosférico de Quito) meteorological stations over, respectively. Our results show a power law behavior of the number of rain events versus mm of rainfall measured for the high resolution case (10 min), and as the resolution decreases this behavior gets lost. This statistical property is the fingerprint of a self-organized critical process (Peter and Christensen, 2002) and may serve as a benchmark for models of precipitation based in phase transitions between water vapor and precipitation (Peter and Neeling, 2006).

Keywords Self organized criticality, rainfall, data resolution, TRMM, REMMAQ, INAMHI.

Introduction

SOC is a theoretical model for complex systems proposed by Bak, Tang and Wiesenfeld in 1987. Critical phenomena occur near phase transitions. That is, when a tuning parameter crosses a critical value, an order parameter obeys a power law. When these parameters couple, the critical point becomes an attractor and the result is a SOC phenomenon (Yeomans, 1992). A power law behavior is represented by the following equation (Ec. 1)

$$N(M) \alpha M^{\tau} \quad (1),$$

where $N(M)$ is the number of events with a given magnitude M, and τ is an exponent which reflects the scale-free behavior, benchmark of SOC (Peters *et al.* 2002).

Although this concept has been applied in many different processes ranging from geophysics (Olami et al., 1992), evolution (Raup, 1986) to economy (Mandelbrot, 1982); meteorology is a new area where tradionally has being considered as chaotic systems far from self-organization.

Rainfall as a fluid is described by Navier Stokes nonlinear differential equations that have no analytical solution and as a result its behavior is difficult to predict (Palacios et al, 2009). Nevertheless, this system was conceived as an evaporation process (energy accumulation), followed by abrupt energy dissipation (rainfall) (Arakawa and Schubert, 1974). This system is in balance between slow driving large-scale processes of buoyancy and rapid release by moist convection, is called quasi-equilibrium. And this is the theoretical scheme which agrees with SOC: a system that accumulates energy and releases it through events of different sizes ranging from too small rains to heavy storms, i.e a scale-free behavior (Peters and Christensen, 2002), (Serrano and Basile, 2012).

This scheme is rooted in complex systems theory and does not come from dynamical non analytical differential equations. Therefore it offers a complementary understanding of these unpredictable weather events. Besides, this approach to study weather phenomena is quite recent (Peters, 2002) and new in Ecuador. It could provide a reliable description of the Andean equatorial weather patterns. Weather in the Andes has many peculiarities due to location and topography, and so it is beyond fluid dynamics.

However, in the study of rain the power law behavior (Ec.1) is not evident with all the available data, the majority of which are annual, monthly or daily, due to the effort involved in national meteorological services to provide higher resolution data. The aim of this study is to determine the influence of the temporal resolution on the critical behavior observed in precipitation data. To this we study the power law behavior of precipitation data at three levels of resolution: one day, three hours and ten minutes.

Materials and Methods

This study took three types of rain data with different temporal resolution and rank. First, was INAMHI`s 30 years of daily resolution data obtained from Izobamba station, located at 0°22`S and 78°33`W and 3058 masl into the DMQ (Fig. 1). Second data type were six years of TRMM satellital data with a temporal resolution of 3 hours over all Ecuador (Fig.1). Finally, six years of four REMMAQ meteorological station data this had the highest resolution available of 10 min, inside DMQ. The stations characteristics are detailed in Table 1.

Table1. Weather stations of REMMAQ network used in this study.

Station	Code	Latitude	Longitude	Altitude [m]
Cotocollao	COT	0°6'28" S	78°29'50" W	2793
Carapungo	CAR	0°5'54" S	78°26'50" W	2660
Belisario	BEL	0°10'48" S	78°29'24" W	2835
Los Chillos	LCHI	0°18'00" S	78°27'36" W	2453

Results

Each data set was calculated by a precipitation histogram, counting the number of rain events against size. In the case of Izobamba´s daily data, the power law behavior is not evident. The reason seems to be due to the accumulation of precipitation amounts along one day. Thus, the actual intensity of the precipitation is not evident, since rain events can last from minutes to hours, or even more. At that time, the graph which should look like a straight line on this log-log scale is skewed to the right, forming a kind of hump (Fig.2).

In the case of satellite data acquired by TRMM, because these have a higher resolution of 3-hours can visualize a behavior with a more linear trend in the log-log graph (Figure 3). This behavior seems to occur because in this case the precipitation accumulates every 3 hours, and therefore it better approximates the real behavior of the precipitation.

Finally, when analyzing the data with the highest resolution available in this study, equal to 10 minutes, can see that the behavior is almost linear (Fig.4), i.e that it satisfies the power law. Given that there is little rainfall with an intensity of less than 10 minutes, is evidenced that only increasing the resolution of the device in order to capture the true intensity of the studied event, it will be able to show their critical behavior. This occurs in each of the stations studied, Cotocollao, Carapungo, Belisario and Los Chillos located into the DMQ.

Discussion

SOC phenomena appear in precipitation data, but it is not evident if the temporal resolution of the instrument is low. Then apparently, the free scale does not imply the fact "split" a particular event at a given scale. It is necessary to consider the true magnitude and duration of the event just in this case will become evident the critical behavior.

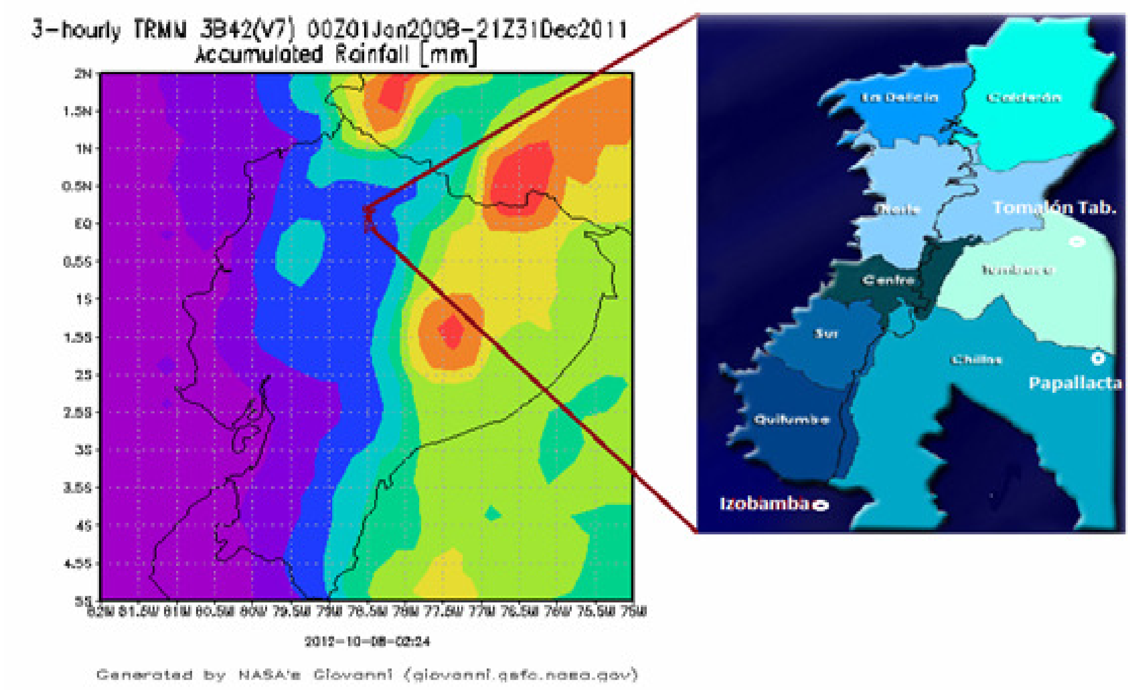

Figure 1. Data used in this study, 30 years daily data from Izobamba, meteorological station of INAMHI, six years of TRMM precipitation satellital data with a resolution of 3 hours. And 12 years of 10-minute resolution from 4 meteorological REMMAQ stations. Font of the caption: REMMAQ and Giovanni Services GES-DISC.

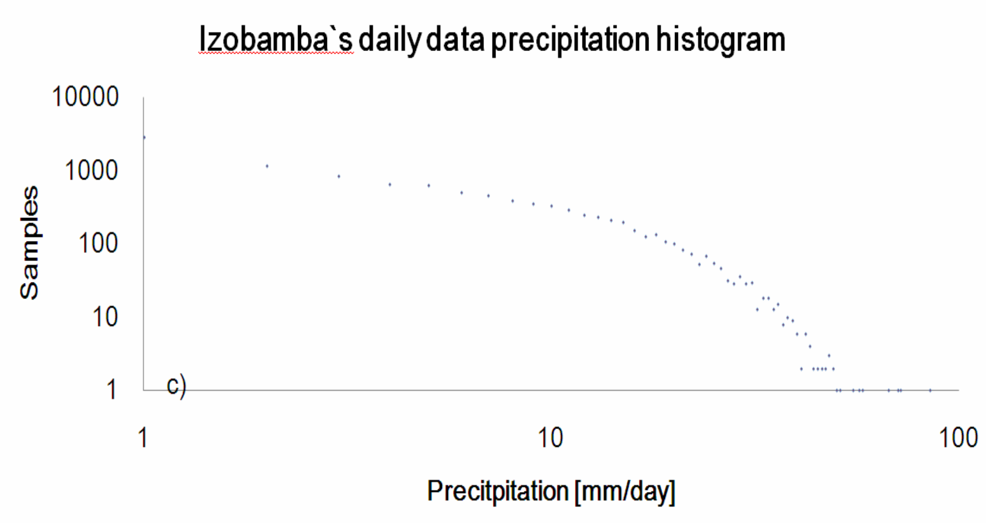

Figure2. Frequency histogram in log-log scale of the intensity of precipitation accumulated in a day, recorded in 30 years from Izobamba weather station.

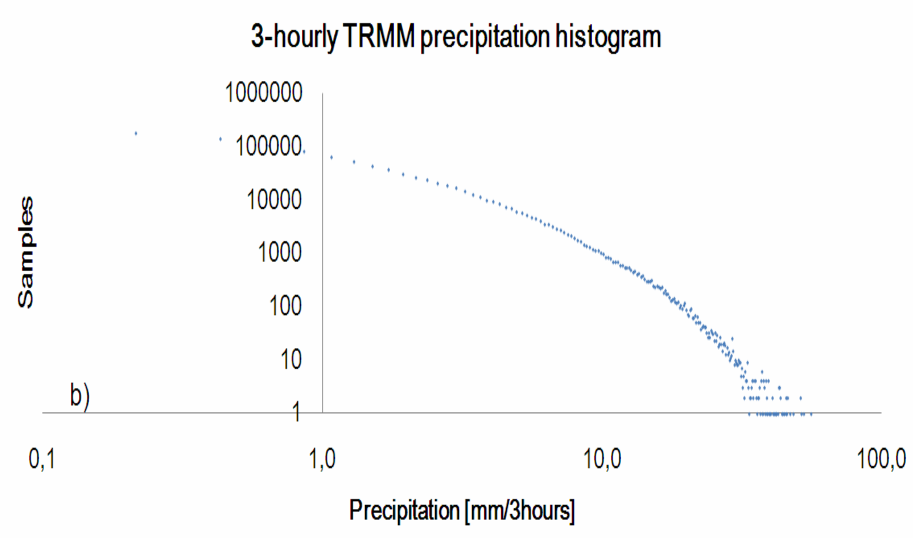

Figure3. Frequency histogram in log-log scale of the intensity of precipitation accumulated in 3 hours, recorded in 6 years from TRMM satellite.

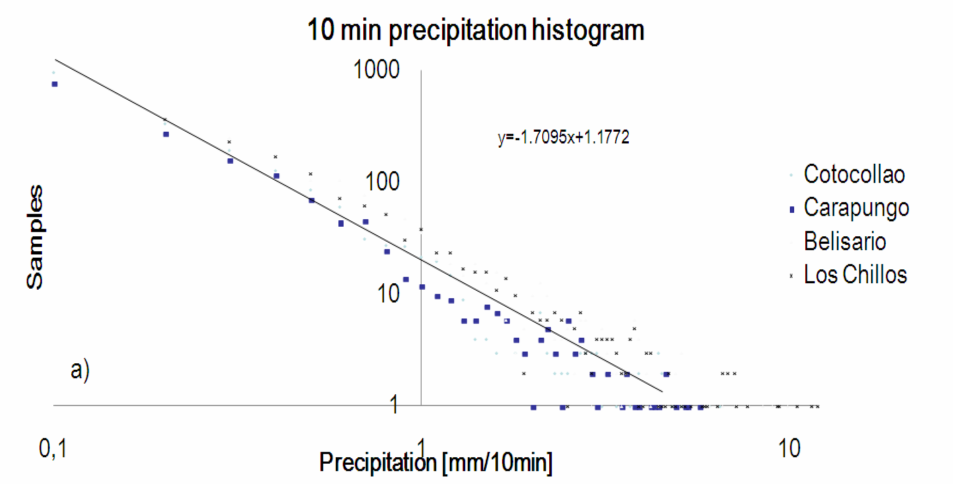

Figure4. Frequency histogram in log-log scale of the intensity of precipitation accumulated in 10 minutes, recorded in 6 years from REMMAQ meteorological stations of Cotocollao, Carapungo, Belisario and Los Chillos.

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