E1-504: Evidence of self organized criticality in rainfall

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Rainfall is a product of a number of complex processors having completely different temporal and spatial characteristics. The hypothesis that rainfall might be a case of self organized criticality was tested using rainfall records from the dry zone of Sri Lanka. The time series data of the daily rainfall records for the time period 1900-2000 was used in this work.

It was shown that the wet spells and dry spells distributions exhibit an inverse power law form $f^{-\tau}$ with τ ranging from 1.01 to 1.95. The intensity of rainfall deviates from the power law behaviour except in extreme events. In general, the daily rainfall data records from the dry zone show the presence of a Self Organized Criticality (SOC) phenomena characterized by scaling extending to a few orders of magnitude. Since the rainfall dynamics in the dry zone seem to be governed by SOC, the long range spatial and temporal correlations can form the basis for the development of statistical prediction models.

Acknowledgment: *Financial assistance by National Research Council of Sri Lanka (NRC grant number 06-18) is acknowledged.*

Proceedings of the Annual Sessions, SLAAS, 66 (2010) E1-504

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1. INTRODUCTION

After the introduction of fractural concepts, numerous examples of scaling behavior in natural events were discovered. It is generally believed that any complex dynamical system could be reduced to a small set of simple differential equations. Concept of Self Organized Criticality (SOC) introduced by Bak et al (1987) has shown fractal behavior in complex systems such as earthquakes. SOC provides a general mechanism for the emergence of complex natural process.

Rainfall is a product of number of complex processors having completely different temporal and spatial characteristics. It has been long studied by means of statistical methods. Studying rainfall still continues for the purpose of preventing natural disasters and planning hydrological systems. Since rainfall dynamic is too complex to describe with known statistical techniques, evidence of self organized criticality in rainfall may provide the necessary link between spatial and temporal correlations. The SOC mimic two common properties (i) the ability to store some energy for some time and (ii) the avalanche like release of energy when a certain threshold is reached. The avalanches like energy releases close a cycle which is repeated over and over again. The steady state behavior is characterized by power law behaviour of several quantities: relative frequency N of avalanches releasing energy E,

$$N(E) \sim 1/E^{\alpha}$$

In this paper the evidence for SOC behavior in long term data records of rainfall in dry zone of Sri Lanka was investigated. Study specifically looked at power law or hyperbolic distributions of extreme events. Presence of such a behavior provides the necessary evidence for SOC behavior in rainfall dynamics.

2. METHODOLOGY

Daily precipitation records for 10 weather stations located in dry zone were selected for this study (see Figure 1). The data were obtained from the Meteorology Department of Sri Lanka. The smallest and largest time series data sets have 30 and 100 years of daily precipitation data.

Following data sets were created with respect to three precipitation categories; (i) without rain interval (length of dry spells), (ii) interval with daily rainfall (length of wet spells) and (iii) rain intensity. The intervals without rainfall I represent the drought periods. These time intervals could be said as the waiting times between two outbursts or the time taken by the system to restore energy again. The rain duration *R* is the life time of an outburst. Rain intensity then could be said as the amount of energy released in a single outburst. The distributions $n(x)$ of events with property x which behaves as $N(x) \sim x^{-\tau}$ are usually analyzed with cumulated distribution. For this study the relevant data were cumulated in logarithmic bins and was plotted on a double logarithmic scale.

Table 1: Summary of the data sample

Station Name	Time period (Years)	Latitude °N	Longitude °E	Altitude (m)
Trincomalee	70	08, 35	81, 15	3
Vavniya	70	08, 45	80, 30	98
Puttalam	68	08, 02	79, 50	2
Mannar	70	08, 58	79, 54	4
Mahailluppallama	30	08, 07	80, 28	138
Medawachchiya	30	80, 48	8, 55	95
Nochchiyagama	30	80, 20	8, 27	16
Mihinthale	30	80, 52	8, 35	16
Maradankadawala	30	80, 57	8, 13	137
Anuradhapura	69	08, 21	80, 23	93

The duration of wet spells (duration of outbursts) and dry spells (waiting time) were not directly available in data. It was assumed that the rain has continued when two consecutive days have rainfall greater that 0.3 mm values. Intervals without rainfall are the consecutive days having less than 0.3 mm rainfall. Any day with rainfall below 0.3 mm was taken as a dry day.

3. RESULTS AND DISCUSSION

The rainfall events can be tested to find the presence of SOC behaviour according to the power law described in the previous section. Figure 1 shows a typical result for the wet spell distribution function N(*R*) for the dry zone (Mahailluppallama). The data exhibit power law behavior with τ=1.48. This could be regarded as a strong evidence for SOC to be presence in the precipitation dynamics.

The SOC behavior in rain intensity *R*, was seen only for extreme events. The best distributions were seen for Anuradhapura (τ=1.311) and Vavniya (τ=1.279) stations. The reasons for the lack of power law behavior in the intensity distributions are yet to be investigated.

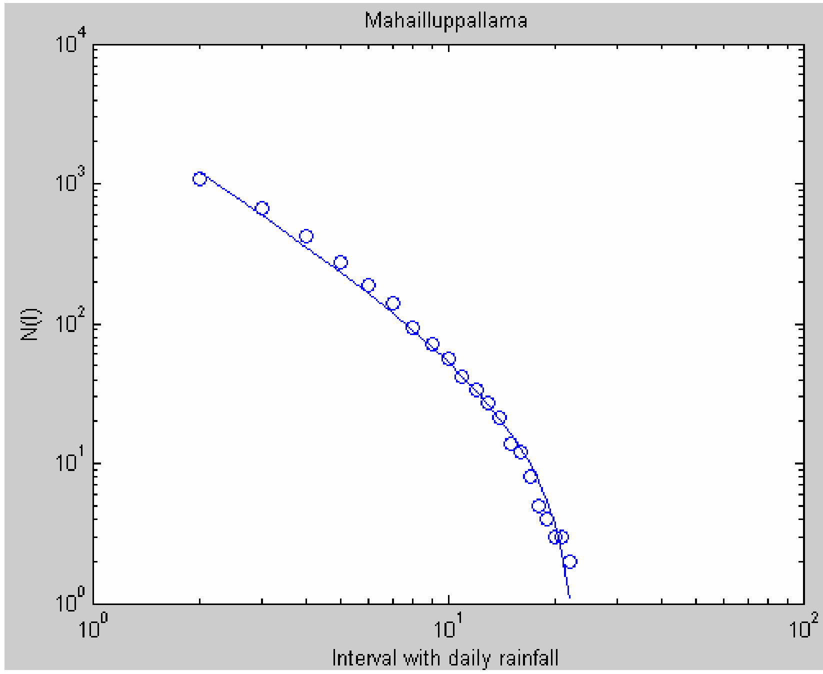

Figure 1: Log-log plot of the distribution function N(R) for the rain spell for Mahailluppallama (τ =1.48).

The SOC for the dry spell distribution also show reasonable power law behaviour. Since the largest event value is relatively small, it is difficult to analyze extreme events for scaling behaviour for many orders of magnitude in the dry zone. With the presence of SOC phenomena it can be decided that the extreme events are periodical. Even though the waiting time statistics should have the same characteristic as the rain intensity, the study did not show correlation between the two events.

The τ values vary between 1.01 and 1.95 for the dry zone.

4. CONCLUSION

Long term daily rainfall data of dry zone of Sri Lanka show the existence of power law behavior. This strengthens the link between the SOC and the rainfall. Since the rainfall dynamics is governed by SOC we could expect the rainfall dynamics to have a periodical behavior. This leads to the development of new statistical models for prediction of extreme events. The non existence of power law behavior in some stations could be a result of underline trends observed in them. The study could be further improved and accurate results could be obtained with a high precision data set.