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Full Length Research Paper

Discriminating climatological regimes in rainfall time series by using the Fisher-Shannon method

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The Fisher-Shannon (FS) information plane, defined by the Fisher information measure (FIM) and the Shannon entropy power (N_x), was robustly used to investigate the complex dynamics of 8 long monthly rainfall time series in central Argentina, recorded from 1860 to 2006. In the FS plane, the rainfall series seem to aggregate into three different clusters corresponding to three different climatological regimes in central Argentina. Our findings suggest the use of the statistical quantity defined by the FS information plane as a tool to discriminate among different climatological regimes.

Key words: Rain, Fisher information measure, Shannon entropy.

INTRODUCTION

Changes in weather and climate are impacting on socioeconomic and natural systems, and future changes associated with continuous warming will present additional challenges (Al-Amin et al., 2011; Shirazi et al., 2011). Precipitation is a key climate variable, as its variability affects different areas of the globe (Jones and Mann, 2004; Xoplaki et al., 2005; Touchan et al., 2003, 2005). Trends in precipitation series were observed on both global and hemispheric scales during the 20th century, which may influence future water supply (Easterling et al., 2000; Folland et al., 2001; Touchan et al., 2003, 2005; Xoplaki et al., 2004). Techniques for the evaluation of trends in rainfall were performed worldwide (El-shafie et al., 2011; Obot et al., 2010). A strong positive trend in precipitations during the second half of the 20th century characterized the central zone of Argentina. Considerable climate variability was reported in this region at various temporal scales, from a decadal-scale enhancement of spring/summer precipitation as presented in Castañeda and Barros (1994) to inter-annual variability associated with the El Niño-Southern Oscillation (ENSO) phenomenon (Vargas et al., 1999; Grimm et al., 2000; Rusticucci and Vargas, 2002). In southern Brazil and Northern Argentina, recent studies (Camilloni, 2005a, b) have detected increased rainfall and river discharge in the region since the mid-1970s. These increases are linked to changes in the regional circulation, that is, the southward displacement of the subtropical Atlantic high.

In this short communication the Fisher-Shannon (FS) information plane is presented as a new method of discrimination between different climatological regimes in central Argentina by investigating the complex dynamics of rainfall time series; the FS approach is based on the information content of the data using the statistical measures of the Fisher information measure (FIM) and the Shannon entropy.

The FIM is a powerful tool to describe the evolution laws of physical systems (Frieden, 1990), and allows to characterize the complex signals generated by these

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Abbreviations: FS, Fisher-Shannon; **FIM,** Fisher information measure; **ENSO,** El Niño-Southern oscillation; **Nx,** Shannon entropy power; **BUE,** Buenos Aires; **BHI,** Bahia Blanca; **CDB,** Cordoba; **COR,** Corrientes; **MDP,** Mar del Plata; **TUC,** Tucuman; **SGO,** Santiago del Estero; **POS,** Posadas.

systems (Vignat and Bercher, 2003), disclosing FIM as an important quantity involved in many aspects of the theoretical and observational description of natural phenomena. The FIM was used in studying several geophysical and environmental phenomena, revealing its ability in describing the complexity of a system (Telesca et al., 2008; Balasco et al., 2008; Telesca et al., 2009a) and suggesting its use as to reveal reliable precursors of critical events (Telesca et al., 2009b; Telesca et al., 2005a; Telesca et al., 2005b; Telesca et al., 2010).

The Shannon entropy defines the degree of disorder of a system providing a scientific method to understand the essential state of things (Fuhrman et al., 2000; de Araujo et al., 2003).

METHODS

Let us introduce the relevant Fisher- and Shannon-associated quantities (Martin et al., 2001). Let *f(x)* be a probability density of the variable *x*. The FIM is defined as the (possibly infinite) non-negative number *I*

$$I = \int_{-\infty}^{+\infty} \left(\frac{d}{dx} f(x) \right)^2 \frac{dx}{f(x)} \qquad (1)$$

The Shannon entropy is given by the following formula (Vignat and Bercher, 2003):

$$H_X = -\int_{-\infty}^{+\infty} f(x) \log f(x) dx \qquad (2)$$

For convenience the alternative notion of entropy power (Dembo et al., 1991)

$$N_X = \frac{1}{2\pi e} e^{2H_X} \qquad (3)$$

will be use rather than the entropy H_X. The use of the power entropy N_X instead of the Shannon one H_X arises from the so-called 'isoperimetric inequality' (Dembo et al., 1991; Romera and Dehesa, 2004; Angulo et al., 2008; Esquivel et al., 2010), a lower bound to the Fisher-Shannon product which reads as $IN_X \geq d$, where *d* is the dimension of the space. The 'isoperimetric inequality' suggests that the FIM and the Shannon entropy are intrinsically linked, so that the dynamical characterization of signals should be improved when analyzing them in the so called FS information plane (Vignat and Berchet, 2003), in which the *y*- and *x*-axis are the FIM and the entropy power N_X.

Equations 1 and 2 involve the calculation of the probability density function (pdf) *f(x)*, whose estimation may be obtained by means of the kernel density estimator technique (Devroye, 1987; Janicki and Weron, 1994). The kernel density estimator provides an approximate value of the density in the form

$$\hat{f}_M(x) = \frac{1}{Mb} \sum_{i=1}^{M} K\left(\frac{x - x_i}{b} \right) \qquad (4)$$

where *M* is the number of data and *K(u)* is the kernel function, which is a continuous non-negative and symmetric function satisfying

$$K(u) \geq 0 \text{ and } \int_{-\infty}^{+\infty} K(u) du = 1, \qquad (5)$$

whereas *b* is the bandwidth. In our estimation procedure the kernel used is the Gaussian of zero mean and unit variance. In this case

$$\hat{f}_M(x) = \frac{1}{M\sqrt{2\pi b^2}} \sum_{i=1}^{M} e^{-\frac{(x-x_i)^2}{2b^2}} \qquad (6)$$

The Gaussian kernel allows evaluating the kernel density estimator and the bandwidth with a low computational complexity (Raykar and Duraiswami, 2006).

DATA ANALYSIS AND DISCUSSION

We analyzed 8 long monthly rainfall time series recorded in central Argentina: 1) Buenos Aires (BUE) from 1861 to 2006, 2) Bahia Blanca (BHI) from 1860 to 2006, 3) Cordoba (CDB) from 1873 to 2006, 4) Corrientes (COR) from 1876 to 2006, 5) Mar del Plata (MDP) from 1888 to 2006, 6) Tucuman (TUC) from 1880 to 2006, 7) Santiago del Estero (SGO) from 1931 to 2003 and 8) Posadas (POS) from 1903 to 2003.

Figure 1 shows the geographical location of the rainfall stations. Selection was based on record length and location of the stations in order to cover a long range of years and a wide latitude distribution. Data covers the instrumental period, proved to be good quality measurements and correspond to different climatic regions of central and north of Argentina. The data present annual and seasonal oscillations, which were removed before applying the FS information plane method. The residual normalized data are shown in Figure 2.

Figure 3 shows the FS information plane for the rainfall data. The *y*-axis represents the FIM *I*, and the *x*-axis represents the entropy power N_X. Each symbol represents a rainfall series. On the basis of the obtained results, through the analysis of the FS information plane, it is possible to detect the climatological regimes that characterize the North-eastern sites, represented by POS and COR, North-western ones, represented by TUC, SGO and CDB, and in between the extra-tropical sites (BHI, MDP and BUE). It is striking that the eight rainfall time series aggregate in the FS information plane into three clusters according to the different climatological conditions. The extra-tropical sites are characterized by bi-modal seasonal distribution of rainfall with one peak before the austral summer (October-November) and the other in the early austral autumn (March-April); according to Prohaska (1976) the mild climate of pampas region is

Figure 1. Locations of the rain stations.

influenced by extra-tropical cyclones and by the Atlantic subtropical high. The North-western are located in the Argentinean subtropical-tropical zone, characterized by a monsoonal climate with rainy austral summers, while the North-eastern stations are featured by humid climate and constant and regular rain all year long.

In the future, we plan to apply the FS methodology to more rainfall time series in Argentina and in other different areas worldwide with more frequent data, in order to see how the complexity climatological patterns (represented on the FS information plane) can be discriminated. Such analysis could contribute to the current assessments that provide expected impact on climate change based on observational records of inter-annual

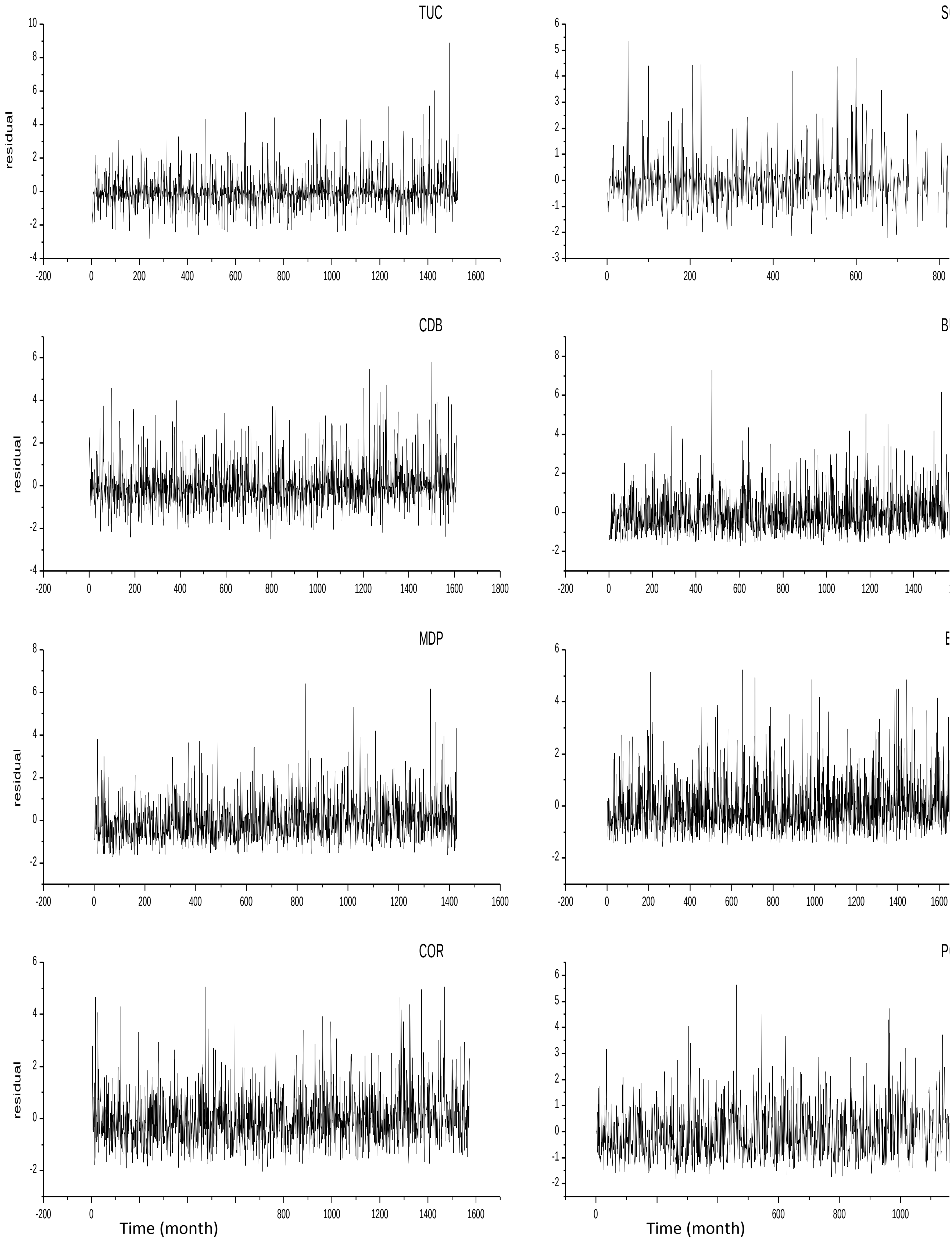

Figure 2. Rainfall time series. The series were Fourier-filtered by periodic components.

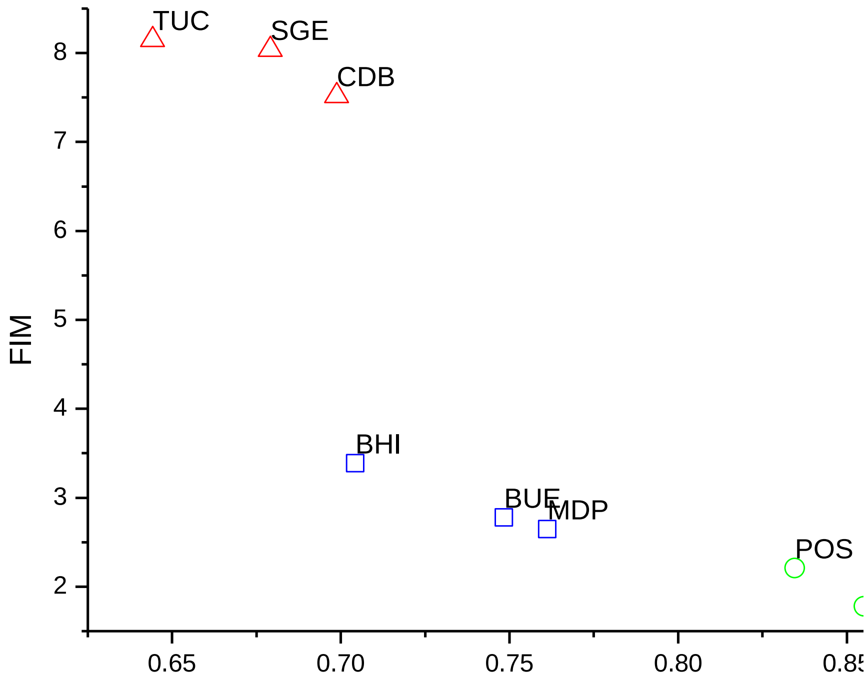

Figure 3. FS information plane. The red triangles indicate the North-western stations, characterized by subtropical continental regime with austral summer rains (monsoon type); the blue squares indicate the extra-tropical sites with transition regime, with dry austral winters; the green circles indicate the North-eastern stations, characterized by humid subtropical regime without dry season, rainy all year long.

annual fluctuations of precipitation and warming climatic factors.

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