



Characterization of river flow fluctuations via horizontal visibility graphs



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HIGHLIGHTS

- We use the horizontal visibility graph for studying river flows.
- A large dataset of rivers is analyzed.
- Evolutive trends are observed in the river flow dynamics.

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ABSTRACT

We report on a large-scale characterization of river discharges by employing the network framework of the horizontal visibility graph. By mapping daily time series from 141 different stations of 53 Brazilian rivers into complex networks, we present a useful approach for investigating the dynamics of river flows. We verified that the degree distributions of these networks were well described by exponential functions, where the characteristic exponents are almost always larger than the value obtained for random time series. The faster-than-random decay of the degree distributions is an another evidence that the fluctuation dynamics underlying the river discharges has a long-range correlated nature. We further investigated the evolution of the river discharges by tracking the values of the characteristic exponents (of the degree distribution) and the global clustering coefficients of the networks over the years. We show that the river discharges in several stations have evolved to become more or less correlated (and displaying more or less complex internal network structures) over the years, a behavior that could be related to changes in the climate system and other man-made phenomena.

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1. Introduction

The study of earth-related systems has become even more important with the growing concerns about environmental changes and the awareness of sustainable development. As a paradigm of complex systems, this research topic relies on

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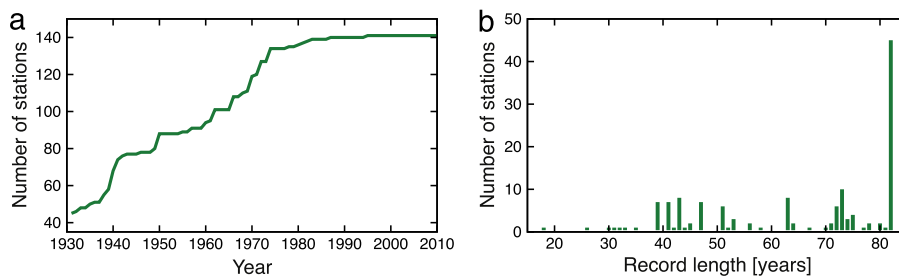


Fig. 1. (Color online) Schematic description of the dataset. (a) Number of stations over the years. The dataset starts with 45 stations in 1931 and since 1995 there are 141 stations covering 53 Brazilian rivers. (b) Histogram of the record length (in years) for all stations.

multidisciplinary efforts and has also been addressed by physicists via methods of statistical physics. Earthquakes [1,2], geomagnetic activities [3], climate [4] and weather-related systems [5,6] are just a few examples of systems that researchers have tackled in these pages. In particular, as pointed out by Dove and Kammen [7], one of the foremost global environmental challenges is the climate change. In a broader sense, the complexity of climate systems is related to the complex interactions between atmosphere, biosphere, cryosphere, lithosphere and hydrosphere. The latter one is the part of the climate system that comprises oceans, lakes and rivers, that is, the liquid water at the Earth's surface and underground [8] and it is well known the extremely important role of water in global environmental change [9,10].

In this context, important systems are the rivers and their discharges, which have a large impact on human activities, and that may also suffer huge influence from these activities. A river flow results from complicated interactions between the weather-related systems (such as rainfall, temperature and evaporation), the landscape (such as basin area and land relief) and human activity (such as pollution and power generation). These many features make river flow rates (river discharges) a complex process that has attracted the attention of scholars over the last six decades. For instance, the seminal work of Hurst about the long-range dependence of runoff records from several rivers [11] has fostered several discussions on the fractal/multifractal and scaling properties of the temporal evolution of river flows [12–25]. The correlations between river flows and other systems have been also studied, for instance, climate systems such as rain fall [26–28] and sunspots [29]; and economic systems such as the growth of companies [30,31]. Moreover, chaos theory [32,33], stochastic models [34] and permutation entropy [35–39] are examples of approaches used to probe the complexity of runoff time series.

Despite the considerable attention towards the investigation of river flows, several works are still based on small datasets and a large-scale characterization of time series related to river flows is rarely reported. Furthermore, previous efforts have been mainly focused on well established/traditional methods of time series analysis (such as fractal/multifractal analysis) and, for instance, the interesting advances in mapping time series into networks have just recently attracted the attention of researchers working on this topic [40–44]. Here, we further fill this gap by studying the flows in 141 different measuring stations that cover 53 Brazilian rivers via daily time series obtained from the period of 1931–2012. Specifically, we have employed the network framework of the horizontal visibility graph [45–47] for mapping these river flow series into networks. By tracking the evolution of topological properties of these networks, the horizontal visibility approach reveals that the flow in several stations is becoming more or less correlated (and displaying more or less complex internal network structures) over the years, a behavior that could be related to changes in the climate system and other man-made phenomena.

This work is organized as follows. We first describe our database and review some properties of the horizontal visibility approach. We next employ the horizontal visibility graph to our time series. Then, we characterize these networks by investigating the degree distribution and the clustering coefficient as well as evolutive features of these two measures. We also find that these measures display a kind of coupling. Finally, we present a summary of our findings and some concluding remarks.

2. Data presentation and analysis

The data we have accessed consist of time series of the natural river flow rates (river discharges) with daily resolution measured in 141 different stations. These time series cover 53 Brazilian rivers, span the period from 1931 to 2012 (as described in Fig. 1(a) and (b)) and are made freely available by the Operador Nacional do Sistema Elétrico – ONS – (a federal institution that controls the power system in Brazil) [48]. Let us denote the flow rates by $F_t(i)$, where $i = 1, 2, \dots, 365$ is a discrete time variable indexing the days of the year and t stands for the year associated with the flow; thus, $F_{1986}(10)$ represents the flow rate in Jan. 10 1986 in a given station. For the matter of convenience, we have removed the datapoint associated to Feb. 29 from all time series of leap years.

We have focused our analysis on a normalized version of the flow rates defined as

$$f_t(i) = \frac{F_t(i) - \mu(i)}{\sigma(i)}, \quad (1)$$

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