On the detection of climate change by using simple scaling analysis on temporal rainfall series

M. Carmen Casas-Castillo[1,*] and Raúl Rodríguez-Solà[2]
[1]*Department of Physics, ESEIAAT, Universitat Politècnica de Catalunya, Colom 1, 08222 Terrassa (Barcelona), Spain.*
[2]*Department of Physics, ETSEIB, Universitat Politècnica de Catalunya, Avda. Diagonal 647, 08028 Barcelona, Spain.*
*m.carmen.casas@upc.edu

In nature it is common to observe the phenomenon known as fractal self-similarity, whereby the division of some structures gives rise to parts that have a similar shape to the original, and such kind of structures are said to show scale invariance. Unlike mathematical fractals in which the parts are an exact copy of the whole, in natural processes the fractal self-similarity usually has a statistical character. The development of theories based on the invariance of a dynamic system through different scales has allowed some natural extremely complex patterns to show an underlying simplicity that facilitates their study. The process of rainfall generation is a complex nonlinear dynamic process easier to analyse by studying the scaling relationships of one of its possible manifestations, the rainfall intensity time series.

The annual maximum rainfall intensity fulfils scaling relationships as $I_t \overset{dist}{=} \lambda^{K(q)} I_{\lambda t}$, expression which indicates that both members of the equation can be described by the same statistical distribution. The term I_t is the rainfall intensity for a certain duration t, while $I_{\lambda t}$ corresponds to a duration λt, being λ the scaling relationship between both durations. When the scaling function $K(q)$ of the q-order statistical moments can be approximated by a linear expression as βq, the distribution is describing a monofractal magnitude or of simple scale; otherwise, it is a multifractal. There are studies [1-3] showing that the scaling exponent is usually a good indicator of the irregularity of a pluviometric regime. Higher values are obtained in places with more regular registers (usually rainy locations) than where the registers are irregular with isolated intensity peaks (β closer to the limit value -1). Some regional climate projections pointed to a potential increase in torrential rainfall for some European areas for the 21st century while the annual pluviometry might decrease, which means the occurrence of more frequent isolated episodes of high rainfall intensity in increasingly drier places. This trend towards irregularity in the rainfall patterns due to global warming can be detected by the study of the scaling exponent β and its evolution through time towards lower values, using moving temporal intervals along the series. As an example, Figure 1 shows the decreasing evolution of β in Barcelona calculated from historical series for the last 25 years and from simulated series for the 21st century under some IPCC4-A2 climate scenarios, both with a similar decreasing rate of $-0.003/\text{decade}$, the same rate observed under IPCC5 scenarios. Several studies also found similar decreasing trends for the averaged β value of the whole historical dataset of Andalusia (1870-2018, $-0.03/\text{century}$) [1], and for Catalonia (1883-2016, $-0.043/\text{century}$), and specifically for Western Pyrenees and the Ebre Observatory [2]. Nevertheless, global analysis might be masking different trends for individual places, as the increasing trends found by [1] in particular rainy Andalusian locations. The increase in rainfall irregularity is probably more pronounced in areas with more Mediterranean influence.

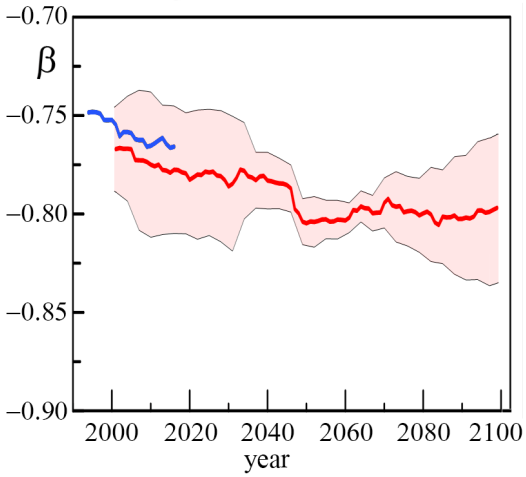

Figure 1. Time evolution of the scaling parameter β in Barcelona for historical (blue) and projected series (red).The shaded area shows the standard deviation.

[1] Casas-Castillo MC, Rodríguez-Solà R, Llabrés- Brustenga A, García-Marín AP, Estévez J, Navarro X (2022) A Simple Scaling Analysis of Rainfall in Andalusia (Spain) under Different Precipitation Regimes. *Water* **14**, 1303. https://doi.org/10.3390/w14081303.
[2] Casas-Castillo MC, Llabrés-Brustenga A, Rius A, Rodríguez-Solà R, Navarro X (2018) A single scaling parameter as a first approximation to describe the rainfall pattern of a place: application on Catalonia. *Acta Geophys* **66**(3): 415-424. https://doi.org/10.1007/s11600-018-0122-5.
[3] Rodríguez-Solà R, Casas-Castillo MC, Navarro X, Redaño Á (2017) A study of the scaling properties of rainfall in Spain and its appropriateness to generate intensity-duration-frequency curves from daily records. *Int J Climatol* **37**(2):770–780. https://doi.org/10.1002/joc.4738