Analyzing the solar activity using the horizontal visibility graph method

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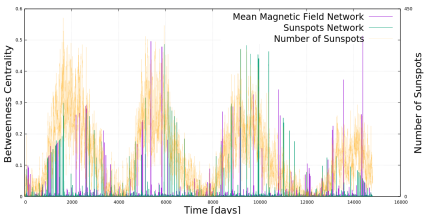
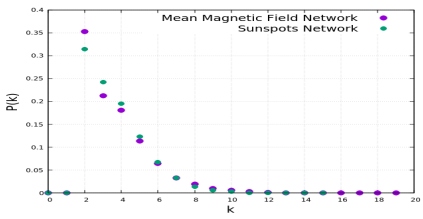
Various measures of complexity can provide relevant ways to study the complexity in the dynamics of magnetized plasma. In this case, the sun and its behavior will be studied through the use of complex networks. We take two time series associated with solar activity, namely total sunspot [1] and global mean magnetic field [2], taken from 1975 to 2015. Both time series will be analyzed through the Horizontal Visibility Graph (VG) technique [3]. Formally, given a series of data Y_N, it is said that each value of the time series correspond to a node, and two arbitrary nodes y_a and y_b "see" each other if for every node y_c the relation $y_a\,,\,y_b > y_c$ is satisfied. Then, once the HVG criteria is established, the method leads to a complex network, where the nodes correspond to the values of each time series. The HVG allows to study statistical properties of time series such as reversibility [4], and it has been successfully used to study a variety of physical systems [5]. Using this analysis, we observed a specific metric of the complex networks that is sensitive to the solar cycle, Betweenness Centrality (BC), which quantifies the frequency at which a node acts as a connecting bridge along the shortest path between any other two nodes. Furthermore, from the connections established within the networks, we also observed that they follow an exponential topology for their degree distribution, which is the fraction of nodes with k connections over the total amount of nodes, $P(k) = n_k/n$.



(a) Betweenness Centrality for both networks, it can be observed that the maxima of this metric match those of the solar cycle.



(b) Exponential topology for both degree distribution associated with the two time series employed.

References

[1] Sunspot data from the World Data Center SILSO, Royal Observatory of Belgium, Brussels

[2] The Wilcox Solar Observatory (WSO) project, `http://wso.stanford.edu`

[3] Lacasa, L., Luque, B., Ballesteros, F., Luque, J., & Nuno, J. C. (2008). From time series to complex networks: The visibility graph. Proceedings of the National Academy of Sciences, 105(13), 4972–4975.

[4] Lacasa, L., Nunez, A., Roldán, É., Parrondo, J. M., & Luque, B. (2012). Time series irreversibility: a visibility graph approach. The European Physical Journal B, 85(6), 1–11.

[5] Acosta–Tripailao, B., Pastén, D., & Moya, P. S. (2021). Applying the Horizontal Visibility Graph Method to Study Irreversibility of Electromagnetic Turbulence in Non-Thermal Plasmas. Entropy, 23(4), 470.