Community Structure Of Earth's Magnetic Field Measurements

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The Earth's magnetic field has variations both in the time and spatial domains, which are due to the internal dynamics of the Earth's core, the forcing by external sources like the solar wind, or fluctuations induced by coupling between neighbouring regions. This leads to various levels of correlations between magnetic field readings on the Earth's surface, which map the interplay of these factors across multiple time and space scales. In this work, we propose to describe and study this complex dynamics of spatiotemporal correlations by means of tools derived from graph theory and complex networks, which have shown to be useful to describe the behavior of various systems of geophysical and astrophysical interest [1-3], on issues such as discriminating between types of pulsating variable stars [4], or correlating the spatiotemporal evolution of solar active regions with the 22-year Hale cycle [5]. In particular, in this work we study the evolution of magnetic field measurements on the Earth's surface along the 23rd solar cycle.

To build the complex network, we consider hourly magnetic field records, between years 1996 to 2008, covering the 23rd solar cycle, registered by 59 magnetometers distributed over the Earth's surface (World Data Center for Geomagnetism, Kyoto, https://wdc.kugi.kyoto-u.ac.jp/index.html). In order to have an adequate coverage of the time window of interest, we select magnetometers that cover, at least, 90% of the 23rd solar cycle. This makes it possible to study the evolution of the community structure throughout the solar cycle, making mobile data windows of one year duration, ensuring that all windows have data taken with all selected magnetometers.

To build our network, we consider the nodes as the points where the measurements are made. These correspond to the location of the magnetometers. The connection of these nodes (the edges of the network) are given by a degree of similarity between their respective time series of magnetic field intensity. We follow strategies similar to previous works which have successfully studied community structure for geophysical variables. The Pearson correlation between time series has been used to study networks of rainfall records [6] and auroral magnetic field records [1], and is a common method to define the connection between nodes since it evaluates the linear relationship between two variables.

We will also consider the event synchronization method [7, 8], previously used to study community structure in rainfall records, and which has the advantage that it has been specifically designed to quantify the synchronicity of extreme events, which in the case of geomagnetic activity is interesting, as it may provide a better focus on intense geomagnetic storms.

Our results show that there is a correlation between the evolution of network community structure and geomagnetic activity. In addition, we study the dependence of the results of the methods used to define the similarity between time series (and, therefore, to define the connection between nodes), in order to establish the best possible sensitivity for the community structure with respect to the geomagnetic activity, as measured by the Dst index and the sunspots number. We show that the choice of similarity method is not as relevant as the choice of the correlation threshold which determines whether two nodes are actually connected or not. Our work suggests that analysis of the Earth's magnetic field variations using complex network and community structure analyses, can be useful to understand the geomagnetic activity along the solar cycle.

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References

[1] L. Orr, S. C. Chapman, J. W. Gjerloev, and W. Guo, Nature Commun. **12**, 1842 (2021).
[2] S. Lu, H. Zhang, X. Li, Y. Li, C. Niu, X. Yang, and D. Liu, Nonlinear Proc. Geophys. **25**, 233–240 (2018).
[3] A. Najafi, A. H. Darooneh, A. Gheibi, and N. Farhang, Astrophys. J. **894**, 66 (2020).
[4] E. Garcés and V. Muñoz, PLoS ONE **16**, e0259735 (2021).
[5] E. Flández, A. Zamorano and V. Muñoz, Astrophys. J. **980**, 4 (2025).
[6] Y. Xu, F. Lu, K. Zhu, X. Song, and Y. Dai, Water **12**, 1739 (2020).
[7] N. Agarwal, N. Marwan, R. Maheswaran, B. Merz, and J. Kurths, J. Hydrol. **563**, 802–810 (2018).
[8] V. Stolbova, P. Martin, B. Bookhagen, N. Marwan, and J. Kurths, Nonlinear Proc. Geophys. **21**, 901–917 (2014).