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Interactive comment on "Complex networks description of ionosphere" *by* Shikun Lu et al.

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The authors would like to express our sincere gratitude for all the constructive comments on our manuscript. The comments and suggestions are very helpful for the improvement of our paper. In what follows, we present detailed comments in response to the individual points raised by the reviewer and elaborate on how the manuscript has been revised.

(The line numbers referred in the response are those in the manuscript tracking changes. This manuscript is provided as the supplement.)

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1 General Comments

Comments: *In recent decades, attentions on complex networks have been more and more paid to the field of geoscience as a powerful tool in investigations, particularly, in the study of climatology and seismology. In this paper, the authors firstly introduce this method to construct a directed complex network to investigate the information flow in the ionosphere. Some new results are gained that both the out-degree and in-degree distribution of the ionospheric network are not scale-free. The topological structure of the ionospheric information network is homogeneous. The spatial variation of the ionospheric network shows the connections principally exist between the neighbors in space, indicating that in the ionosphere the information transmission is mainly based on the spatial distance. Since this is the first time that ionospheric data are used to construct such a network, the results are helpful in understanding some special characteristics of the ionosphere.*

Response: We thank the reviewer very much for these positive comments and present the details of responses to the concerns in the following part. In the document that follows, we describe the associated modifications made to the original version of the paper and address the comments of the reviewers separately.

2 Major Comments

Issue 1: *Can authors make a simple comparison of results of this paper with other relatively similar earlier published networks like surface temperate data structed networks. Such comparison may provide some useful hints for the further development of the complex network construction.*

Response 1: Many thanks for the comment. As the reviewer suggested, we have made a comparison between the network of this paper with other relatively similar earlier published networks. The details are shown as follows,

Peron et al. (2014) built the temperature network by correlation and regarded the global grid points as nodes. They showed that the network characteristics of the North American region have marked the differences between the eastern and western regions. Such differences were a reflection of the presence of a large network community on the western side of the continent. Correlation is a linear measurement of the dynamics in the climate system. To depict the nonlinearity and uncertainty in the climate, information theory is introduced to construct the complex network. Donges et al. (2009a,b) used complex networks to uncover a backbone structure carrying matter and energy in the global surface air temperature field. They used mutual information (MI) to construct the network which was undirected, because the mutual information is symmetric to measure the dynamical similarity of surface air temperature between regions. Hlinka et. al (2013) investigated the reliability of directed climate networks being constructed by conditional mutual information (CMI), using the dimensionality-reduced surface air temperature data. Compared with MI, CMI is asymmetric and able to build directed networks for the global surface air temperature. However, both MI and CMI are standard bivariate methods, which only describe the interactions between two spatial points without considering the influences of the others. So is the correlation. The revisions are shown in lines [15-27] of page 2.

Issue 2: *Is it possible to explain the results of networks in the real ionospheric features*

Response 2: Many thanks for the comment. We try to explain the results of networks in the real ionospheric features, but the explanations still need to be further verified by observations.

1 To explore the influence of the VTEC's variation over a certain GIM cell, the degree of complex network is employed. As one of the most critical parameters to depict the nodes in a complex network, the degree is the number of edges the node possesses. Concerning ionospheric networks, the degree of a cell can be selected to quantify how

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many GIM cells display a causal interaction with that given cell in the globe. In other words, cells with large degree can influence large numbers of GIM cells. We have checked the scale-free topology of the ionospheric network by conducting power-law hypothesis testing about the degree distribution. The result shows that the network of the global ionosphere is not scale-free. Thus, there are no visible hub positions for the dynamic process in the ionosphere. The ionospheric network is homogenous. There are no unique positions acting as the sources or sinks of the variations within the ionosphere. This property is completely different from that of the geomagnetic field. The revisions are shown in lines [6-15] of page 5 and lines [9-15] of page 6.

2 As the referee 2 suggested, the distance between connected grid cells is measured in terms of meters instead of degrees. The propagation of the dynamic processes is related to the transmission of energy or particles in the ionosphere. In order to analyze such transport property, the distribution of the edge distances is calculated. The edge distance is defined by the geographical distance between the origin and destination of an edge. The positive signs of the distances represent the directions of edges and can be either eastward or northward. The results show that the propagation is mainly affected by the geospatial distance and almost satisfies the proximity principle in space. Meanwhile, there are also some exceptional long-range edges existing in the ionospheric network. Accordingly, most of the dynamic processes in the ionosphere are locally propagated with some long-range propagation. Such phenomenon indicates the complexity of the inner ionospheric variations in the globe. The proximal propagation may be due to the diffusion effects of charged particles in the ionosphere, while the long-range one may be caused by the geomagnetic field or other global factors. These explanations still need to be further verified by observations. The revisions are shown in lines [2-15] of page 7 and lines [1,5-14] of page 8.

3 We explore the small-world structure of the ionospheric network to check the stability of the ionosphere which is regarded as a dynamical system, because the small-world structure can make the system be stable to react to the abrupt variations. The results indicate that the dynamic processes in the ionosphere present small-world property. Just as the small-world property in the atmosphere, such ionospheric property also results from the teleconnections in the ionospheric network. The teleconnections make the dynamic processes be propagated within the ionospheric network efficiently. If a disturbance is generated somewhere in the ionosphere, the small-world structure of the ionospheric network allows the ionosphere to react quickly and coherently to the variations introduced into the ionosphere. This propagation mechanism of dynamic processes can diffuse local variations, thereby reducing the possibility of prolonged local anomalies and providing more stability for the global ionosphere. Thus, chances of major ionospheric shifts are reduced. The revisions are shown in lines [16-18] of page 8 and lines [2-4] of page 10.

4 The spatial prediction, especially regional prediction, depends heavily on the self-similarity in the ionosphere. Thus, we investigate the self-similar structure in the ionosphere through fractal analysis, which shows the ionospheric network is not self-similar in the current temporal and spatial resolution. Such phenomenon shows that because of the non-fractal property, the predictability of the ionosphere for one year should decrease. Construction of the long-term geospatial model of the ionosphere is still a challenging work. Spatial characteristics within the ionosphere differ complexly and dramatically with the variation of regions for one year. Such complex spatial variations in the current resolution may disrupt the similarity in the ionosphere. To further investigate the self-similarity within the ionosphere, the temporal and spatial resolution of the ionospheric observations should be considered. In our background, the self-similarity in the ionosphere may be detected by the observations of high temporal and spatial resolution. The revisions are shown in lines [11-13] of page 10, lines [11-14] of page 11 and lines [1-2] of page 12.

Issue 3: *The data used in this paper only with one year's time span, and time resolution is two hours and ranges from* $-180°$ *to* $180°$ *along the longitude and from* $-87.5°$ *to* $87.5°$ *along the latitude with a revolution of 10 and 5 degree in longitude and latitude.*

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Is the revolution affects the results? For example, in such a revolution, ionospheric equatorial anomaly, small-scaled irregularities are excluded, then how can we say the ionospheric network is not fractal?

Response 3: Many thanks for the comment.

As the reviewer suggested, the fractal analysis of the ionosphere really depends on the resolution of the observations. The ionosphere is a dynamic system containing complex temporal and spatial variations. As a description of the ionosphere, the construction of the complex network is also influenced by the time window and spatial position of the ionospheric observations. As the reviewer suggested, in the current revolution, ionospheric equatorial anomaly, small-scaled irregularities are excluded. The previous statement of this conclusion is not precise. For rigorous expression, the conclusion should be presented as follows,

"Therefore, in the current temporal and spatial resolution, the ionospheric network does not have self-similar structure, indicating the complexity of the ionospheric temporal and spatial variations. To further investigate the self-similarity within the ionosphere, the time window and space resolution of the ionospheric observations should be considered. In our background, the self-similarity in the ionosphere may be detected by the observations of high temporal and spatial resolution." The revisions are shown in lines [9-10, 13-14] of page 11 and lines [1-2] of page 12.

Please also note the supplement to this comment:
https://www.nonlin-processes-geophys-discuss.net/npg-2017-29/npg-2017-29-AC3-supplement.pdf

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