Initial findings of Lagrangian Coherent Structures in the ionosphere via simulation

N. Wang*[(1)]
(1) Mechanical, Materials, and Aerospace Engineering, Illinois Institute of Technology, 10 W. 32nd St., RE-243, Chicago, IL, 60616, USA

Extended Abstract

Ionospheric plasma irregularities causing scintillation, a rapid fluctuation in signal amplitude and phase, can adversely affect high-frequency (HF) communications and Global Navigation Satellite System-based (GNSS) navigation systems. Analysis of ionospheric plasma convection at high latitudes, especially during geomagnetic storms, can provide a better understanding of material and energy transport in the ionosphere and improve the predictability of ionospheric irregularities' motion. A recent numerical technique in fluid dynamical analysis known as Lagrangian Coherent Structures (LCSs) predicts transport and interaction processes [1, 2]. LCSs are frame-invariant manifolds indicating ridges of maximum divergence or convergence in a time-varying nonlinear flow. LCSs act as barriers to material transport, demarcating regions of qualitatively different flow patterns. Previous investigation of the thermosphere showed that LCSs are prominent at higher altitudes and latitudes globally, and are responsive to geomagnetic activity [3]. Here we apply the LCS technique to an ionospheric model to explore the LCSs existing in high latitude ionospheric drift motion.

LCSs are found by computing the local maximum finite time Lyapunov exponent (FTLE), a scalar field measuring the degree of stretching of a fluid particle at a certain location after a given interval of time, relative to its initial extent. The Ionosphere-Thermosphere Algorithm for Lagrangian Coherent Structures (ITALCS) [3], a tool used for computing the FTLE scalar fields, is applied to compute the forward-time FTLE and visualize the LCSs in the ionospheric drift field. For the initial study we treat the ionosphere as a spherical domain discretized in longitude and latitude. The Weimer 2005 [4] polar electric potential model and the 12th generation International Geomagnetic Reference Field [5] are used to generate the ExB drift field at each grid point in the ionosphere. The ExB drifts are used as the input to ITALCS.

For the purpose of exploring the effect of geomagnetic activity on LCSs, we compare the simulation results between a geomagnetically stormy period with a geomagnetically quiet period. Based on tri-hourly Kp index values for 17 March 2015, 0:00 UT is chosen as the initial time of the geomagnetic quiet period while 12:00 UT is selected as the initial time of the storm period. For each event, the integration length is chosen to be 6 hours. Time-varying structures are detected in ionospheric drifts at high latitudes based on locally maximum FTLE values for both geomagnetically stormy and quiet periods. The LCSs during the geomagnetically stormy period have more complex topology and move equatorward compared to the LCSs during the quiet time. The response to geomagnetic activity of the ionospheric LCSs shows an agreement with the thermospheric LCSs discussed in [3], indicating the energy exchange and transport in IT system is visible in the formation of LCSs. The result of defining these LCS barriers is that they indicate the degree of equatorward transport that might be expected of high latitude polar cap patches [6] and scintillation-causing irregularities.

References

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