MDIT-04

Analyzing Dynamical Interactions in the IT System via LCS Technique

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Motivation:

- **Previous work showed that LCSs are found in the ionosphere-thermosphere (IT) flows [1,2] and respond to geomagnetic activity.**
- **Ionosphere and thermosphere are coupled through energy and momentum interaction.**
- **Preliminary study showed that the comparison of thermospheric LCSs and ionospheric LCSs according to empirical models can show the evidence of energy interaction in the IT system [3].**
- **Objective: analyze the energy interaction in IT system by comparing the shape of thermosphere LCSs and ionospheric LCSs.**

Introduction:

Lagrangian Coherent Structures (LCSs)

- Describe regions of maximal separation (or convergence) [4], and are independent of the observer [5].
- Can act as material barriers to bound the transport.
- Are used to understand thermospheric and ionospheric material transport [1,2].

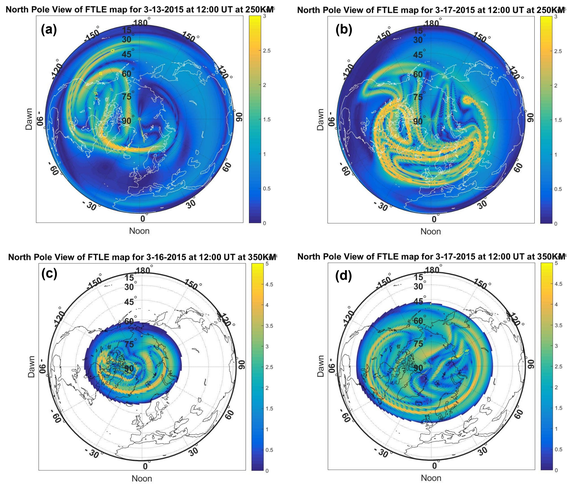

Fig. 1 (a) North pole view of FTLE map for neutral winds velocity field at 250 km during geomagnetic quiet period with t_0 = 12:00 UT on 13 March 2015 with integration time of 2 days. (b) during geomagnetic active period with t_0 = 12:00 UT on 17 March 2015. (c) North pole view of FTLE map for plasma drifts at 350 km during geomagnetic quiet period with t_0 = 12:00 UT on 16 March 2015 with integration time of 3 hours. (d) during geomagnetic active period with t_0 = 12:00 UT on 17 March 2015.

⇒Are defined by the locally maximum finite time Lyapunov exponent.

Finite Time Lyapunov Exponent (FTLE)

- A scalar field measuring the degree of stretching of a fluid particle at a certain point, after a given interval of time τ.

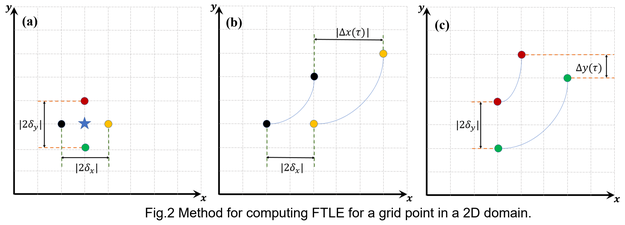

Fig.2 Method for computing FTLE for a grid point in a 2D domain.

$$\mathbf{J} = \begin{bmatrix} \frac{\Delta x(\tau)}{|2\delta_x|} & \frac{\Delta x(\tau)}{|2\delta_y|} \\ \frac{\Delta y(\tau)}{|2\delta_x|} & \frac{\Delta y(\tau)}{|2\delta_y|} \end{bmatrix} \qquad \sigma(\mathbf{J}) = \frac{1}{|\tau|}\log\left(\sqrt{\lambda_{max}(\mathbf{J}^T\mathbf{J})}\right)$$

Method:

Ionosphere-Thermosphere Algorithm for Lagrangian Coherent Structures (ITALCS).

- Given time varying flow fields, ITALCS computes FTLE and tracer positions, more details in [2].
- We will test IT-flows modeled by Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) .

Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM):

- A three-dimensional (3D) global physical model.
- Self-consistently solves dynamic equations in IT system.
- Applies fourth order finite differencing method.
- Models neutral wind fields and plasma drifts.

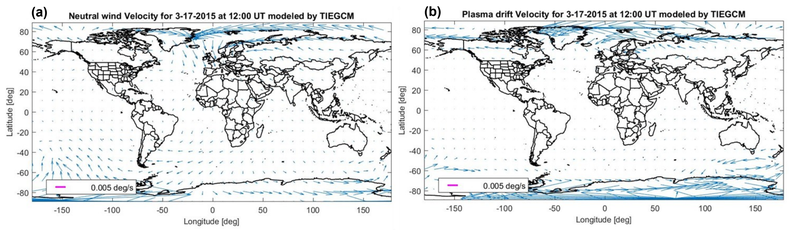

Fig.3 Velocity fields modeled by TIEGCM at 12:00 UT 17 March 2015, (a) neutral winds, and (b) plasma drifts.

- **Charged-neutral collision frequency is a function of energy [6].**
- **Geomagnetic activity influences the energy input of IT system.**
- **LCSs of modeled IT flows are compared during geomagnetic quiet period and active period.**

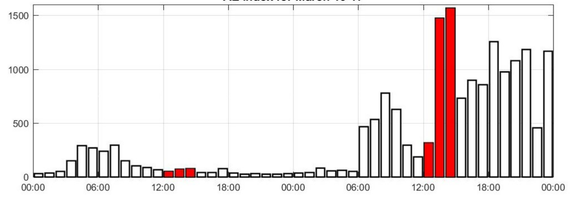

Fig.4 AE index from 16–17 March 2015. The periods labeled in red are used to study the effect of geomagnetic activity.

Parameters:

Integration time: τ = 3 hours.
Altitude: 350km.
Grid space: 2.5 degree.

Geomagnetic quiet period:
t_0 = 12:00 UT 16 March 2015.
Geomagnetic active period:
t_0 = 12:00 UT 17 March 2015.

Acknowledgment :

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References :

[1] Wang, N., U. Ramirez, F. Flores, and S. Datta-Barua (2017), Lagrangian coherent structures in the thermosphere: Predictive transport barriers, ***Geophys. Res. Lett.,*44,** doi:10.1002/2017GL072568.
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[3] Wang, N., U. Ramirez, and S. Datta-Barua, "Dynamic Interactions in the IT System via Lagrangian Coherent Structures Analysis", poster session presented at American Geophysical Union (AGU) Fall Meeting, New Orleans, LA, Dec. 2017.
[4] Haller, G. (2015), Lagrangian coherent structures, ***Annual Review of Fluid Mechanics*, 47,** 137–162, doi:10.1146/annurev-fluid-010313-141322.
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[6] Datta-Barua, S., G. S. Bust, G. Crowley, and N. Curtis (2009), Neutral wind estimation from 4-D ionospheric electron density images, ***J. Geophys. Res., 114,*** A06317, doi:10.1029/2008JA014004 .

Results:

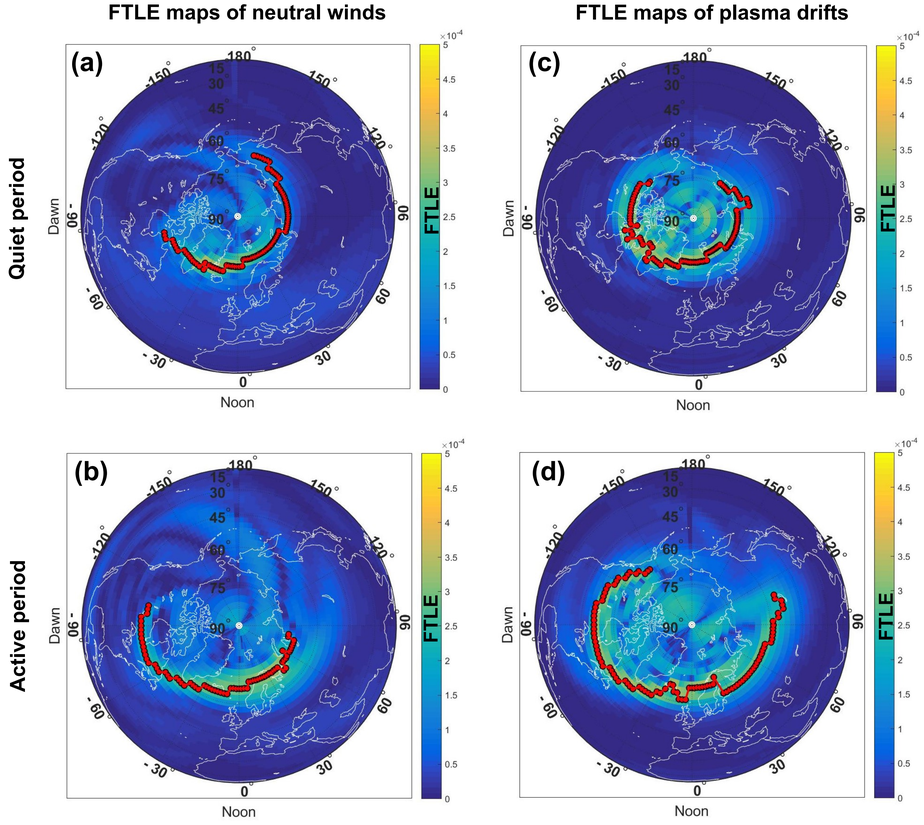

Fig.5 FTLE map for neutral wind field viewed from geographic north pole at 350 km during (a) geomagnetic quiet period with t_0 = 12:00 UT, 16 March 2015, and (b) during geomagnetic active period with t_0 = 12:00 UT, 17 March 2015, at 350km. FTLE map for plasma drift viewed from geographic north pole at 350 km during (c) geomagnetic quiet period with t_0 = 12:00 UT, 16 March 2015, at 350km, and (d) during geomagnetic active period with t_0 = 12:00 UT, 17 March 2015, at 350km. The red dots indicate the locally maximum FTLEs.

Table 1 Comparison of rotation angle between thermospheric LCS and ionospheric LCS during geomagnetic quiet period and storm period

	T-LCSs West boundary	T-LCSs East boundary	T-LCSs Middle point	I-LCSs West boundary	I-LCSs East boundary	I-LCSs Middle point	$\alpha_{I\text{-}T}$
Quiet period	77.5 W	165 E	43.75 E	130 W	142.5 E	6.25 E	-37.5
Storm period	102.5 W	80 E	11.25 W	142.5 W	110 E	16.25 W	-5

Summary

- Both modeled thermospheric LCSs (T-LCSs) and ionospheric LCSs (I-LCSs) are horseshoe-like with the "U"-shaped LCSs opening to the night side, and respond to the geomagnetic activity.
- The T-LCSs and I-LCSs are more aligned during the geomagnetically stormy period.
- During the geomagnetic active period, the collision frequency between neutral particles and charged particles is increased. The alignment of T-LCSs and I-LCSs during active period shows the evidence of dynamical interactions in the IT system.

Future work:

- Compare the FTLE maps with the temperature maps during both geomagnetic quiet period and storm period.
- Analyze backward LCSs in the IT flows to explore the energy input during geomagnetic active period.