MDIT-09

# Seeking Lagrangian Coherent Structures in Ionospheric Plasma Drifts


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## Motivation:

- **Previous work showed that LCSs are found in the thermosphere and that they respond to geomagnetic activity [1].**
- **The thermosphere and the ionosphere are coupled. Science question: are there LCSs in the ionosphere?**
- **Objective: search for global scale Lagrangian coherent structures (LCSs) in the ionosphere.**

## Introduction:

### Lagrangian Coherent Structures (LCSs)

- Are used to understand ocean flow [2] and thermospheric material transport [1].

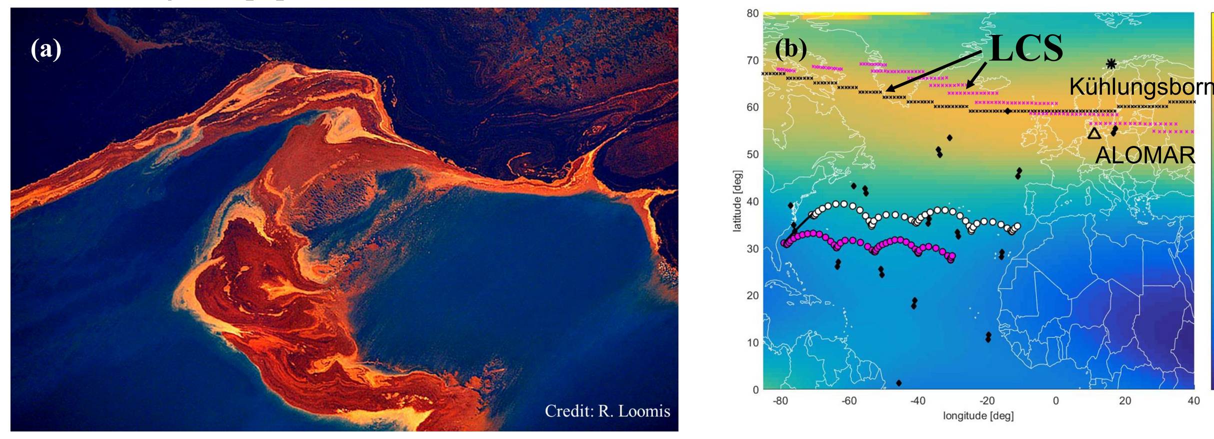


Fig. 1 (a) The 2010 BP oil spill in the Gulf of Mexico, seen from a helicopter, shows coherent structuring [3]. (b) FTLE map for space shuttle water vapor plume simulation at 100 km for 8 July 2011 at 15:35 UT [1].

- Describe regions of maximal separation (or convergence) [4], and are independent of the observer [5].
- The LCSs can act as material barriers to bound the plasma transport.

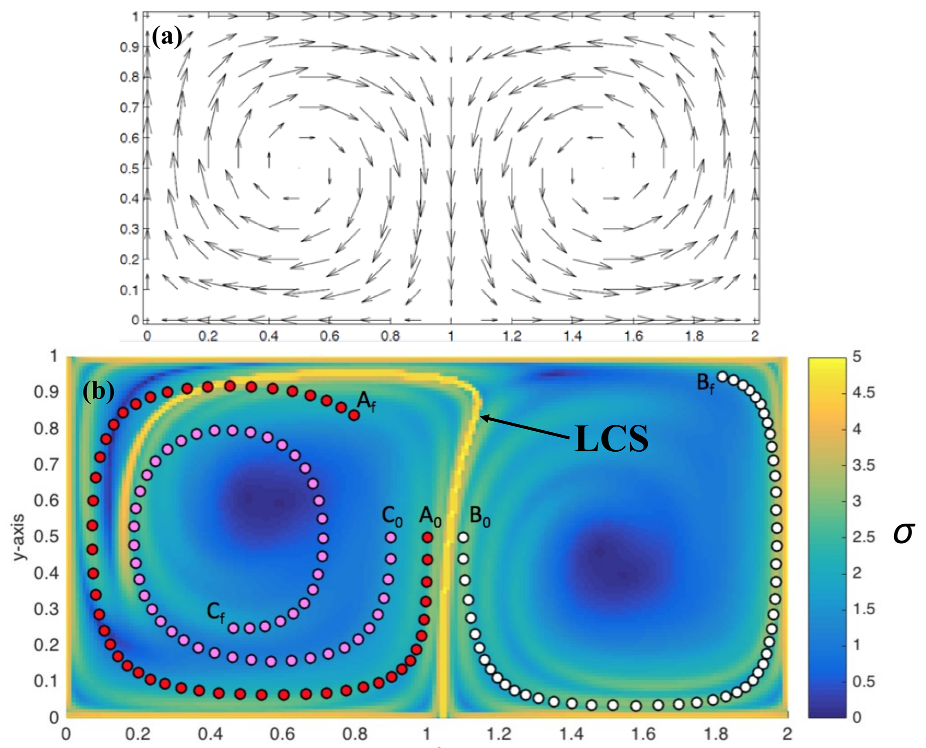


Fig.2 Time varying Double-gyre (a) flow field, (b) FTLE map and tracers at t = 0.

⇒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.

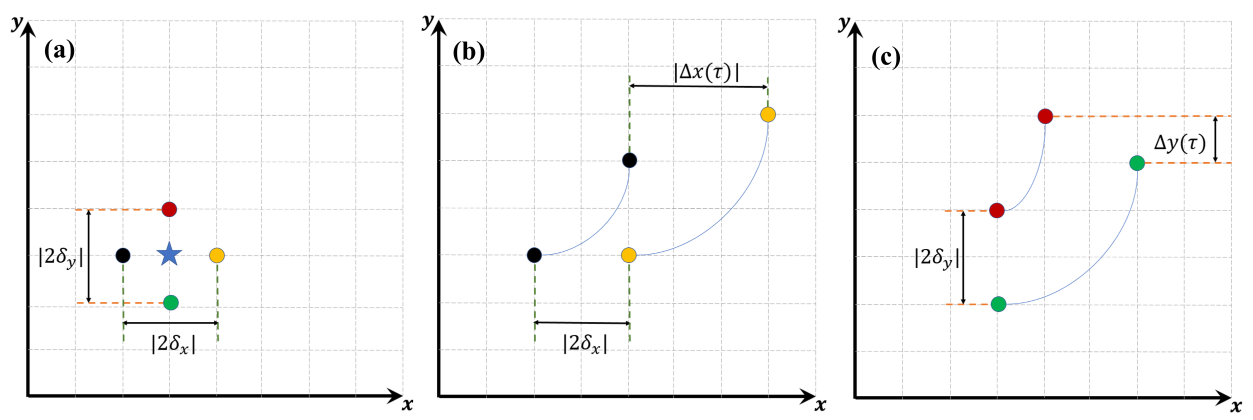


Fig.3 Method for computing FTLE for a gridpoint in a 2D domain.

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

## Method:

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

- Given time varying flow fields, computes FTLE and tracer positions.

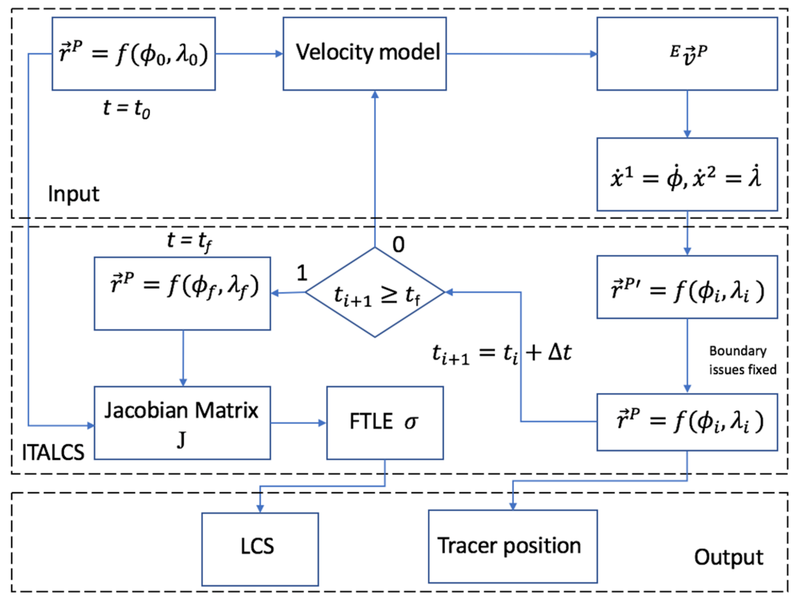


Fig.5 Process for tracing the position of ionospheric particle P over time and computing the FTLE to identify the LCSs in the flow.

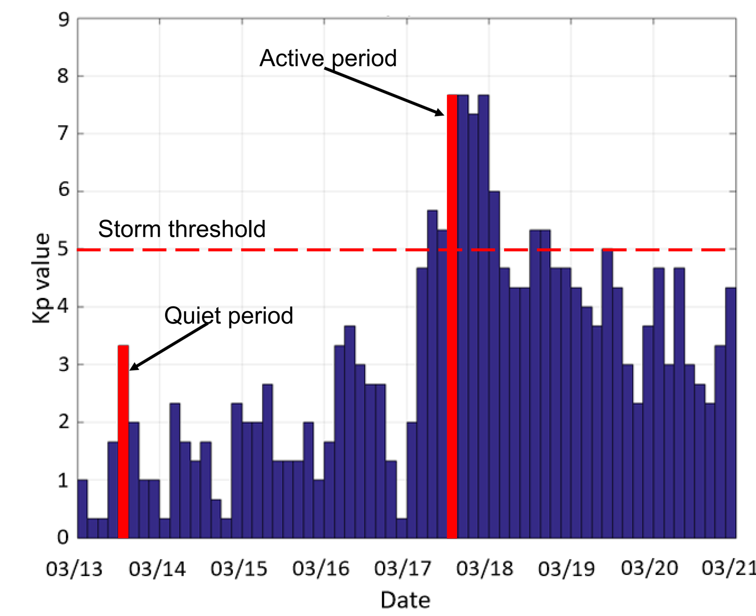


Fig.6 8-day Kp index value

- Test flow fields during geomagnetic quiet and active period.

### High latitude ionospheric plasma drift.

- Generate plasma ExB drift using Weimer 2005 [6], and Twelfth-generation International Geomagnetic Reference Field (IGRF12) [7].

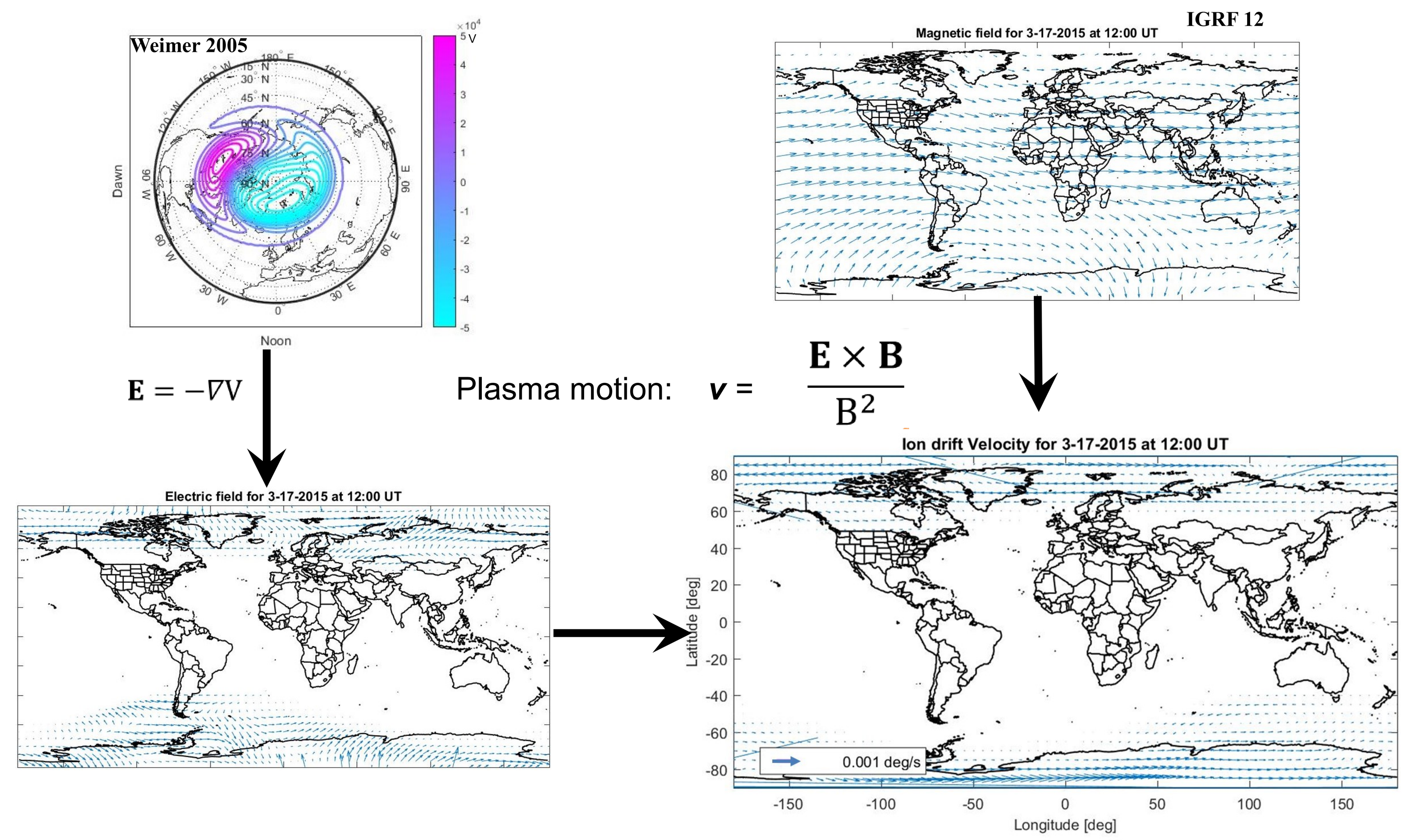


Fig.4 Method for simulating plasma drift flow field.

### Parameters:

Integration time: τ = 3 hours.
Altitude: 250km.
Grid space: 1 degree.

### Tracer location:

| | |
|---|---|
| A(65°N, 0°E) | D(75°S, 0°E) |
| B(75°N, 0°E) | E(85°S, 0°E) |
| C(55°N, 0°E) | F(65°S, 0°E) |

### Examine where LCSs are, and do they respond to geomagnetic activity.


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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.
[2] Jones, C., and S. Winkler (2002), Invariant manifolds and lagrangian dynamics in the ocean and atmosphere, ***Handbook of dynamical systems, 2***, 55–92, doi: http://dx.doi.org/10.1016/S1874-575X(02)80023-6.
[3] R. Loomis. Gulf of Mexico oil spill. ***The Los Angeles Times, 14***, April 2011.
[4] Haller, G. (2015), Lagrangian coherent structures, ***Annual Review of Fluid Mechanics*, 47**, 137–162, doi:10.1146/annurev-fluid-010313-141322.
[5] Haller, G. (2005), An objective definition of a vortex, ***Journal of Fluid Mechanics*, 525**, 1–26, doi:10.1017/S0022112004002526.
[6] D. R. Weimer, "Predicting Surface Geomagnetic Variations Using Ionospheric Electrodynamic Models," ***J. Geophys. Res.*, 110,** 2005, doi:10.1029/ 2005JA011270.
[7] E. Thébault et al., "International geomagnetic reference field: the 12th generation," ***Earth, Planets and Space*, 67.1**, 2015, 1-19, doi: 10.1186/s40623-015-0228-9.


## Results:

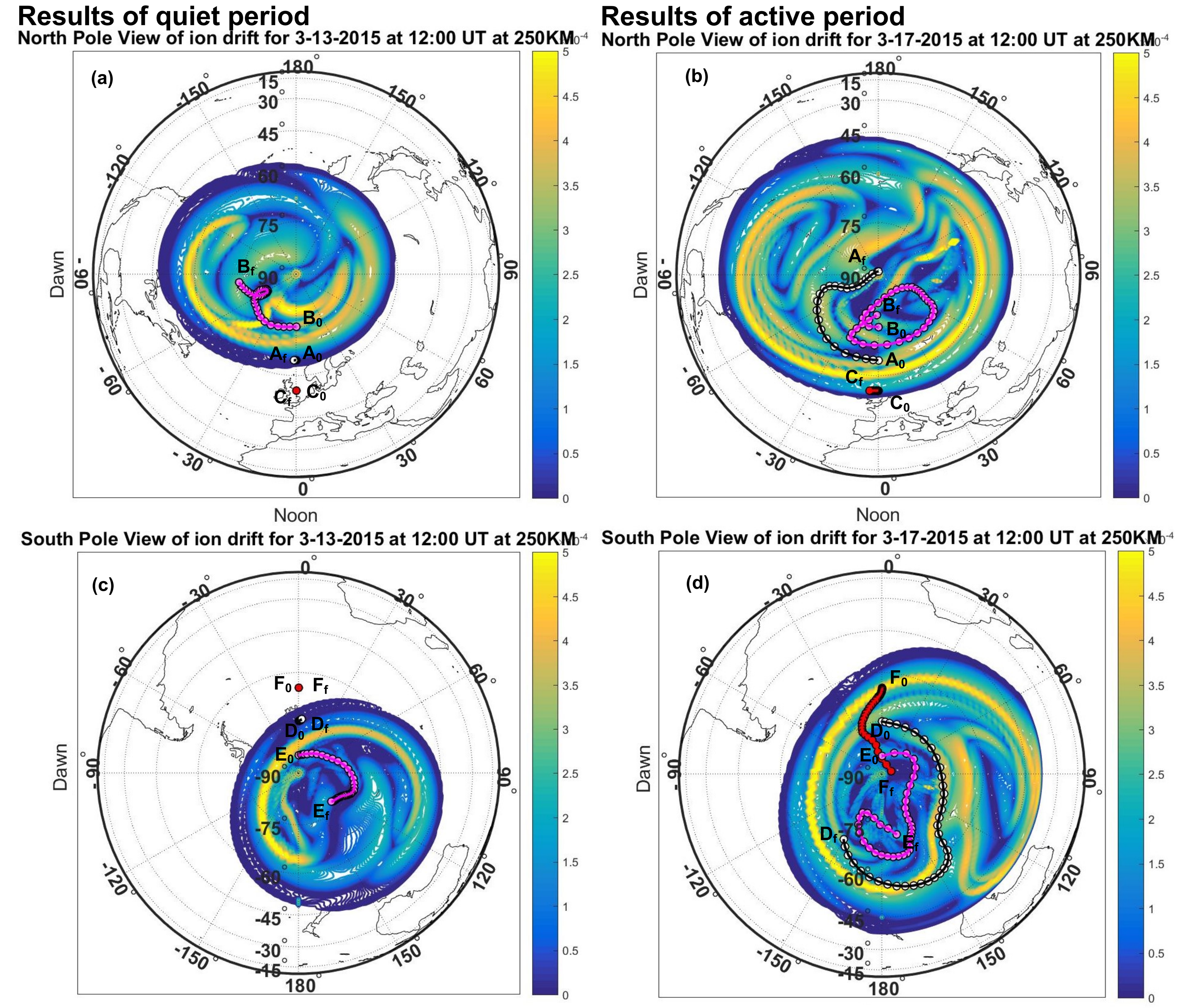


Fig.7 Results of geomagnetic quiet period with $t_0$ = 12:00 UT, 13 March 2015, at 250km, (a) FTLE map for north pole view with tracers. Results of geomagnetic active period with $t_0$ = 12:00 UT, 17 March 2015, at 250km, (b) FTLE map for north pole view with tracers, (d) FTLE map for south pole view with tracers.

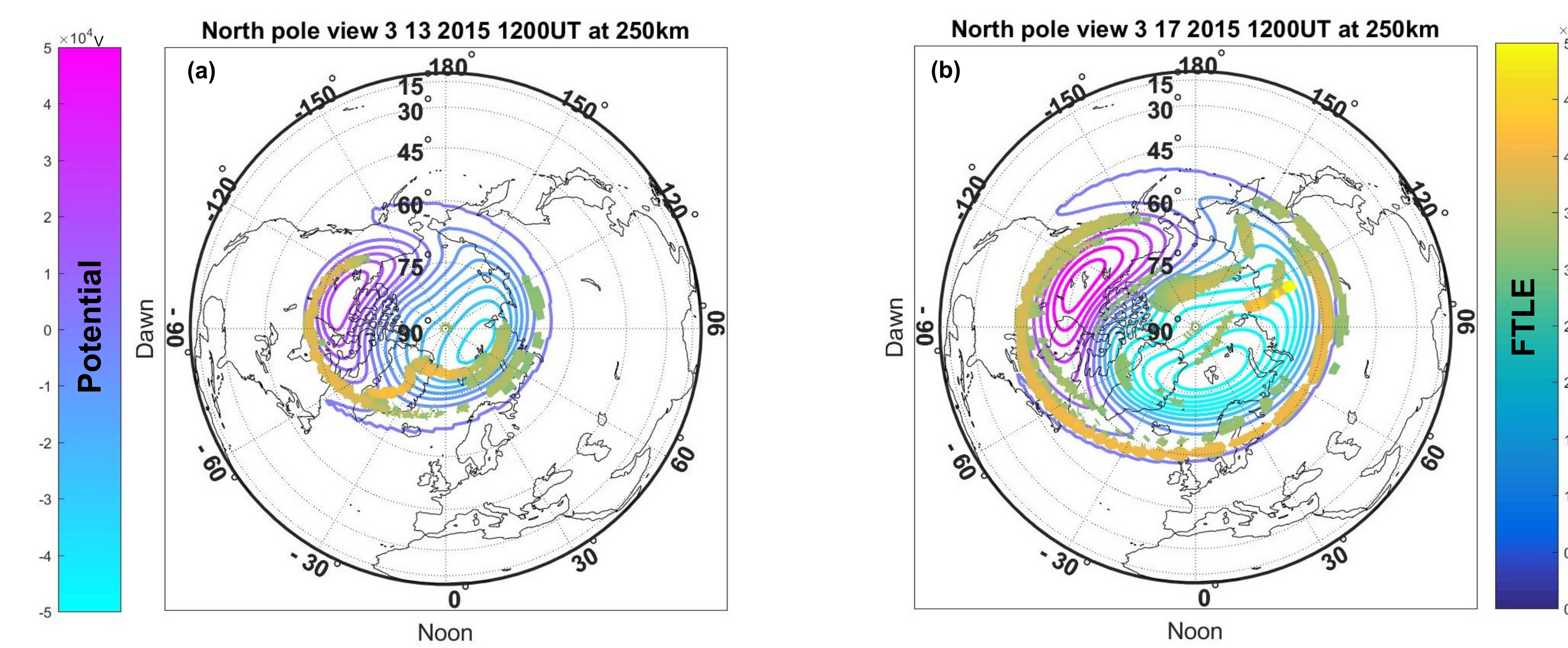


Fig.8 North pole view of electric potential with maximum FTLE values (a) for geomagnetic quiet period, (b) for geomagnetic active period.

## Conclusions:

- LCSs are found at high latitudes for both hemispheres, and act as repelling ridges.
- LCSs appear in the day side and in the boundary of the electric potential.
- LCSs have more complex topology and are at lower latitudes during geomagnetic storm.
- The response to geomagnetic activity of the ionospheric LCSs is in agreement with the thermospheric LCSs discussed in [1].

## Future work:

- Ionospheric LCSs act as poleward barriers which could be used to predict the transport boundaries of the polar cap patch.
- Ionospheric LCSs could be used to study flux tube movement.
- Ionospheric LCSs at lower latitudes can be studied by compute the FTLE map for flows simulated by Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM).