# Data Assimilation and the Search for Lagrangian Coherent Structures in the Ionosphere


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## Introduction

- Lagrangian Coherent Structures (LCSs) are invisible boundaries that separate flow
- LCSs have been found in the ionosphere using drifts from empirical models and were used to study the formation and propagation of a polar cap patch [1]

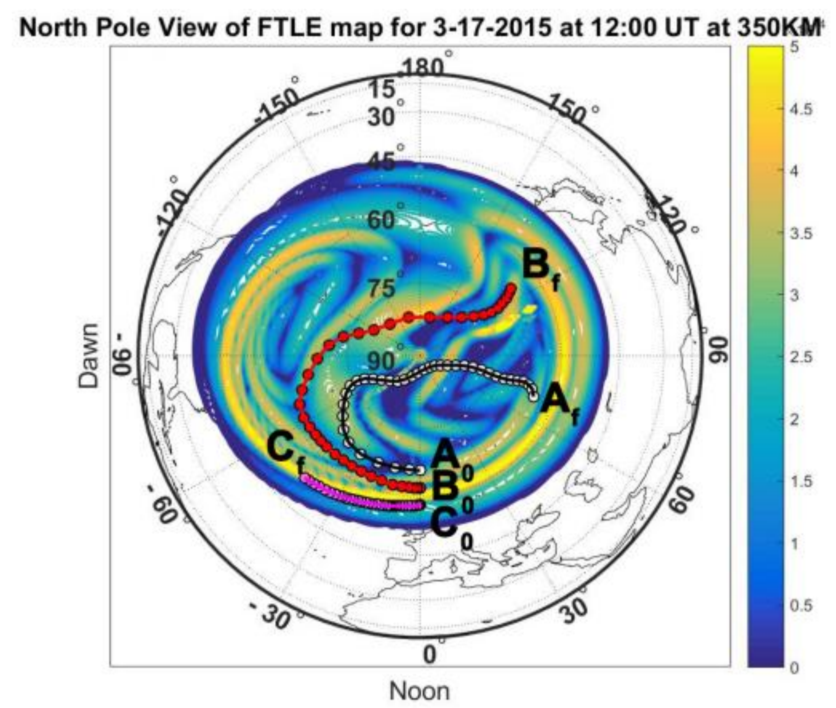


**Figure 1**: Reprinted from [1]. LCS found using ionospheric flow modeled with Weimer 2005 [2] and IGRF 12 [3]

## Objective

In this work, LCS will be found in the ionosphere using data to:

- ❖ Compare LCS found with models and data
- ❖ Compare LCS found during storm and quiet times

## Motivation

- Empirical models, such as Weimer 2005, are based on data that is averaged over long periods of time
- Unable to model processes unique to each geomagnetic storm
- Thus, **data assimilation** may be better suited to obtain LCSs during storm periods

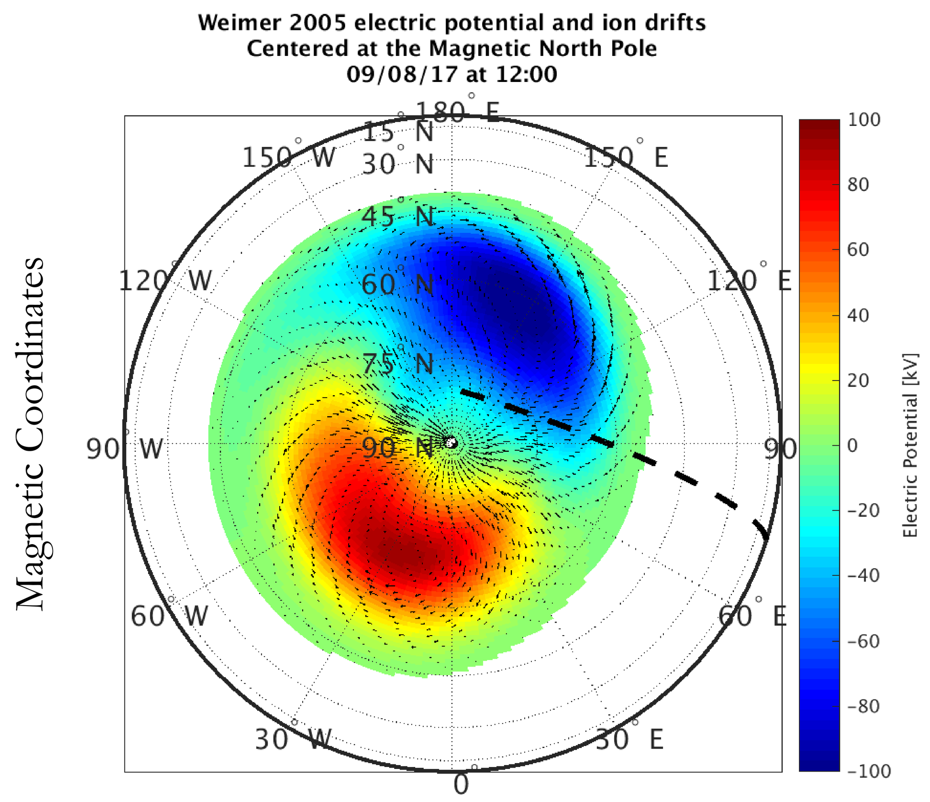


**Figure 2**: Electric Potential (Φ) from the Weimer 2005 at the geomagnetic north pole, in geomagnetic latitude and longitude for September 8, 2017 at 12:00 UT. Black dashed line marks the location of the sun.

## Background

### SuperDARN Radar Data

- By combining radar data and a statistical model, SuperDARN provides high latitude ionospheric drifts [4]

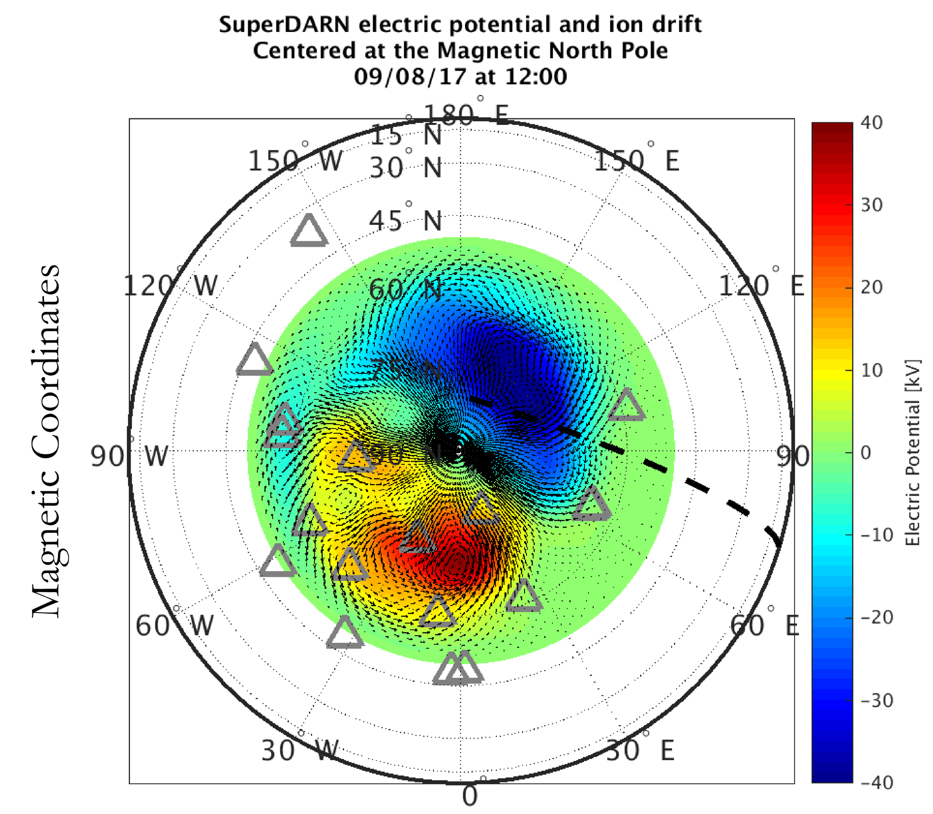


**Figure 3**: SuperDARN data-assimilated electric potential and plasma drifts at the geomagnetic north pole in geomagnetic coordinates on September 8, 2017 at 12:00 UT. Gray triangles mark the locations of the radars. Black dashed line marks the location of the sun.

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

- Computes the FTLE (Finite Time Lyapunov Exponent) value
- LCS is the locally maximum FTLE value

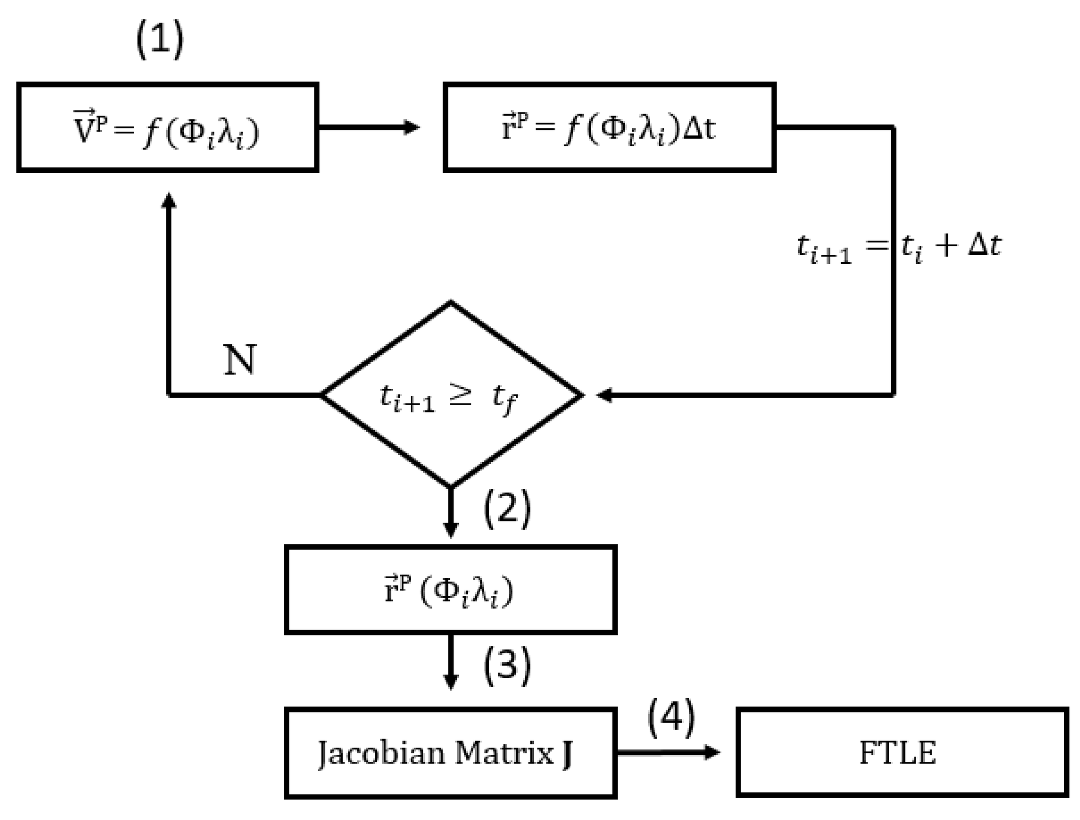


**Figure 4**: Schematic of ITALCS algorithm, modified from [1]

1. Start with a velocity at every magnetic longitude (Φ), magnetic latitude (λ), and time stamp
2. Numerically integrate over time
3. Use the starting and ending position to get the Jacobian Matrix (J), which quantifies the amount of stretching that occurs
4. From the Jacobian Matrix (J) get the FTLE value, which is normalized maximum eigenvalue of $J^TJ$

## Experimental Conditions

| | |
|---|---|
| **Date:** | 07 September 2017, 12:00 to 15:00 UT (Quiet)<br>08 September 2017, 12:00 to 15:00 UT (Storm) |
| **Δt:** | 10 min |
| **Flow:** | Model (Weimer 2005 + IGRF 12)<br>Data (SuperDARN) |

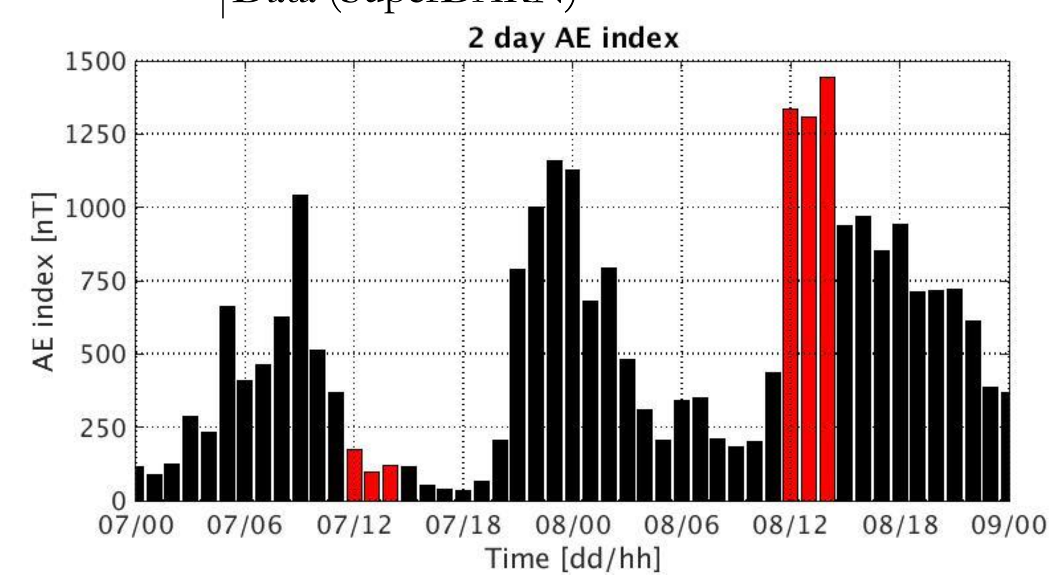


**Figure 5**: AE index from 07 September 2017 to 09 September 2017. Red bars mark the time intervals of interest

## Results

### Data: Quiet Period

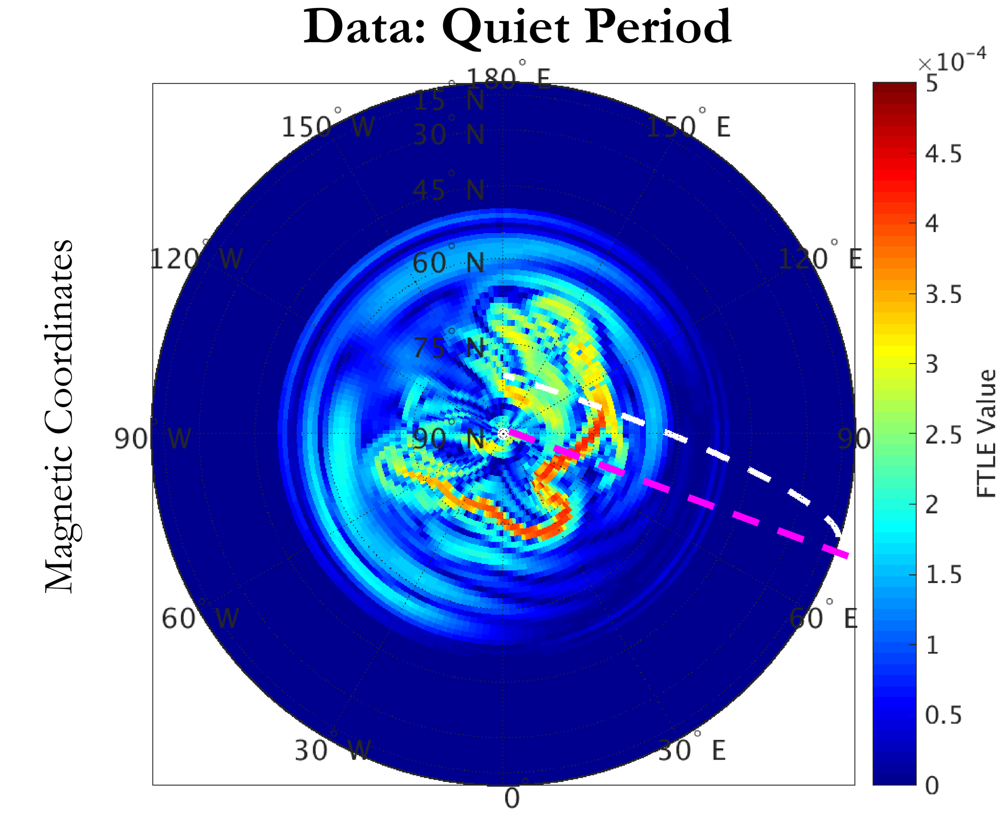


**Figure 6**: FTLE value on 09/07/17 at 12:00 UT (quiet time) from SuperDARN data. White dashed line represents the location of the sun. Dashed pink lines marks the longitudinal midpoint of the LCS

### Data: Storm Period

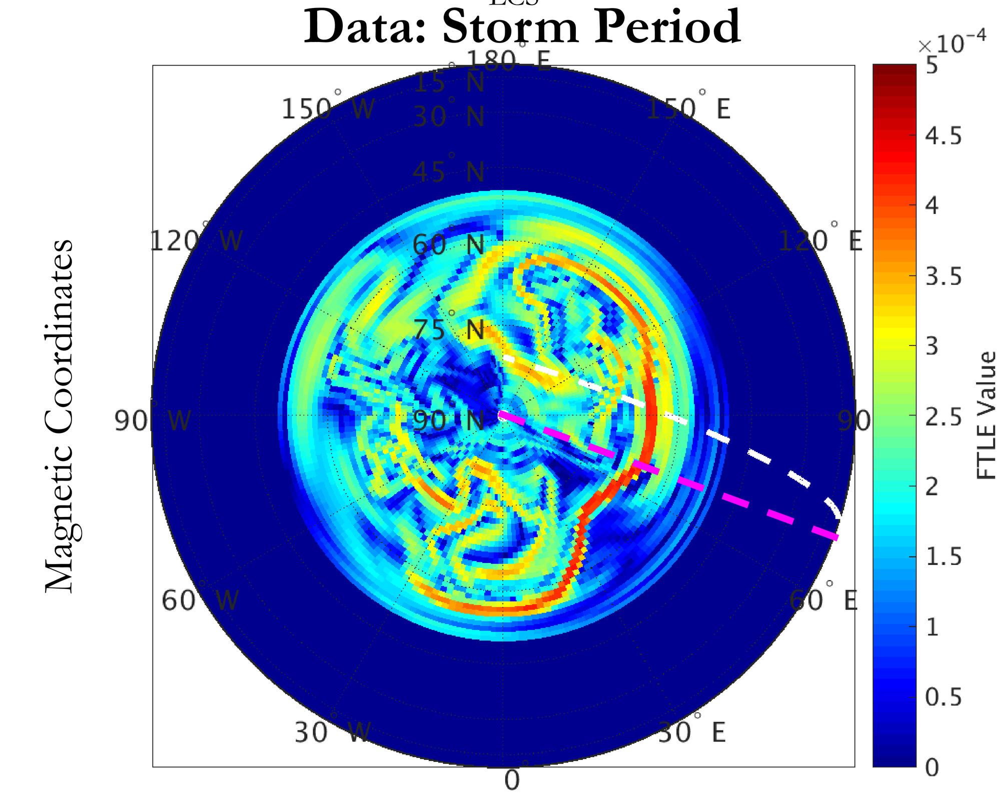


**Figure 7**: FTLE value on 09/08/17 at 12:00 UT (storm time) from SuperDARN data. White dashed line represents the location of the sun. Dashed pink lines marks the longitudinal midpoint of the LCS

## Acknowledgements


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- The authors acknowledge the use of SuperDARN data. SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Italy, Japan, Norway, South Africa, United Kingdom and the United States of America. The authors acknowledge the use of the VT SuperDARN Web site (vt.superdarn.org) for access to radar data and data products.
- AE index values are available at the World Data Center (WDC) for Geomagnetism, Kyoto for AE index service (http://wdc.kugi.kyoto-u.ac.jp/)


## Results Continued

### Model: Storm Period

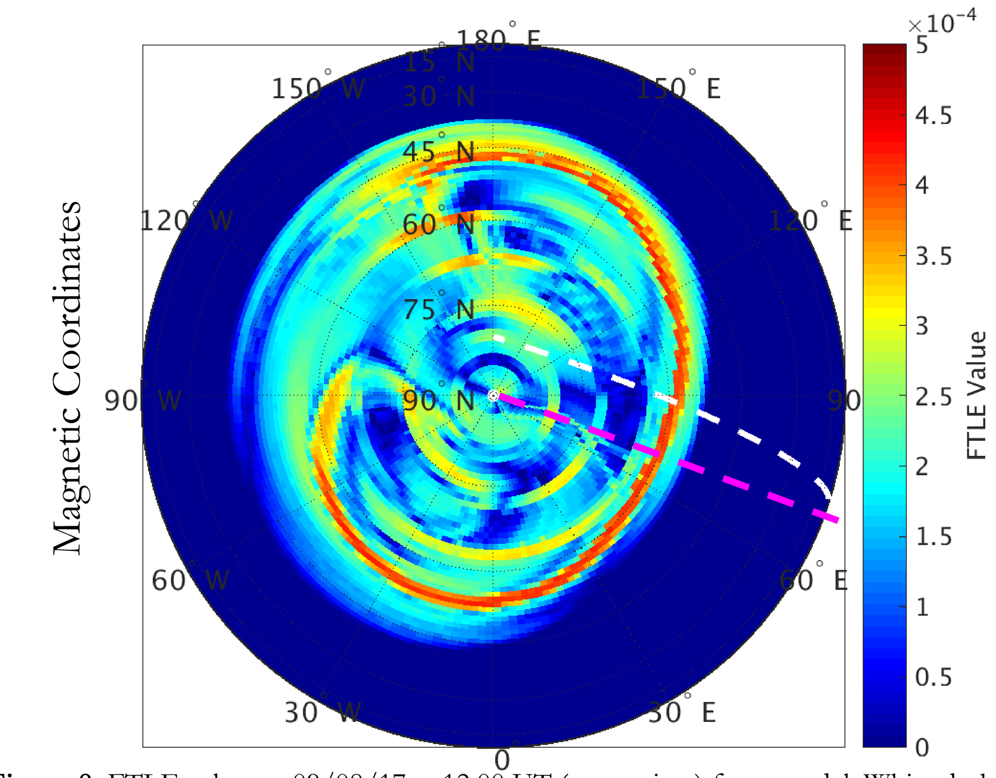


**Figure 8**: FTLE value on 09/08/17 at 12:00 UT (storm time) from model. White dashed line represents the location of the sun. Dashed pink lines marks the longitudinal midpoint of the LCS

### LCS Structures: Models and Data

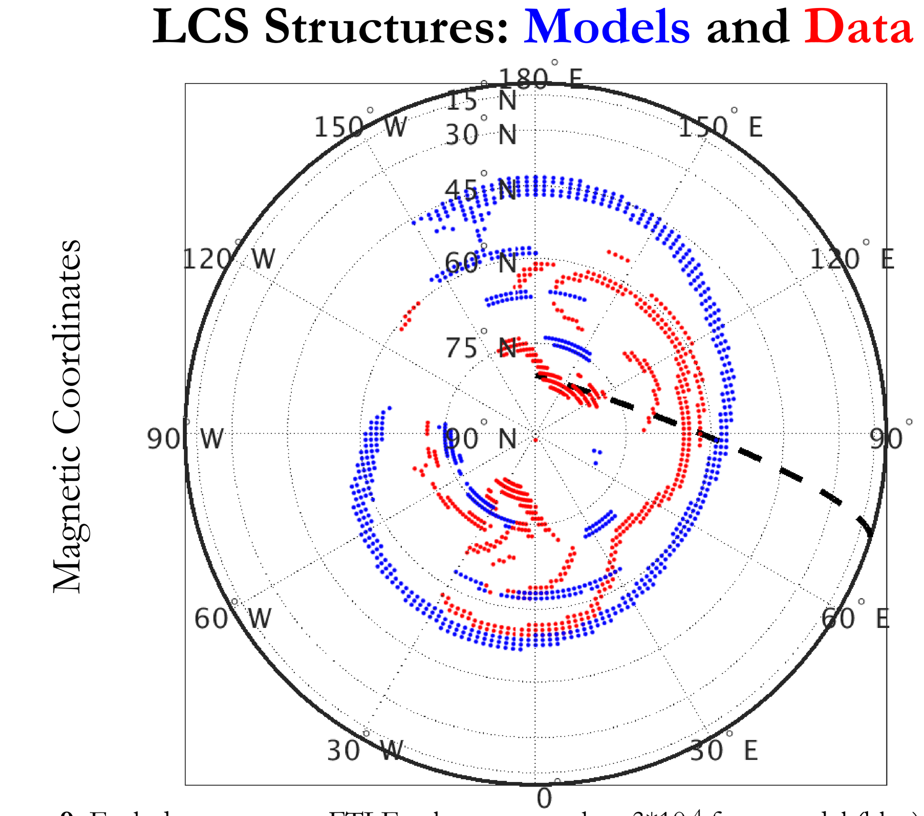


**Figure 9**: Each dot represents FTLE values greater than $3 \times 10^{-4}$ from model (blue) and data (red) on 09/08/17 at 12:00 UT (storm time). Black dashed line represents the location of the sun.

## Conclusions and Future Work

- LCSs were found using data from the SuperDARN
- **Comparison of storm vs quiet time:**
  - ➢ LCS is horseshoe-like with a longitudinal midpoint at 75° (see pink dashed lines) and it expanded equatorward during the storm, consistent with [1]
- **Comparison of model vs data:**
  - ➢ Both LCSs are horseshoe shape, but the model's is more equatorward (45° vs 60°)
  - ➢ The LCS from data has more structures. For example, there is an oval structure at 70° magnetic latitude, 0° magnetic longitude.
  - ➢ **Future work:** Use data's LCSs to study the formation and propagation of polar cap patches

## References


[1] Wang, N., S. Datta-Barua, A. Chartier, and C. N. Mitchell (2018), J. Geophys. Res., in production, doi: 10.1029/2017JA025077.
[2] Weimer, D. R. (2005), Predicting Surface Geomagnetic Variations Using Ionospheric Electrodynamic Models, *Journal of Geophysical Research*, 110, A12307, doi:10.1029/ 2005JA011270.
[3] Thébault, E et al. 2015 International Geomagnetic Reference Field: the 12th generation. *Earth, Planets and Space*, 67 (79). 10.1186/s40623-015-0228-9
[4] Chisham, G., Lester, M., Milan, S.E. et al. (2007) A decade of the Super Dual Auroral Radar Network (SuperDARN): scientific achievements, new techniques and future directions. *Surv Geophys* 28: 33. doi.org/10.1007/s10712-007-9017-8