Lagrangian Coherent Structures in the Ionosphere: Predictive Transport Barriers for Space Weather Effects

Ningchao Wang, Seebany Datta-Barua
Illinois Institute of Technology

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Motivation

Credit: Alex Chartier

Credit: Dan Lamothe
Motivation

Sea-ice area on Sept. 5, 2018
Median sea-ice extent in September (1980-2010)

Credit: Dan Lamothe

Credit: Alex Chartier

Polar cap patch
Motivation

Can we trace and predict the PCP in the high-latitude region?
Ionosphere is dominated by plasma and electromagnetic field behavior.
Electric field and magnetic field:

The Earth’s Magnetic Field

Credit: P. Reid

Ionospheric flows

The Earth’s Magnetic Field

Ion drift Velocity for 3-17-2015 at 12:00 UT

22 April 2017
06:36 UT

Hidden structures bound the oil transport

Modified from: R. Loomis
Hidden structures bound the oil transport
Hidden structures bound the oil transport

Modified from: R. Loomis
Objective

• Find the hidden structures in the ionosphere.
• Find the connection between the structures and the polar cap patches.
Method

- **ITALCS:** Ionosphere-Thermosphere Algorithm for Lagrangian Coherent Structures
- **FTLE:** Finite Time Lyapunov Exponent
- **TEC:** Total Electron Content

Plasma ExB Drifts

- ionospheric flow
- ITALCS
- FTLE maps
- ionospheric LCSs

Ionospheric imaging

- TEC map
- Polar cap patch
- Compare the PCP location to the LCSs position.

10/29/19
Results

Wang et al., 2018

Polar cap patch

LCSs
Results

Wang et al., 2018

10/29/19
Summary and future work

- The polar cap patches originate from plasma that is poleward of the dayside LCS boundary.
- The necessary condition for the PCPs’ formation is that storm enhanced density exists poleward of the LCS.
- The LCSs are likely representative of the material transport barriers.
- The modeled LCSs form channels through which the polar cap patches propagate.

- Next step is to apply the LCS method to small-scale irregularity, which will require:
  - An algorithm for computing local LCS.
  - High spatial resolution flows.
Extra slides
Ionospheric convection

- Ionosphere is dominated by plasma and electromagnetic field behavior.

\[ \vec{v}_{drift} = \frac{\vec{E} \times \vec{B}}{B^2} \]

Credit: J. A. Bittencourt
Introduction

Polar cap patch

- Is a few 100-km-scale ionospheric enhancement.
-Appears at high-latitude upper atmosphere.
-Is associated with the plasma density irregularities.
- Causes Global Navigation Satellite System (GNSS) signal scintillation.

Tracking patches will:

- Provide better understanding of its formation.
- Improve the predictability of space environment.
- Help to avoid the effect of GNSS signal scintillation.

Objective:

Analyze the PCP’s formation and transport by using governing structures in the plasma drift.

10/29/19
Simulate ionospheric plasma drifts

- Weimer 2005 is:
  - An electric potential model.
  - Used for generating the high latitude electric field.
- International Geomagnetic Reference Field (IGRF-12) is:
  - Used for simulating the global magnetic field.

\[ \mathbf{E} = -\nabla V \]

\[ \mathbf{E} \times \mathbf{B} \bigg/ B^2 \]

Drift Velocities
LCSs in the ionosphere

North Pole View of FTLE map for 3-17-2015 at 12:00 UT at 350KM

FTLE: finite time Lyapunov exponent
Finite Time Lyapunov Exponent (FTLE):

A scalar field measuring the degree of stretching. Local maximum FTLE surfaces are defined as the LCSs.
Finite Time Lyapunov Exponent (FTLE):

\[ J = \begin{bmatrix} \frac{\Delta x(\tau)}{|2\delta_x|} & \frac{\Delta x(\tau)}{|2\delta_y|} \\ \frac{\Delta y(\tau)}{|2\delta_x|} & \frac{\Delta y(\tau)}{|2\delta_y|} \end{bmatrix} \]  

\[ \sigma(J) = \frac{1}{|\tau|} \log \left( \sqrt{\lambda_{max}(J^TJ)} \right) \]
Finite Time Lyapunov Exponent (FTLE):
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[Diagram of FTLE with LCS ridge marked]