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

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Illinois Institute of Technology

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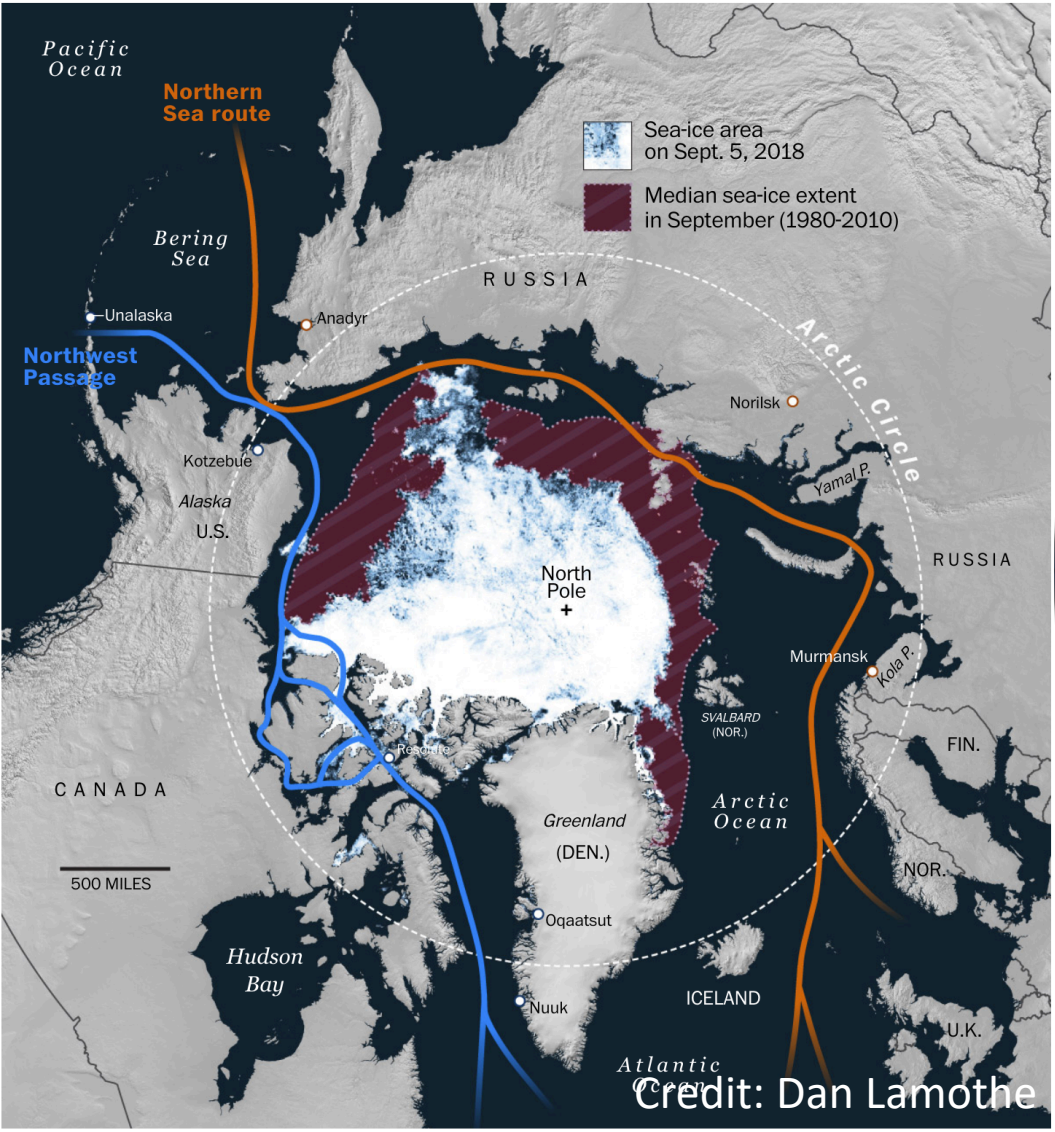
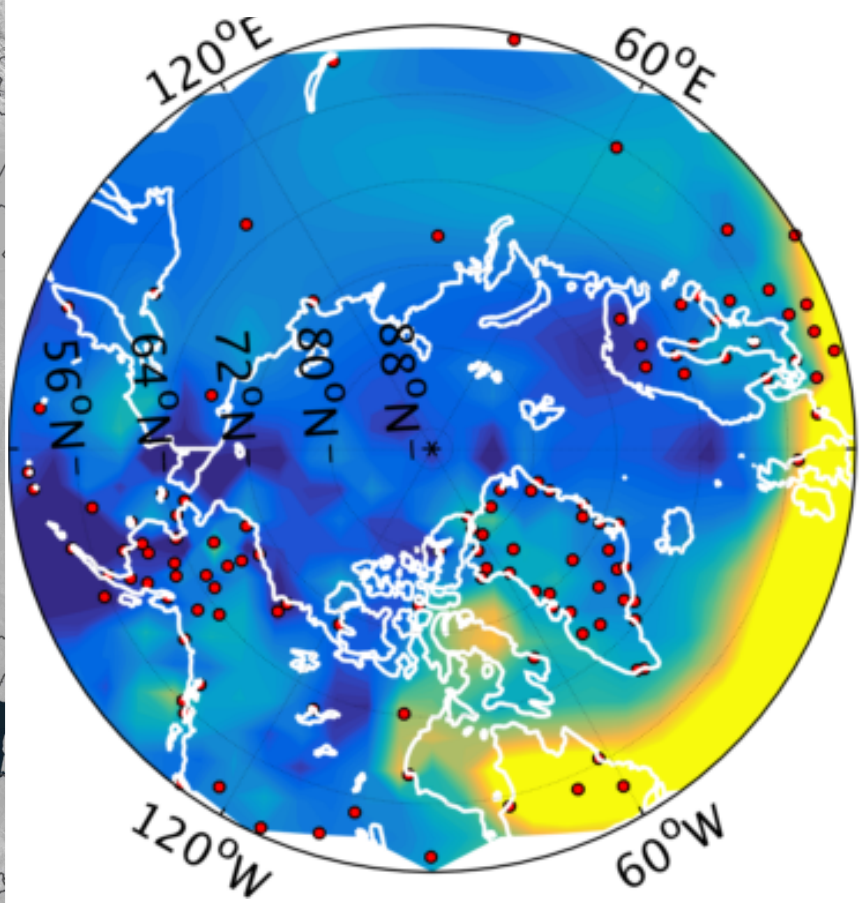
Motivation

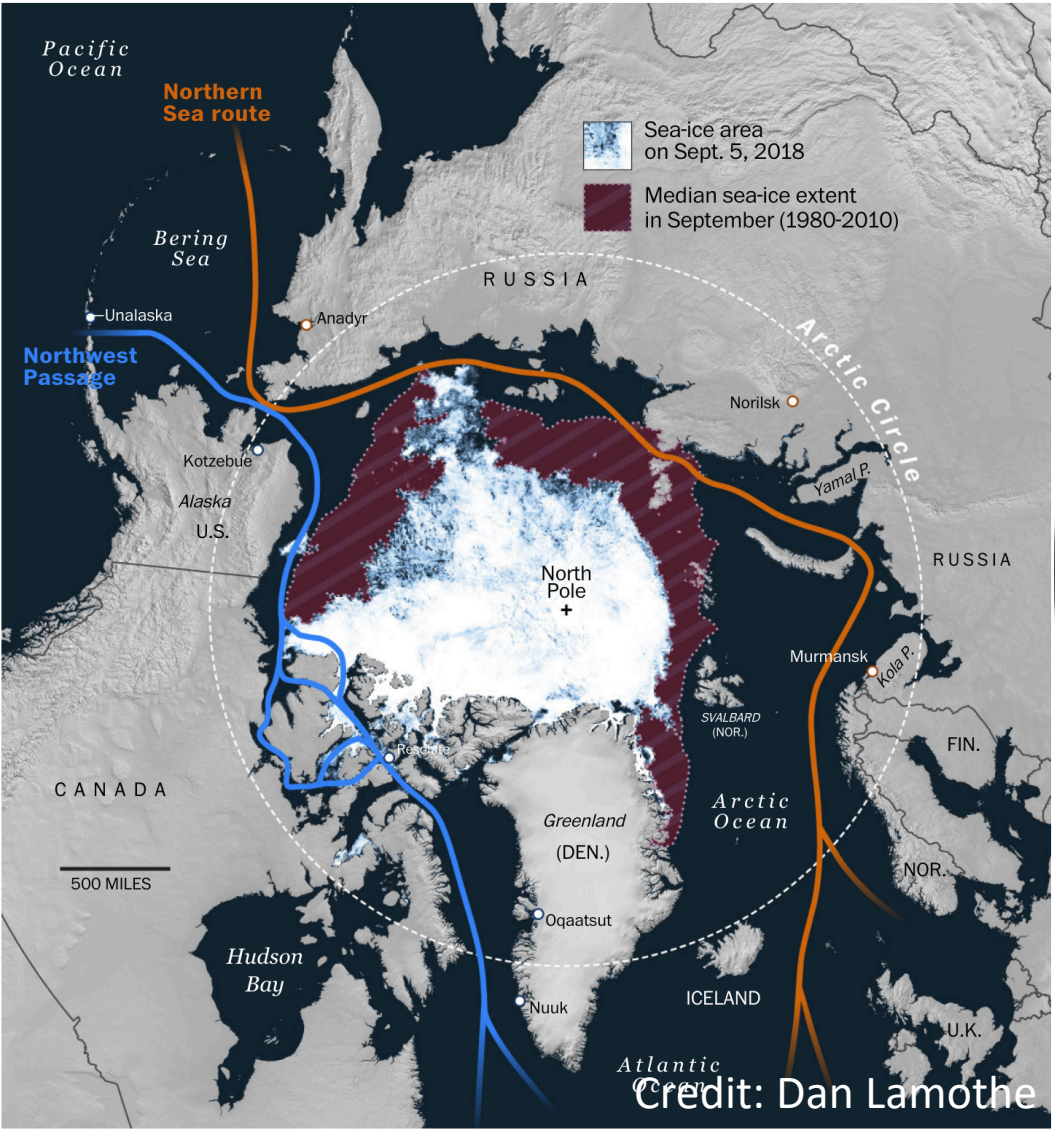


Credit: Dan Lamothe



Credit: Alex Chartier

Motivation



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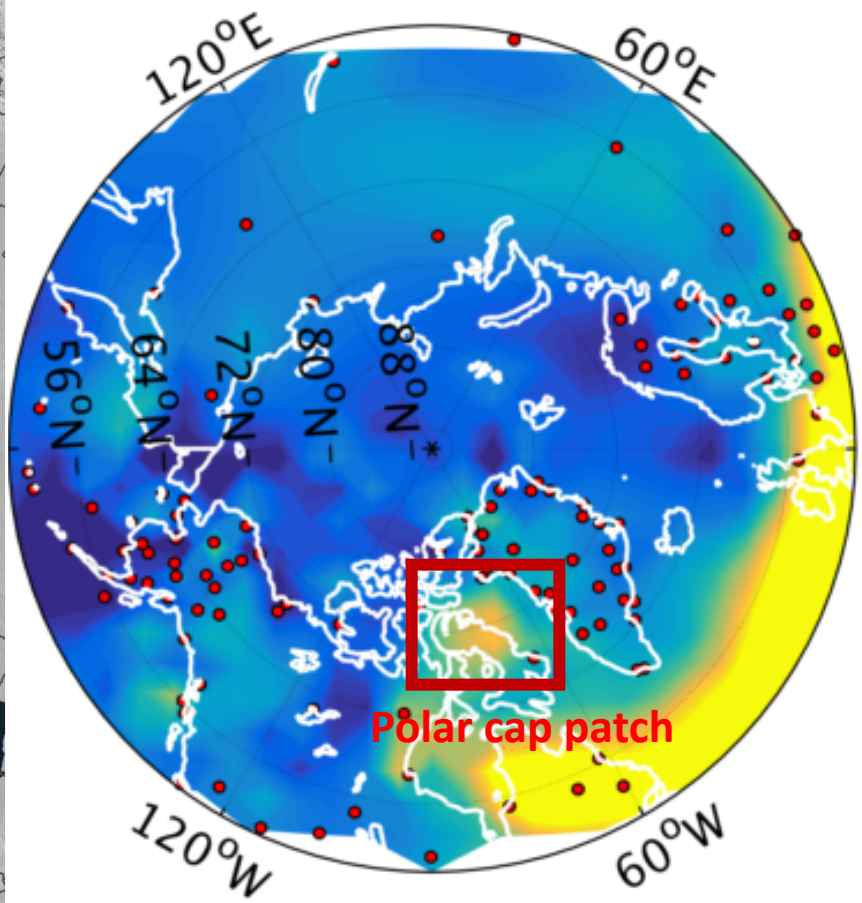
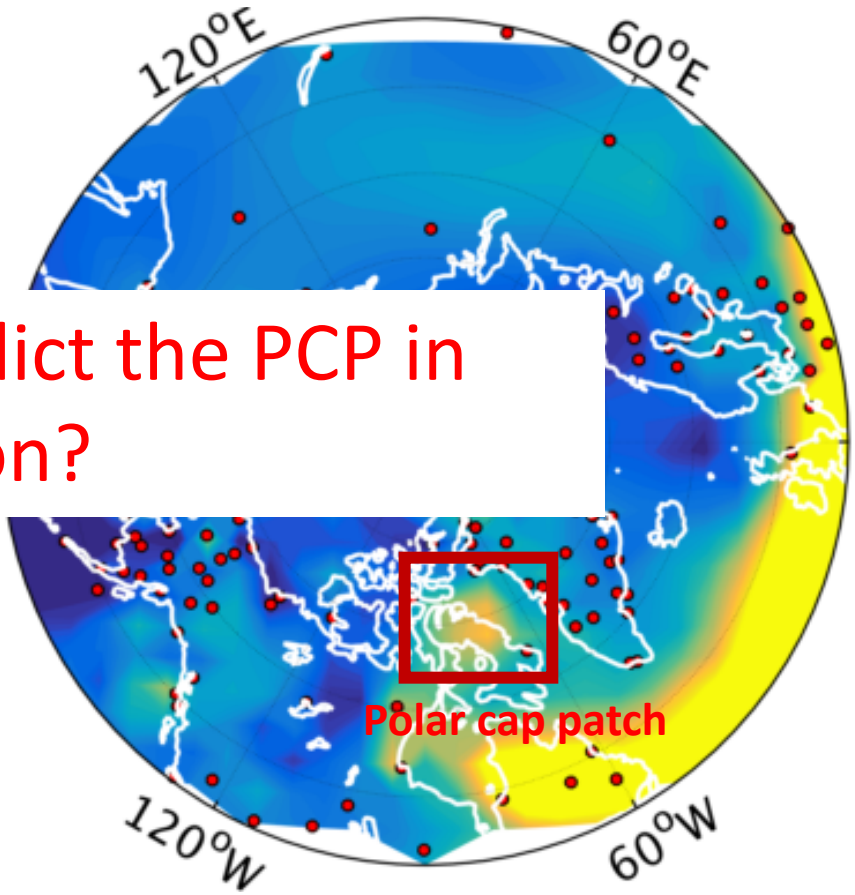


Credit: Alex Chartier

Motivation

Credit: Dan Lamothe

Can we trace and predict the PCP in the high-latitude region?



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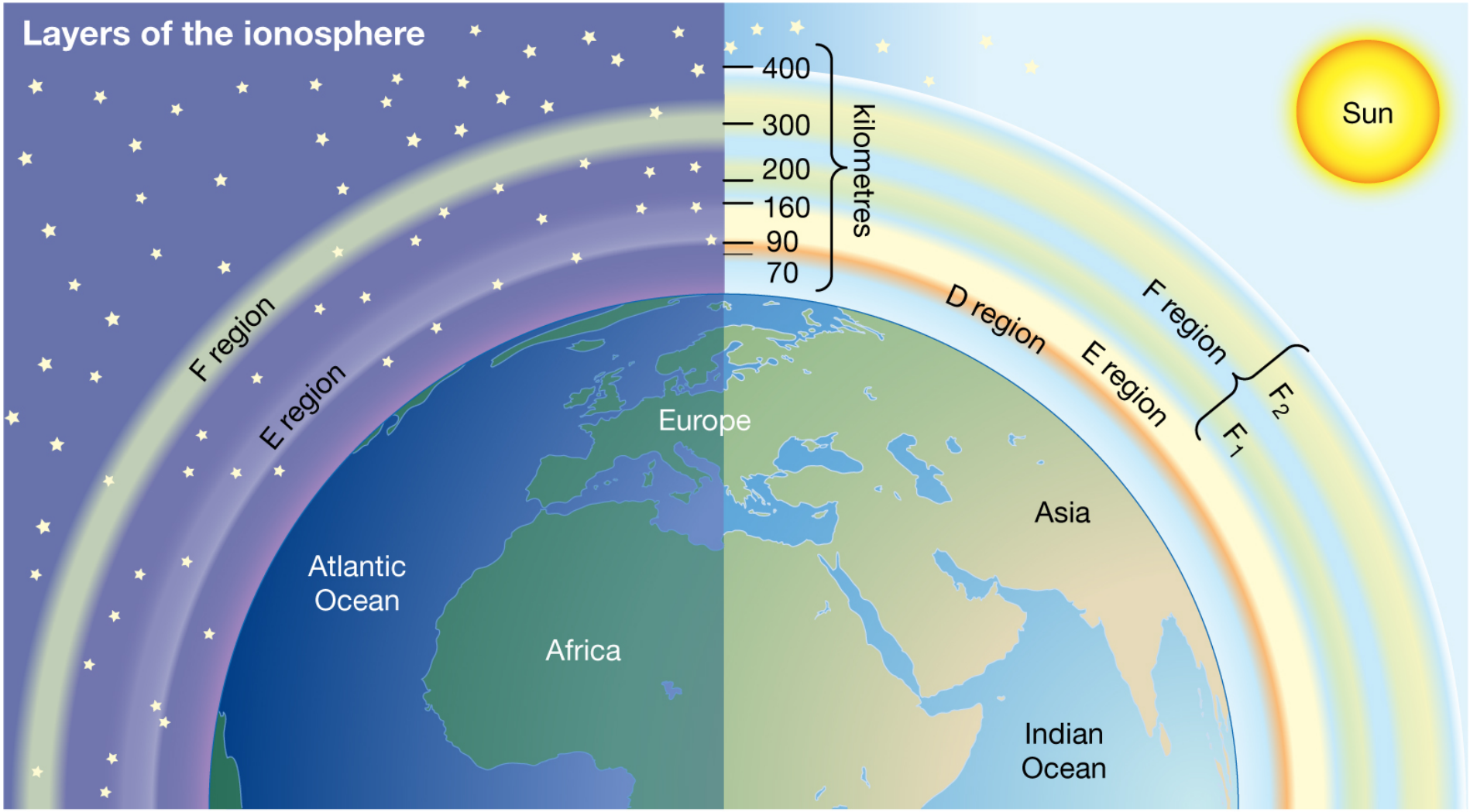
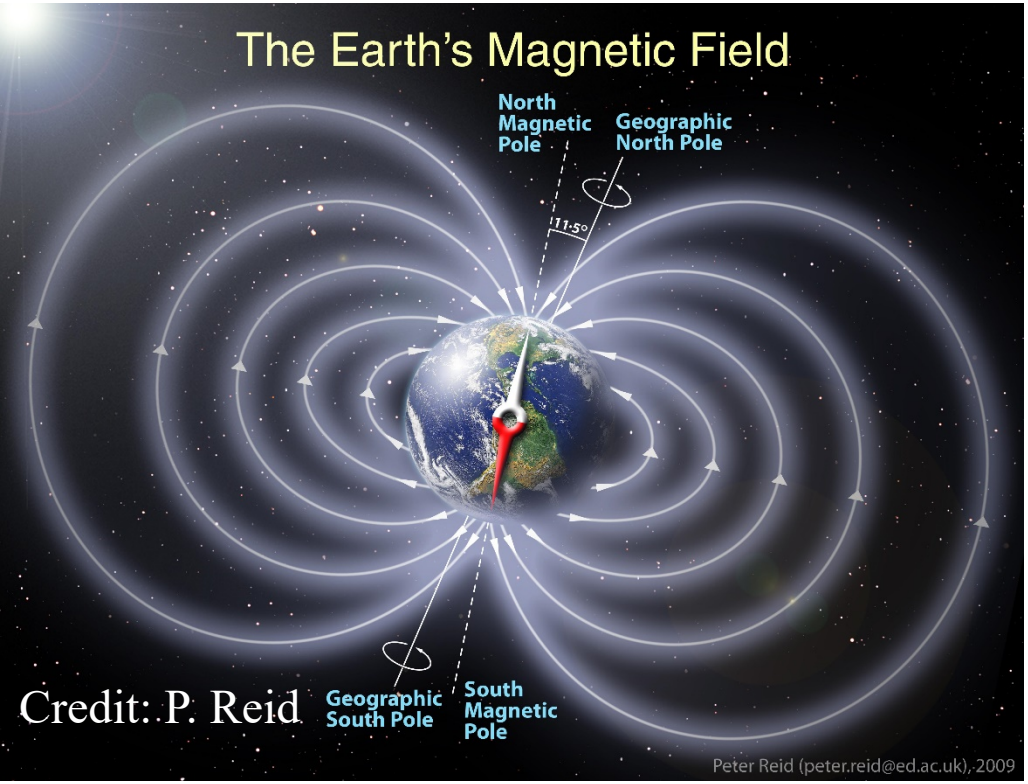
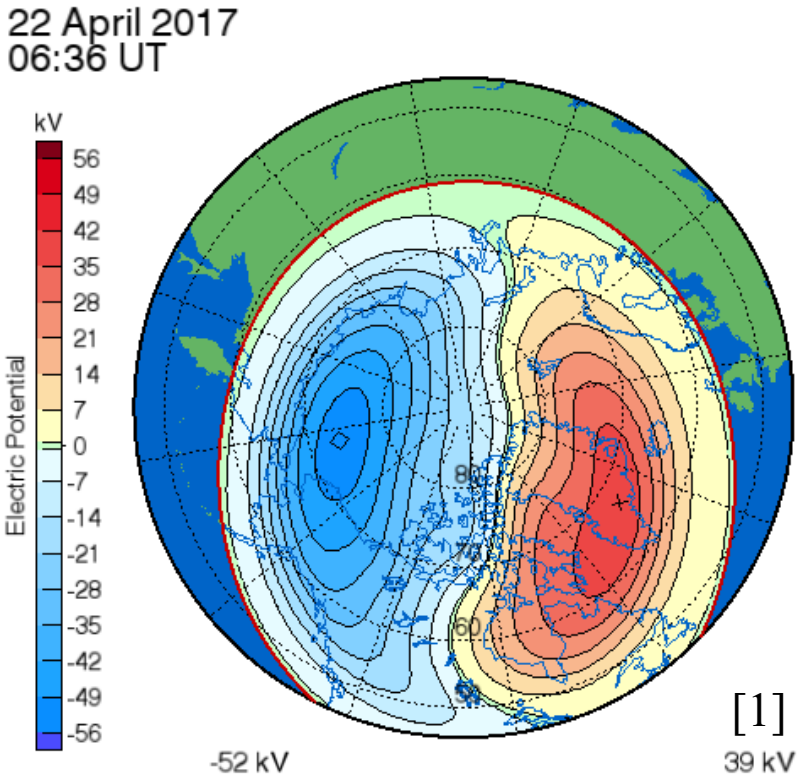
Ionosphere



- Ionosphere is dominated by plasma and electromagnetic field behavior.

Electric field and magnetic field:

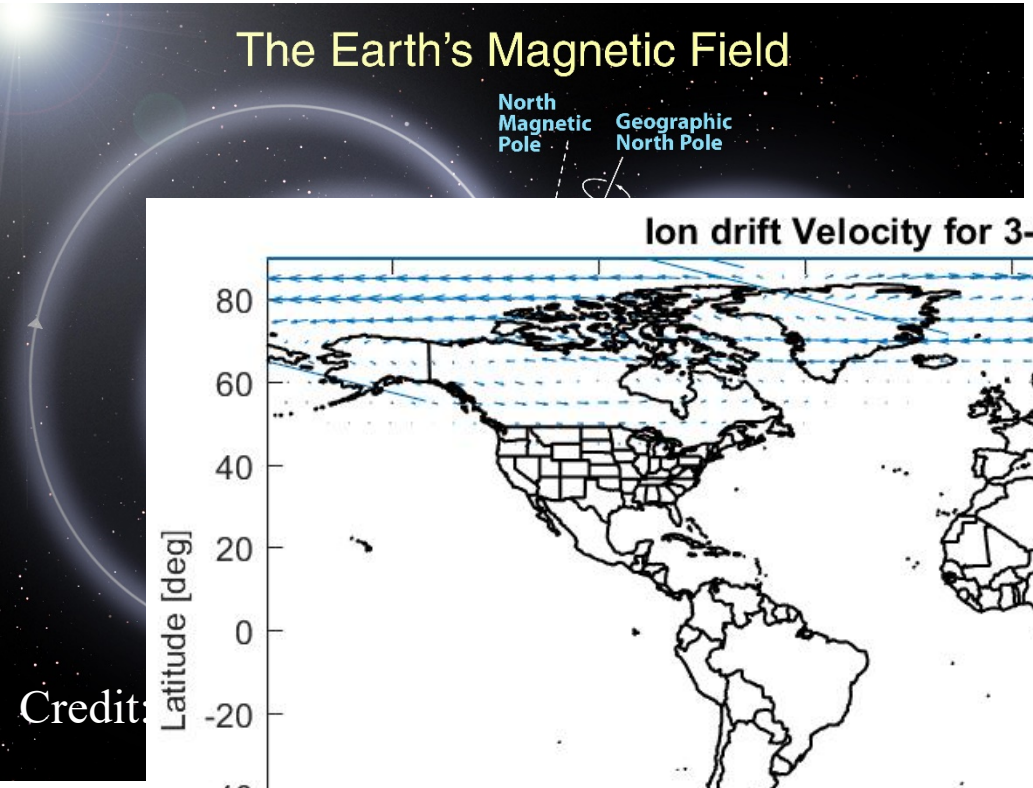


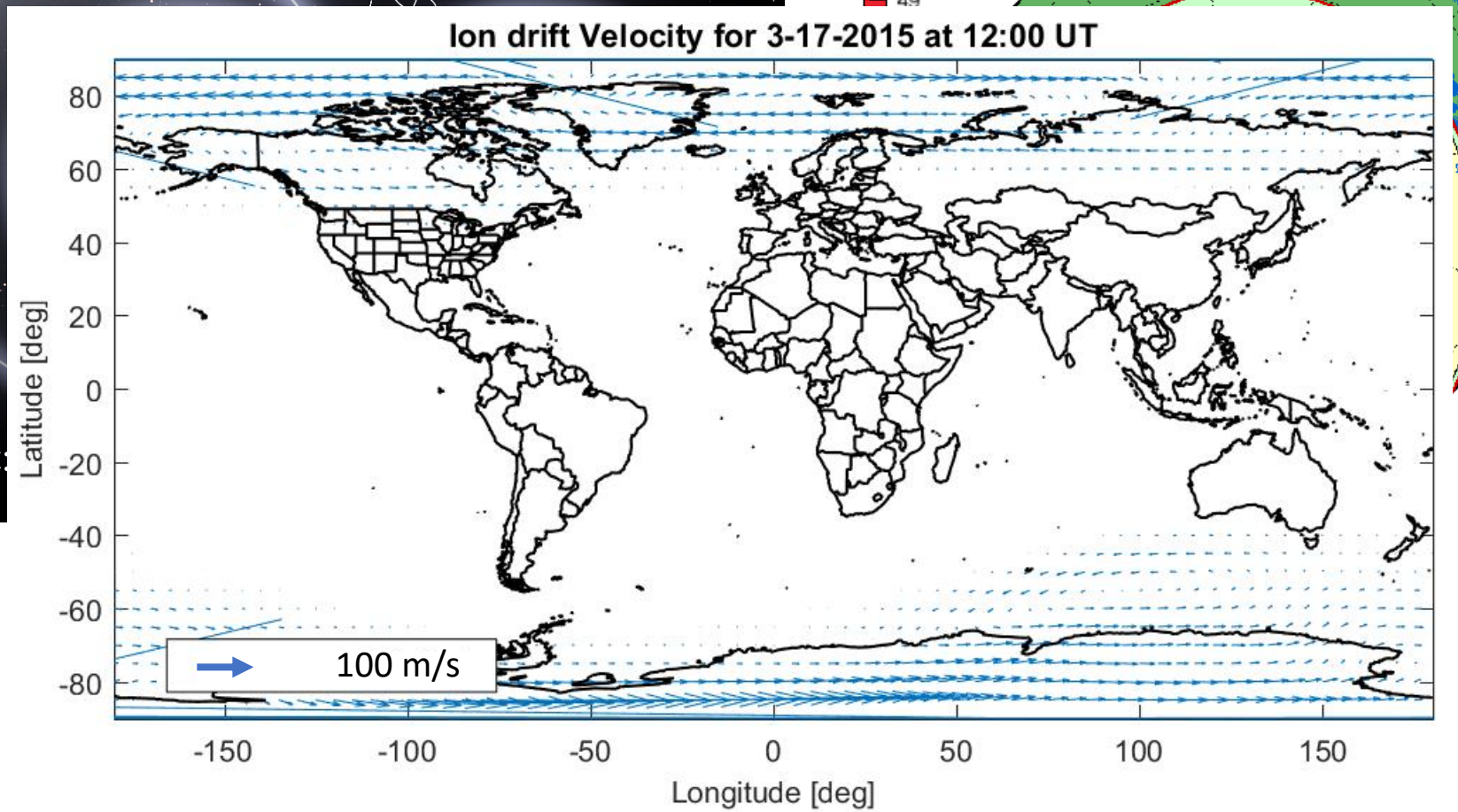


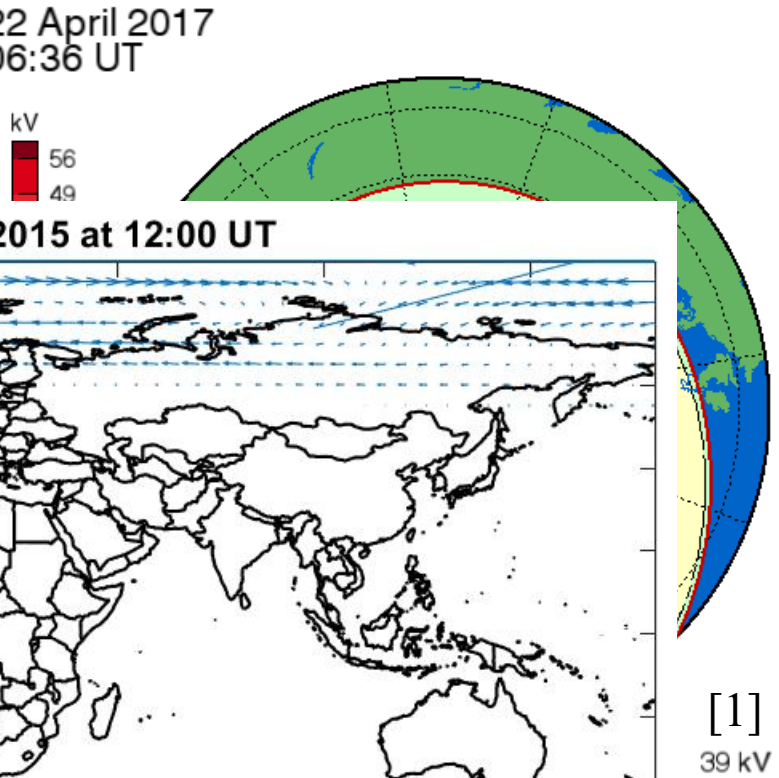
[1]

[1]. http://mist.nianet.org/RealTimeArchive/2017/04/170422/0636EPOT.PNG

Ionospheric flows







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Lagrangian Coherent Structure (LCS)

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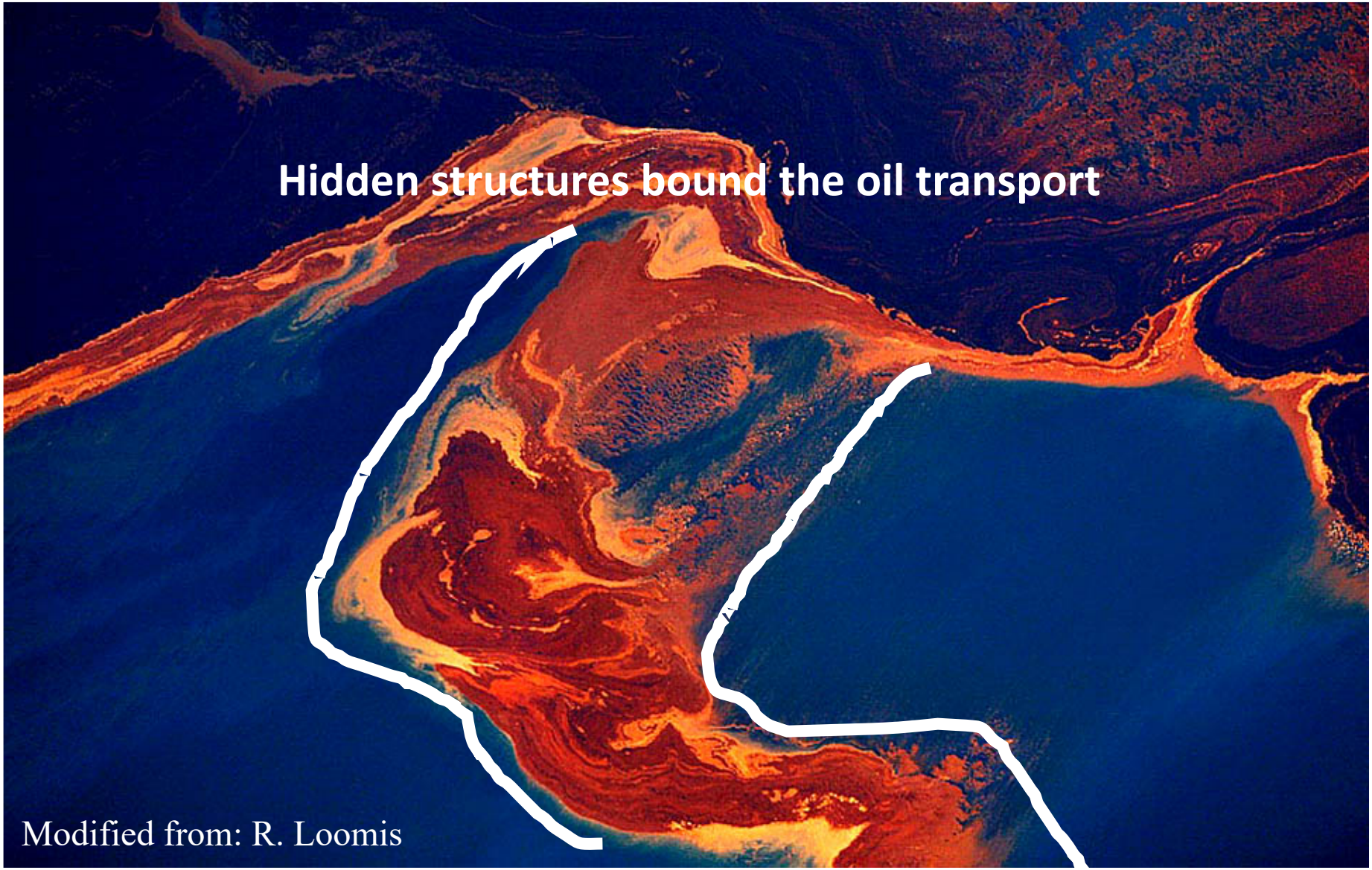

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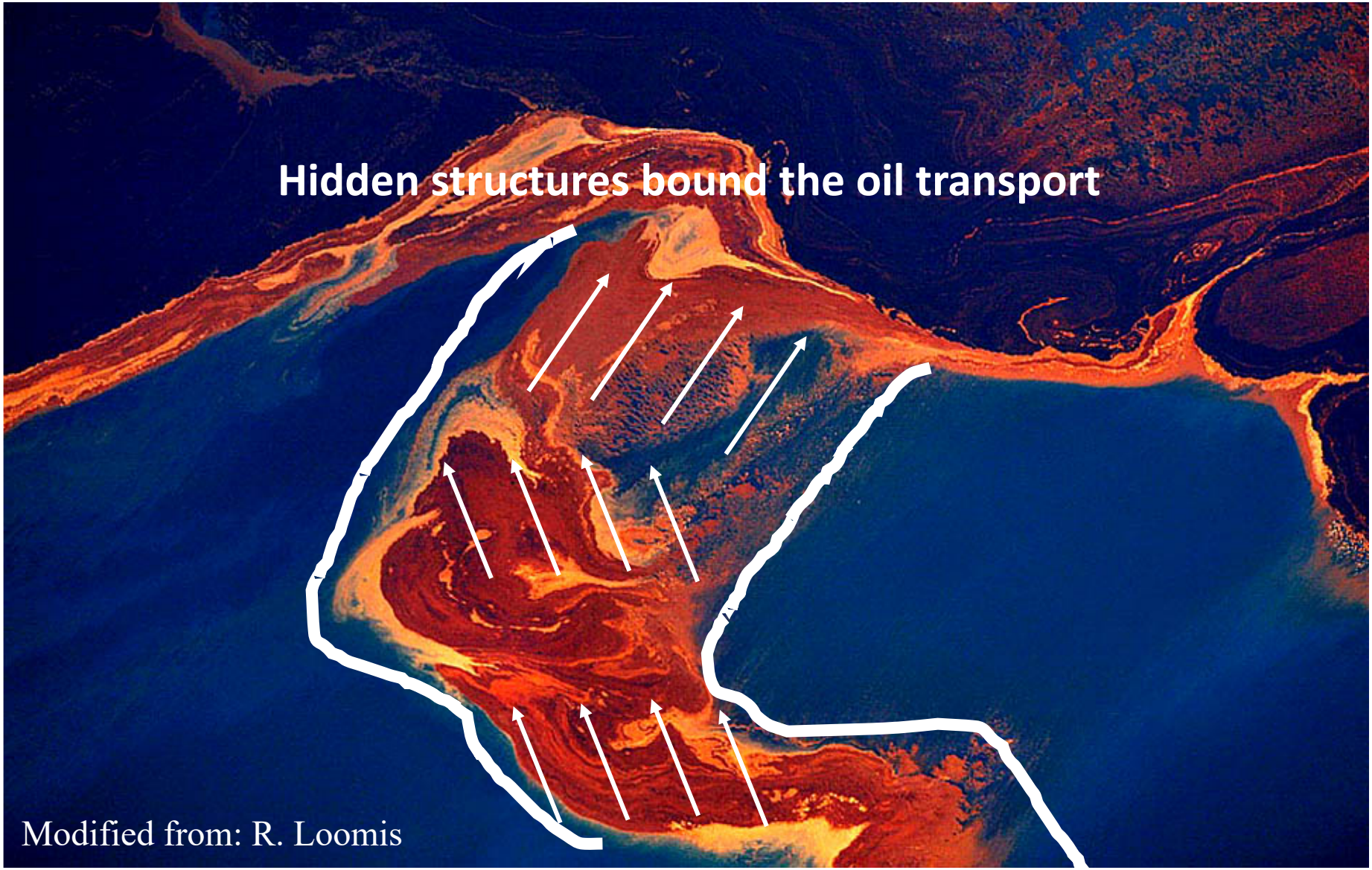

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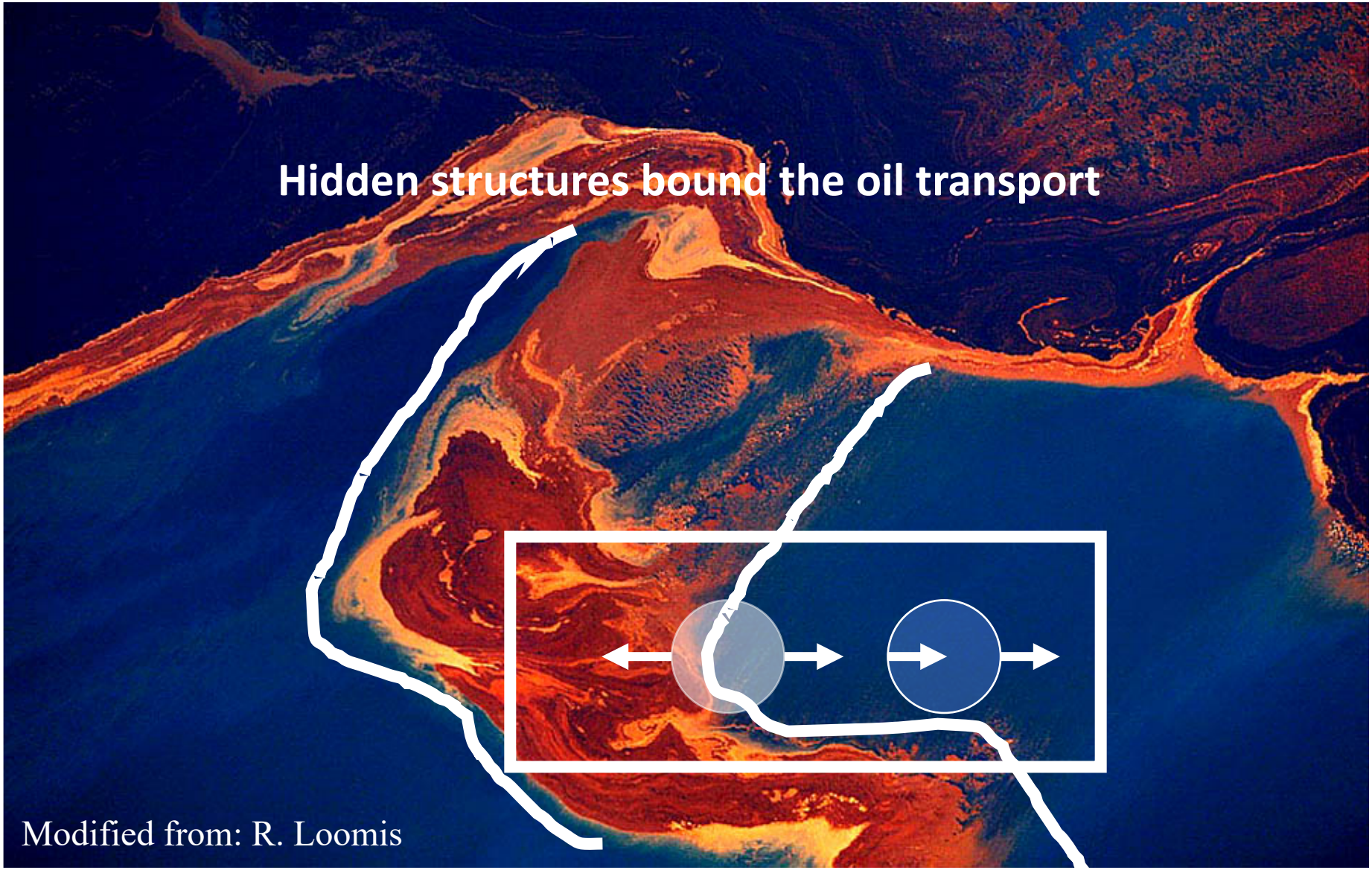
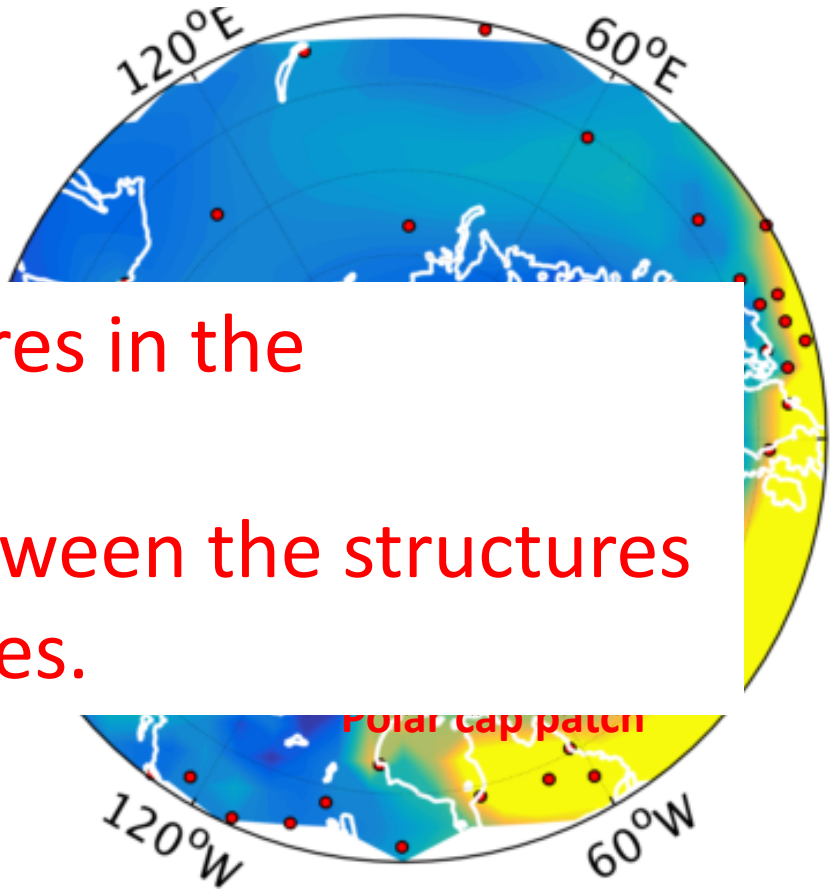


Objective

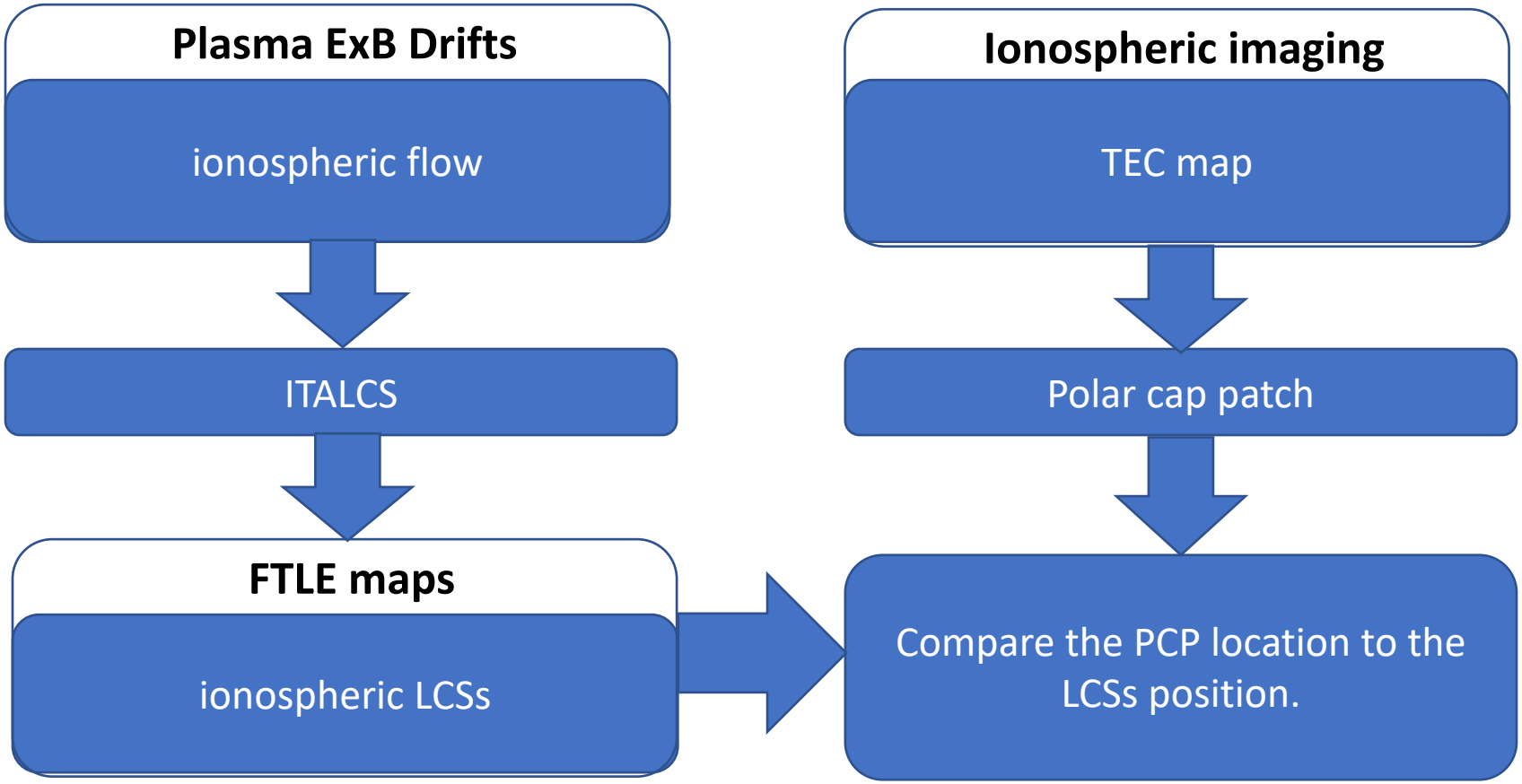
Credit: Dan Lamothe



Credit: Alex Chartier

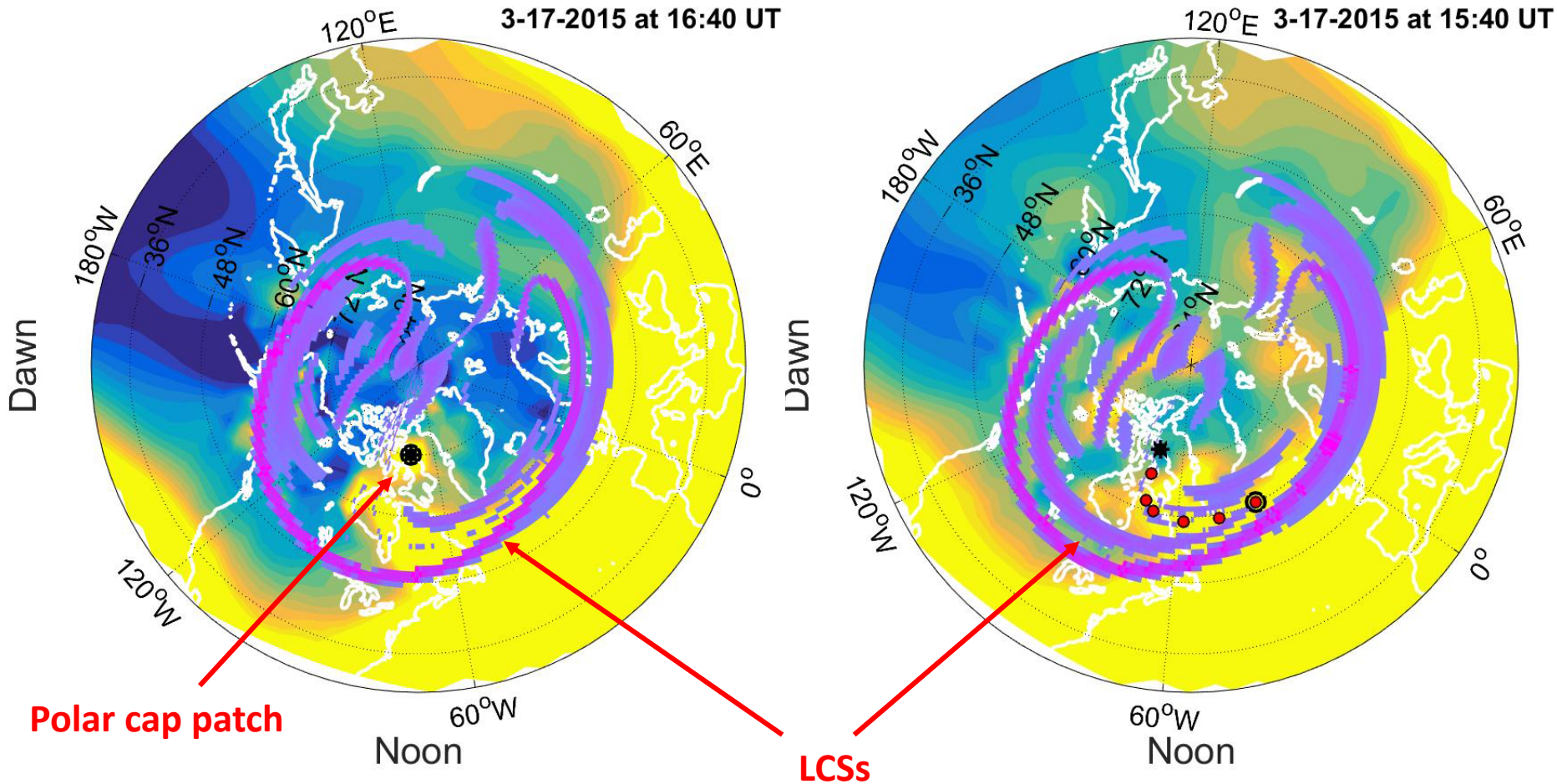
- Find the hidden structures in the ionosphere.
- Find the connection between the structures and the polar cap patches.

Method



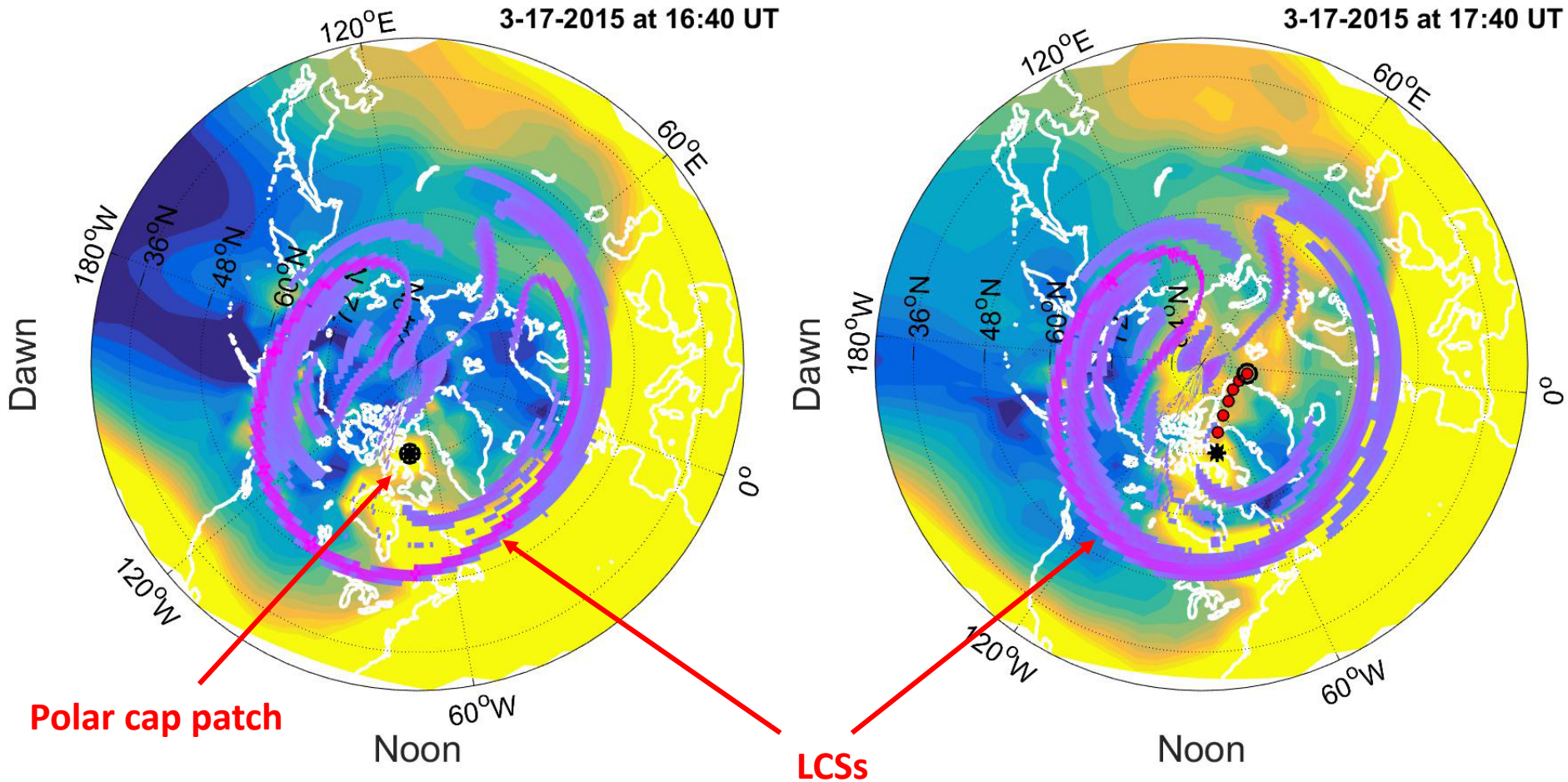
- ITALCS: Ionosphere-Thermosphere Algorithm for Lagrangian Coherent Structures
- FTLE : Finite Time Lyapunov Exponent
- TEC: Total Electron Content

Results



Wang et al., 2018

Results



Wang et al., 2018

Summary and future work

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- 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.

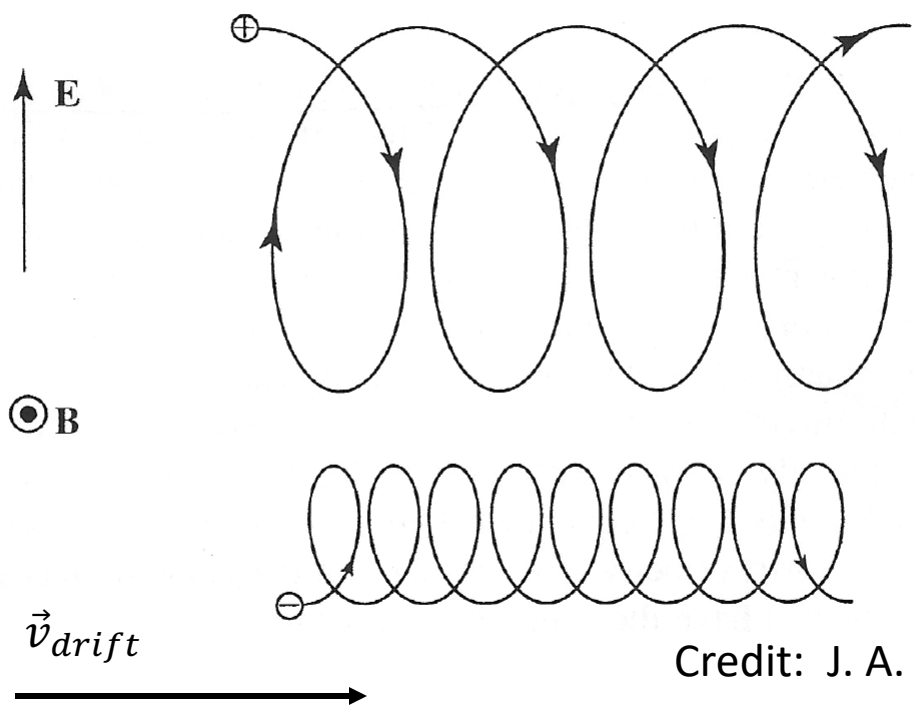
- Next step is to apply the LCS method to small-scale irregularity, which will require:
  - An algorithm for computing local LCS.
  - High spatial resolution flows.

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

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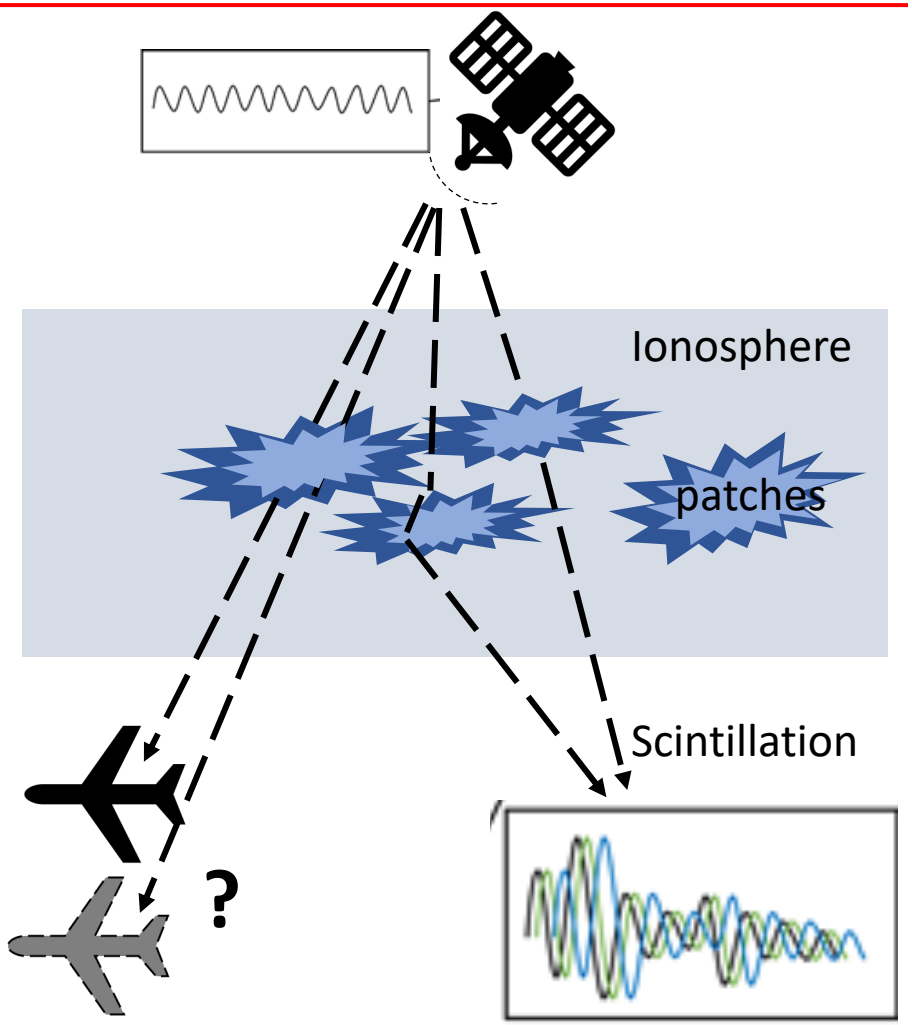
Polar cap patch

- 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.

Simulate ionospheric plasma drifts

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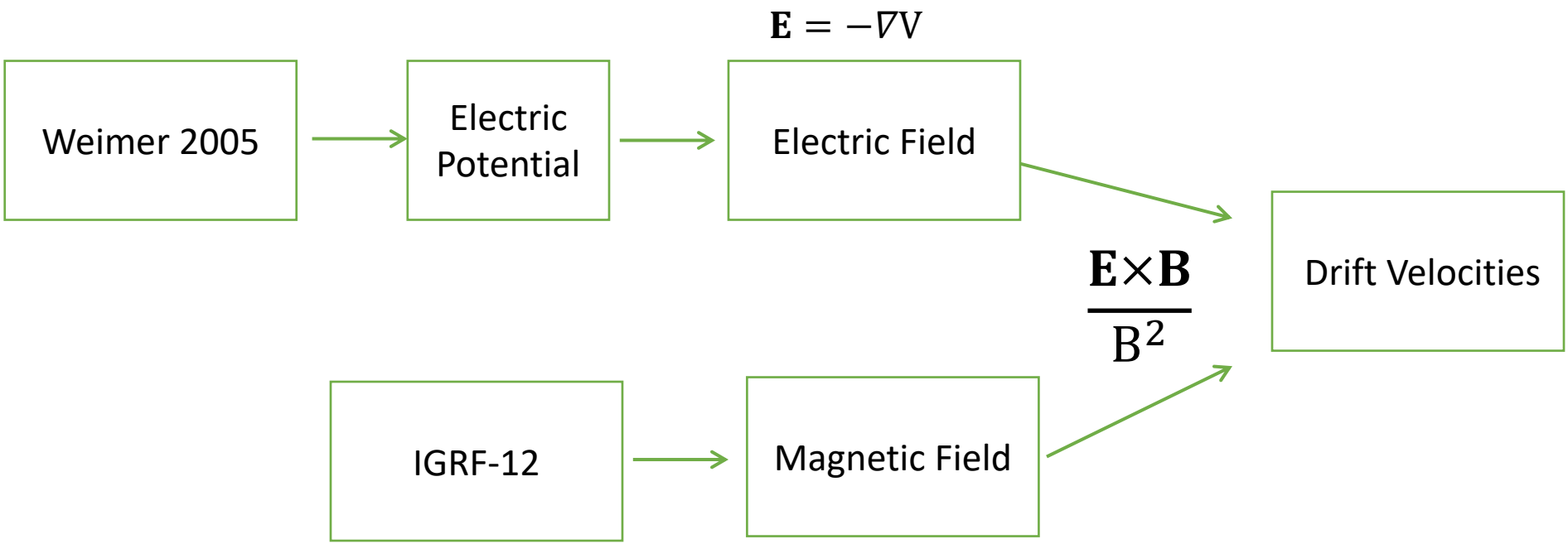
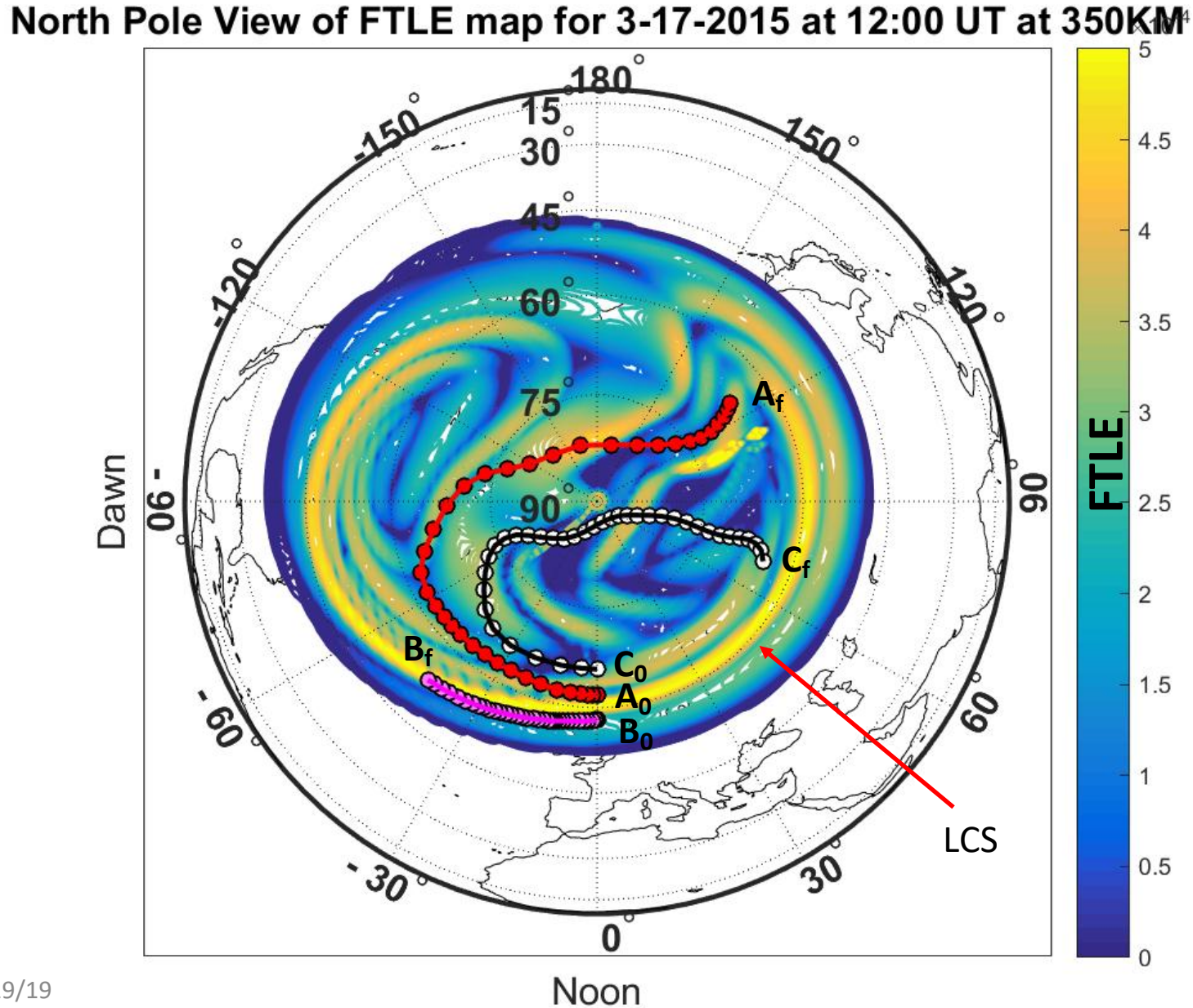
- Weimer 2005 is:
  An electric potential model.
  Used for generating the high latitude electric field.
- International Geomagnetic Reference Field (IGRF-12) is:
  Used for simulating the global magnetic field.



LCSs in the ionosphere



FTLE: finite time Lyapunov exponent

Finite Time Lyapunov Exponent (FTLE):

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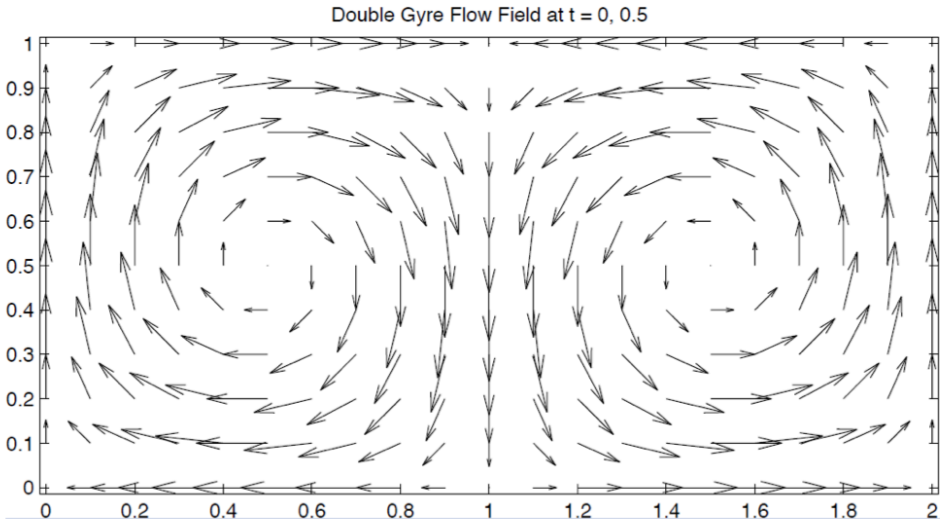
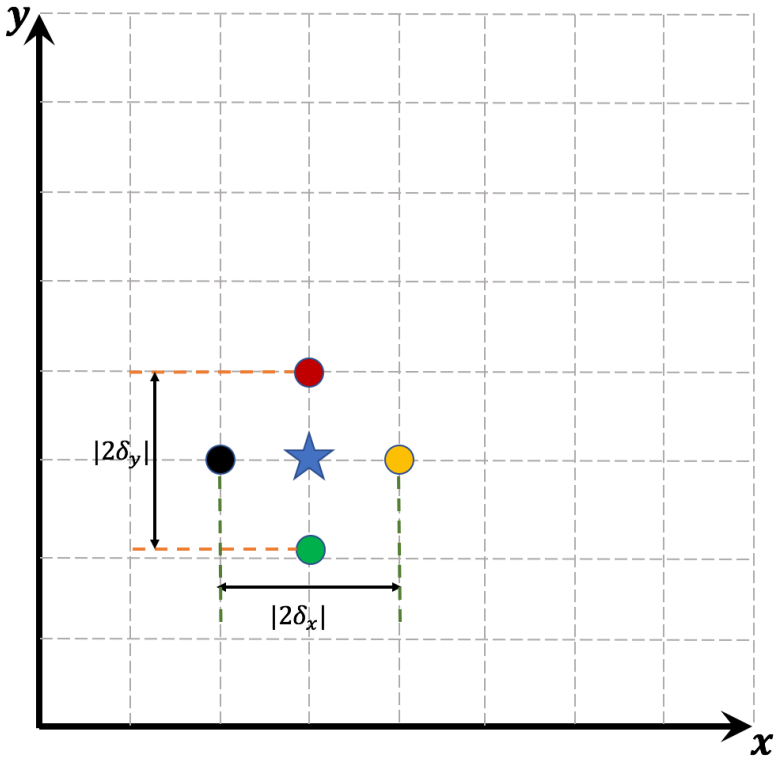
A scalar field measuring the degree of stretching.
Local maximum FTLE surfaces are defined as the LCSs.





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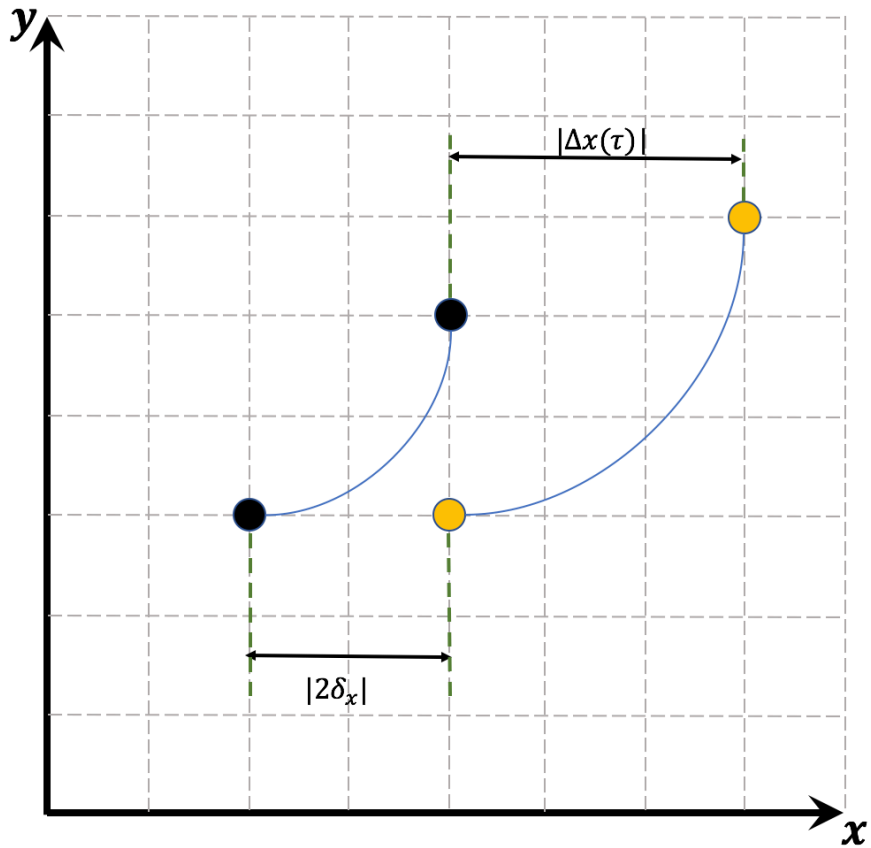
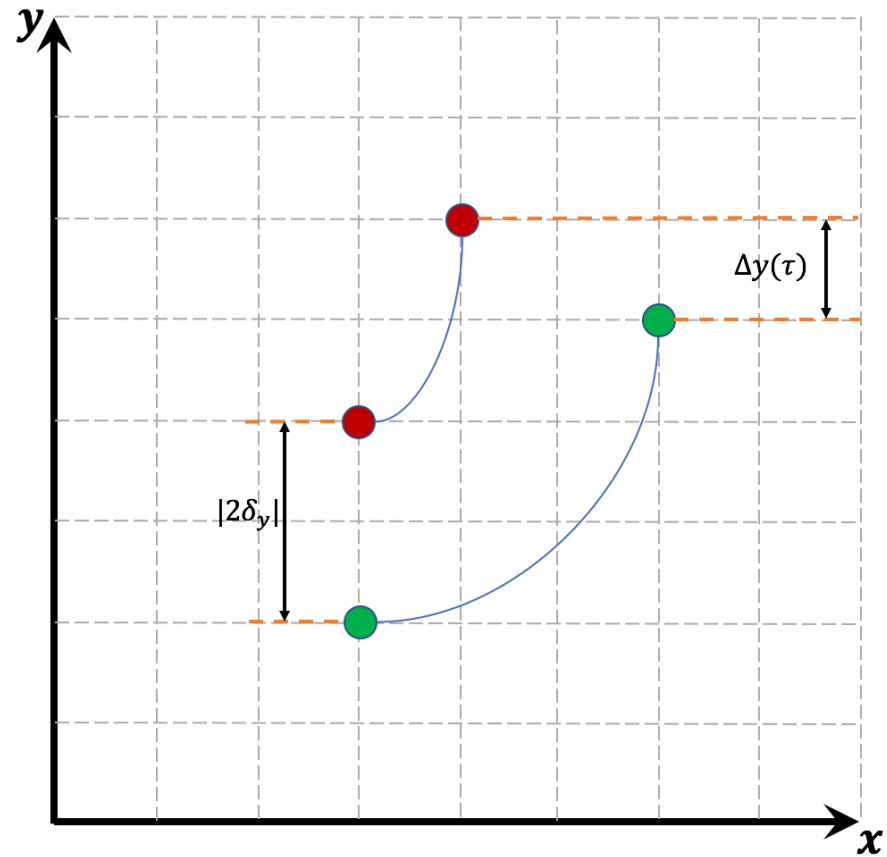
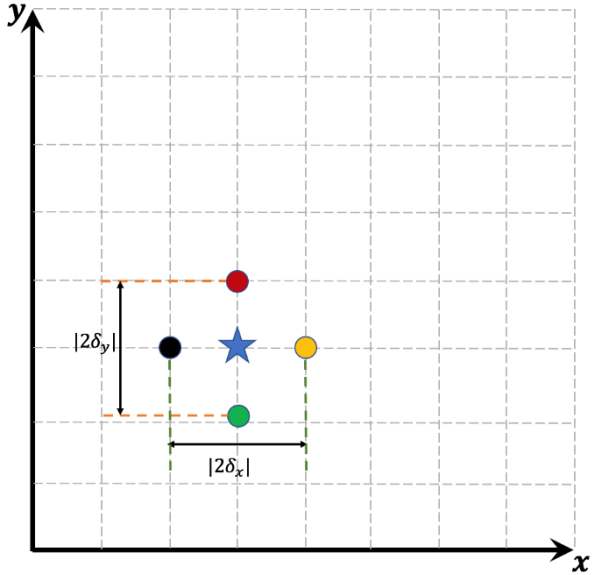


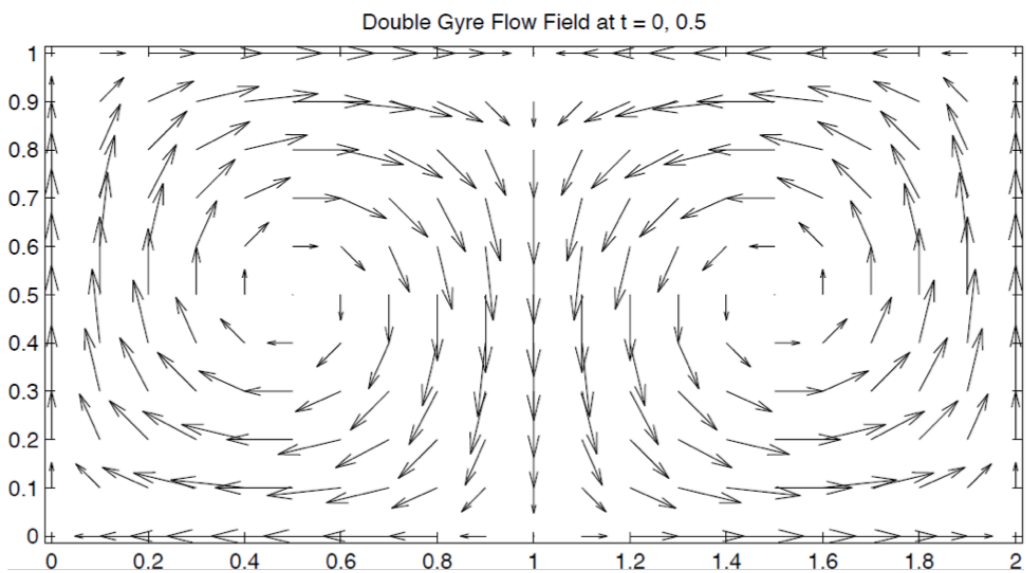


$$\mathbf{J} = \begin{bmatrix} \frac{\Delta x(\tau)}{|2\delta_x|} & \frac{\Delta x(\tau)}{|2\delta_y|} \\ \frac{\Delta y(\tau)}{|2\delta_x|} & \frac{\Delta y(\tau)}{|2\delta_y|} \end{bmatrix} \tag{1}$$

$$\sigma(\mathbf{J}) = \frac{1}{|\tau|} \log\left(\sqrt{\lambda_{max}(\mathbf{J}^T\mathbf{J})}\right) \tag{2}$$

Finite Time Lyapunov Exponent (FTLE):





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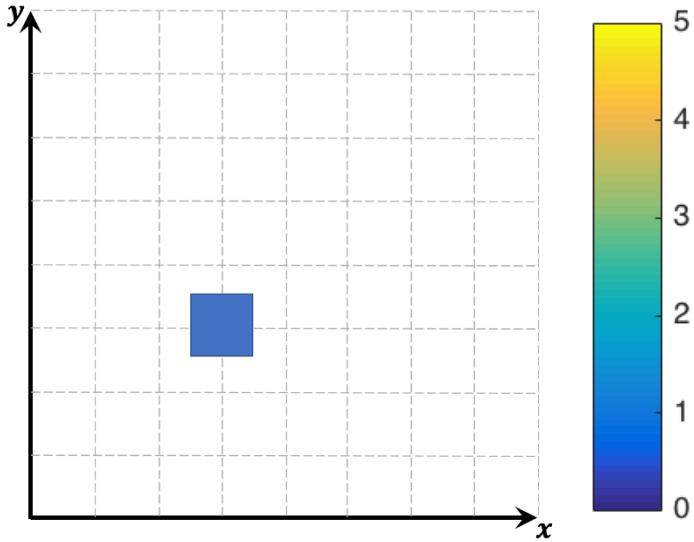

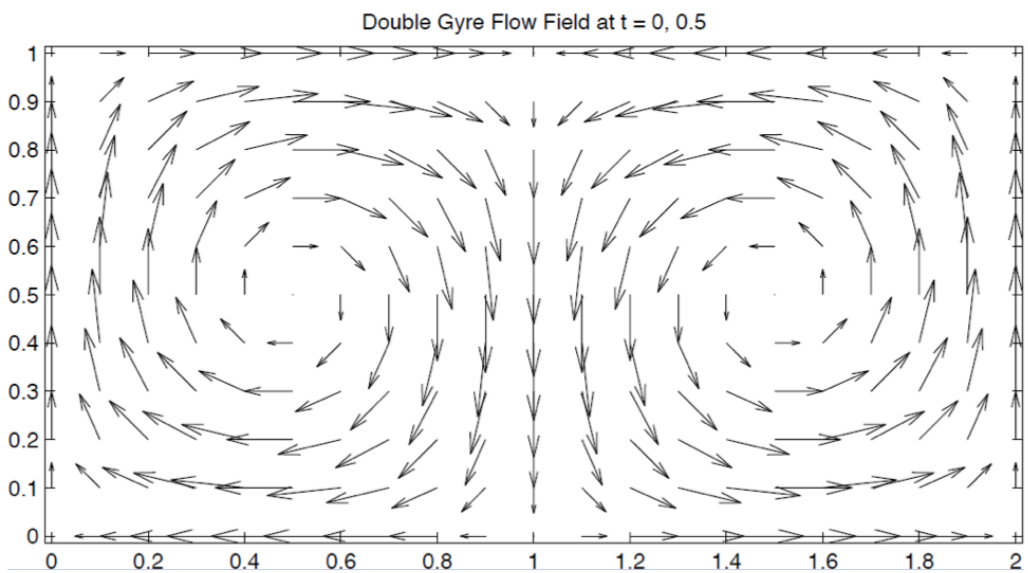

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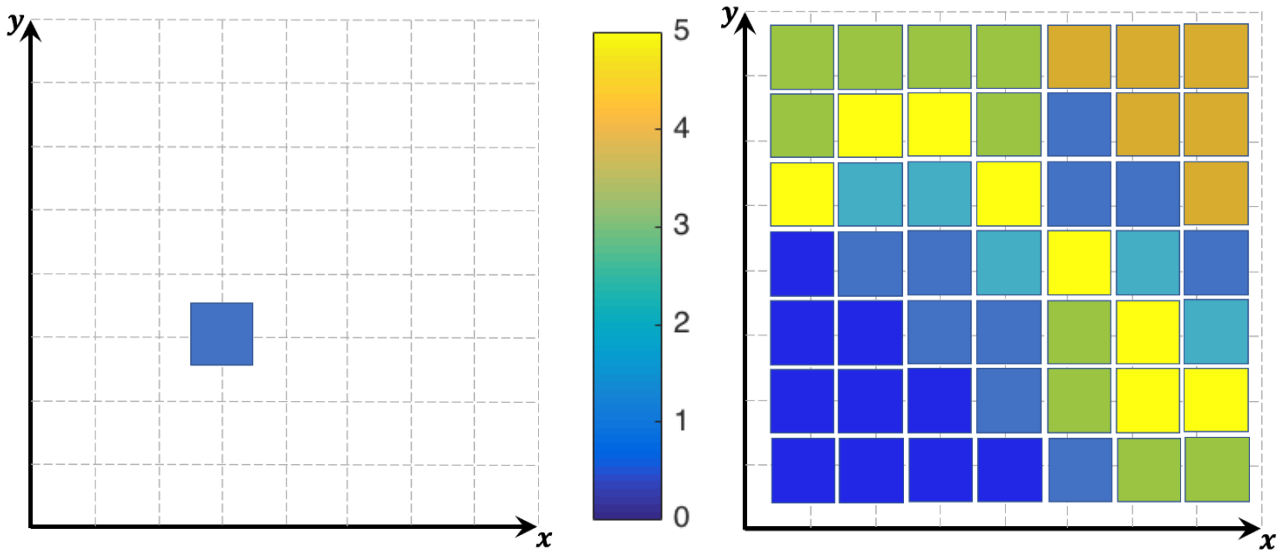

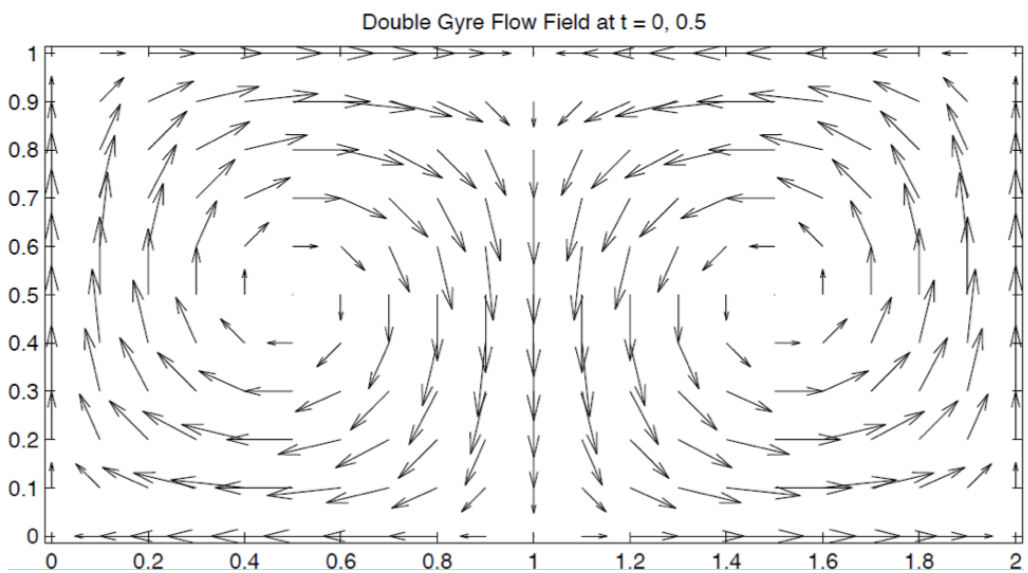

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