The Earth's Magnetospheric Convection in Vlasiator

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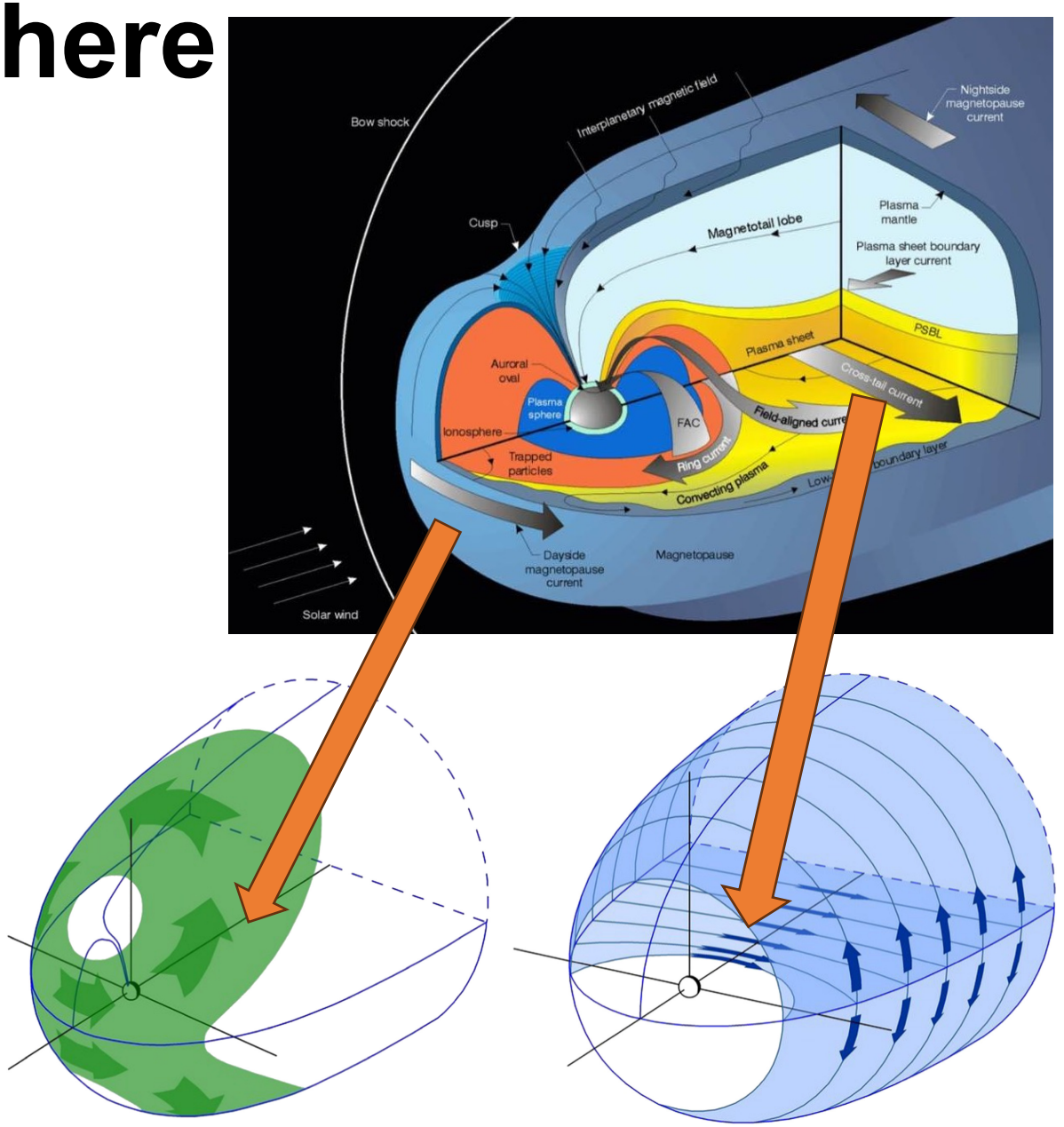
PAP301

Contents

The Earth's Magnetosphere

- The Earth's Magnetosphere is formed by the interaction between
  - The Earth's intrinsic magnetic field
  - The solar wind

- A current system forms due to this interaction
  - Dayside magnetopause current
  - Cross-tail current

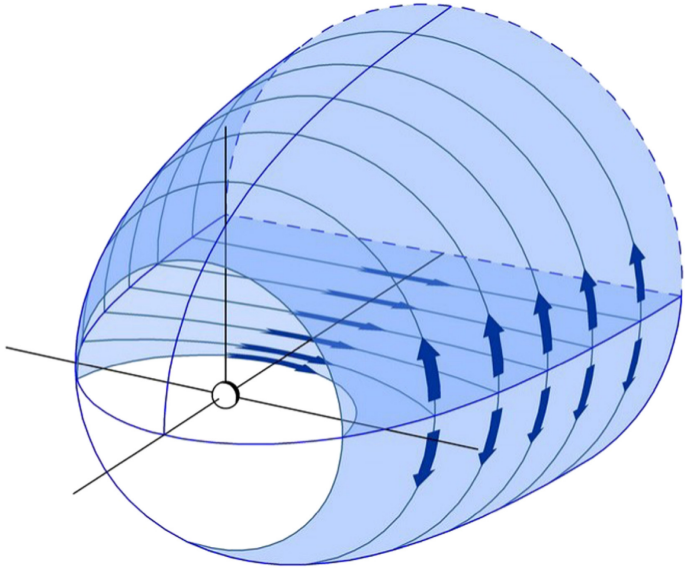


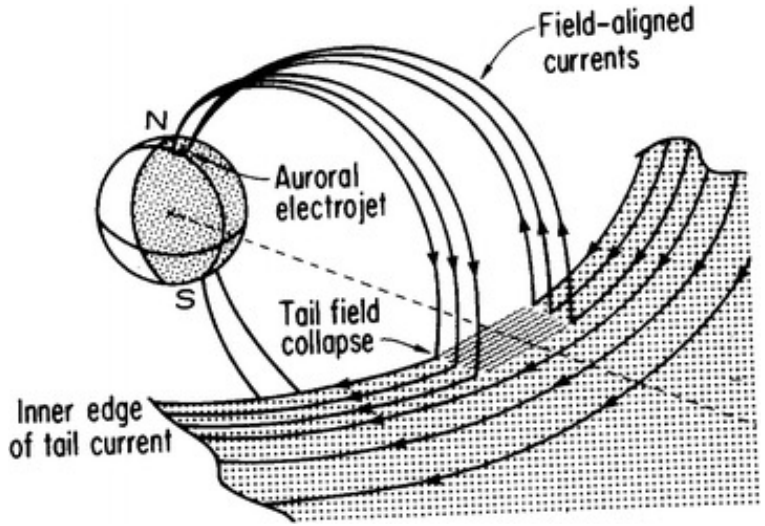
(Ganushkina, N. Y., Liemohn, M. W.,& Dubyagin, S. , 2018)

Magnetosphere-Ionosphere Coupling

- The Earth's magnetosphere and ionosphere are strongly coupled.

- A space weather event known as a substorm that leads to an eruption from the magnetotail can
  - Disrupt the cross-tail current
  - Form a new current system (substorm current wedge) that connects the Earth's magnetotail and ionosphere.

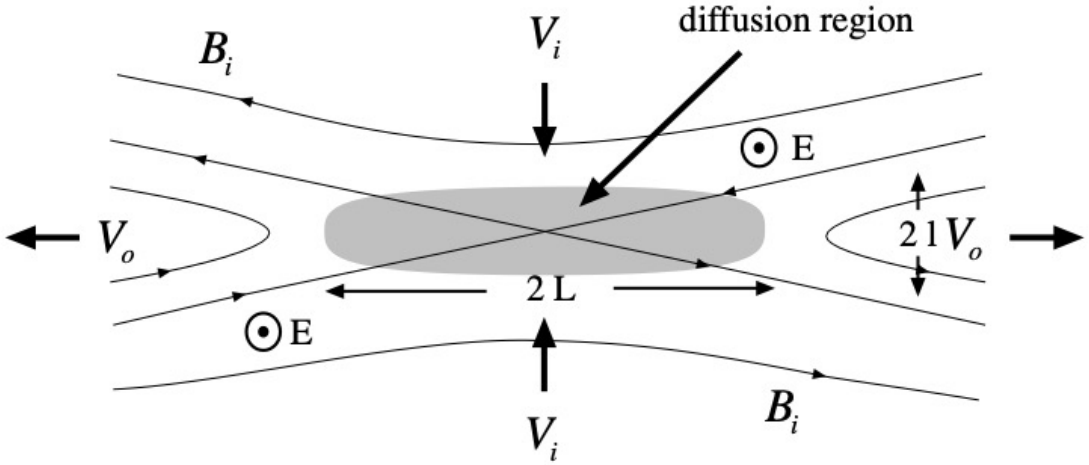




Schematic sketch of substorm current wedge
(McPherron et al., 1973)

Magnetic Reconnection

- The plasma is ‘frozen-in’ in with the magnetic field lines in collisionless space plasmas.
- Magnetic reconnection breaks this condition
  - Change the topology of the magnetic field
  - Convert magnetic energy to kinetic energy
- The mechanism of magnetic reconnection is still a highly-debating topic.



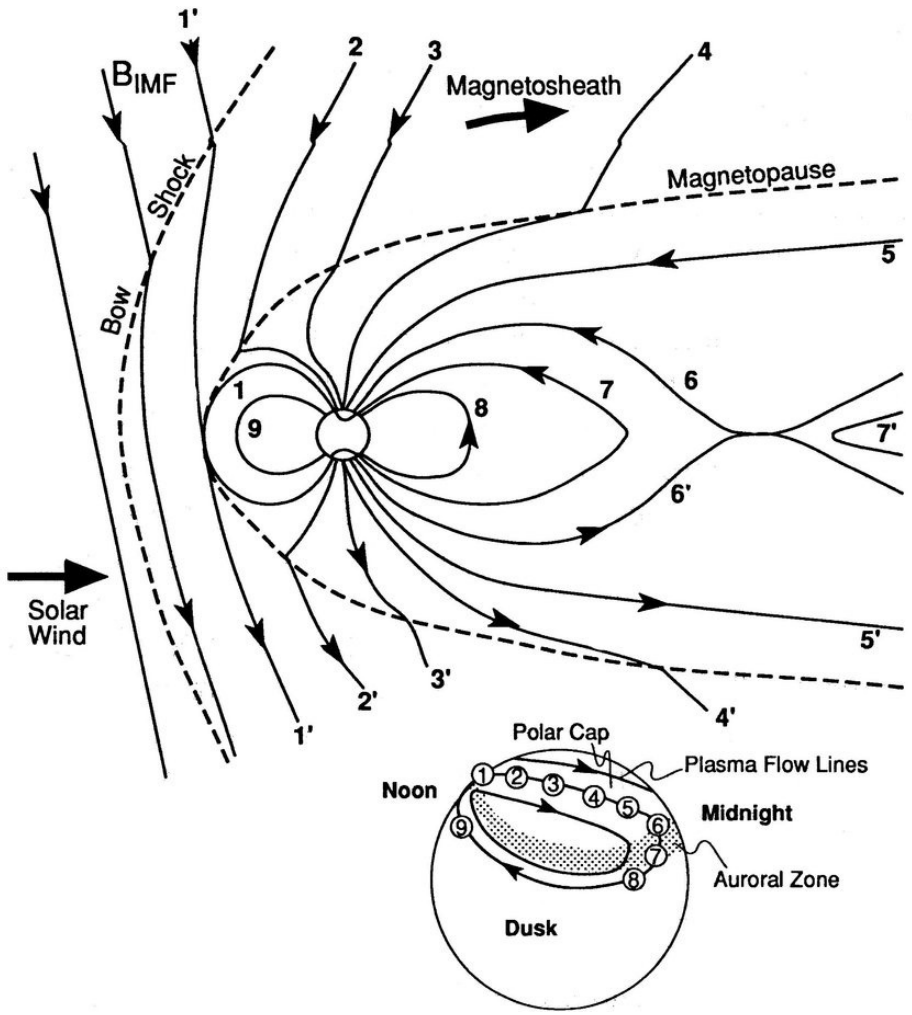
Sweet-Parker Model of reconnection

Smith, D. A., & Sojka, J. J. (2019)

Dungey Cycle

- Dungey cycle is a convection pattern in the Earth's magnetosphere
  - Dayside reconnection
  - Nightside reconnection

- The footprints in the ionosphere cause a twin-cell convection.



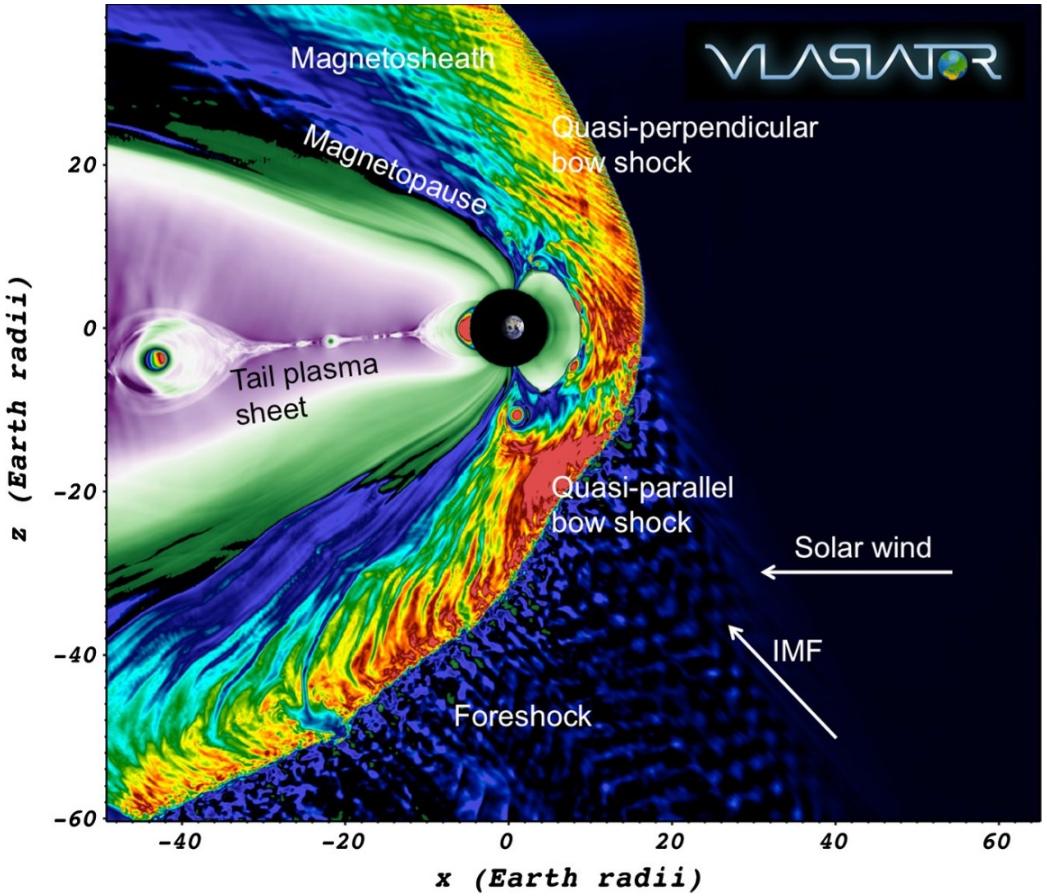
The schematic figure of Dungey cycle and its corresponding configuration in ionosphere.

(Hughes,1995)

Vlasiator

- Vlasiator is a 6D hybrid-Vlasov simulation for the near Earth space.
  - Model ions as a distribution function in six (three spatial and three velocity) dimensions.
  - Model electrons as a charge-neutralizing fluid.
  - Evolve the electromagnetic fields using Maxwell equations

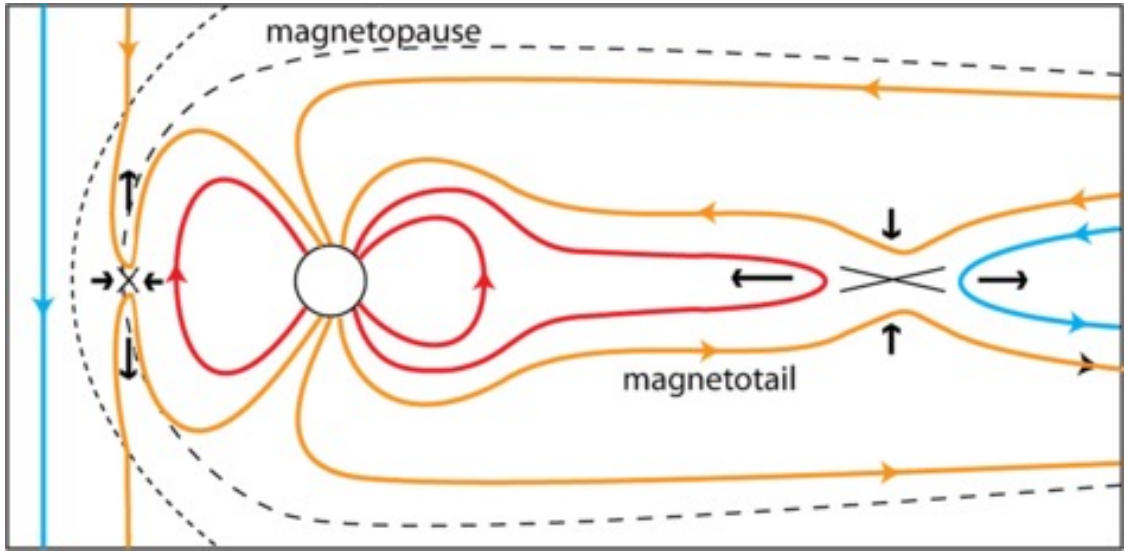
Solar wind conditions (FHA):
Bz = -5nT; Vx = -750 km/s
Bx,By = 0; Vy,Vz = 0



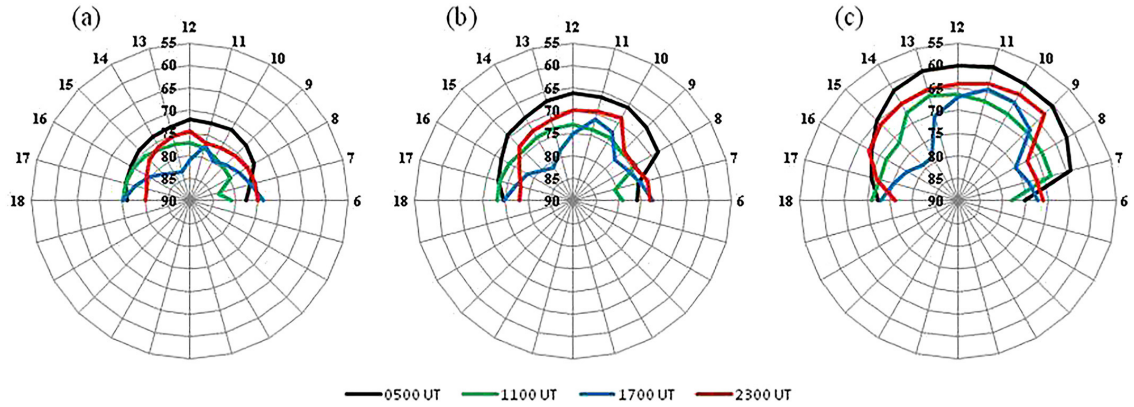
Noon-midnight meridian plane of the magnetosphere modelled by Vlasiator.
(Palmroth et al.,2018)

Convection Quantification Method

- Magnetosphere
  - Subtraction of dayside and nightside reconnection rate $(\Phi_D - \phi_N)$
- Ionosphere
  - The rate of change of open flux $\frac{dF_{pc}}{dt}$



Eastwood, J. P., et al., 2017



Dayside open/closed field line boundary

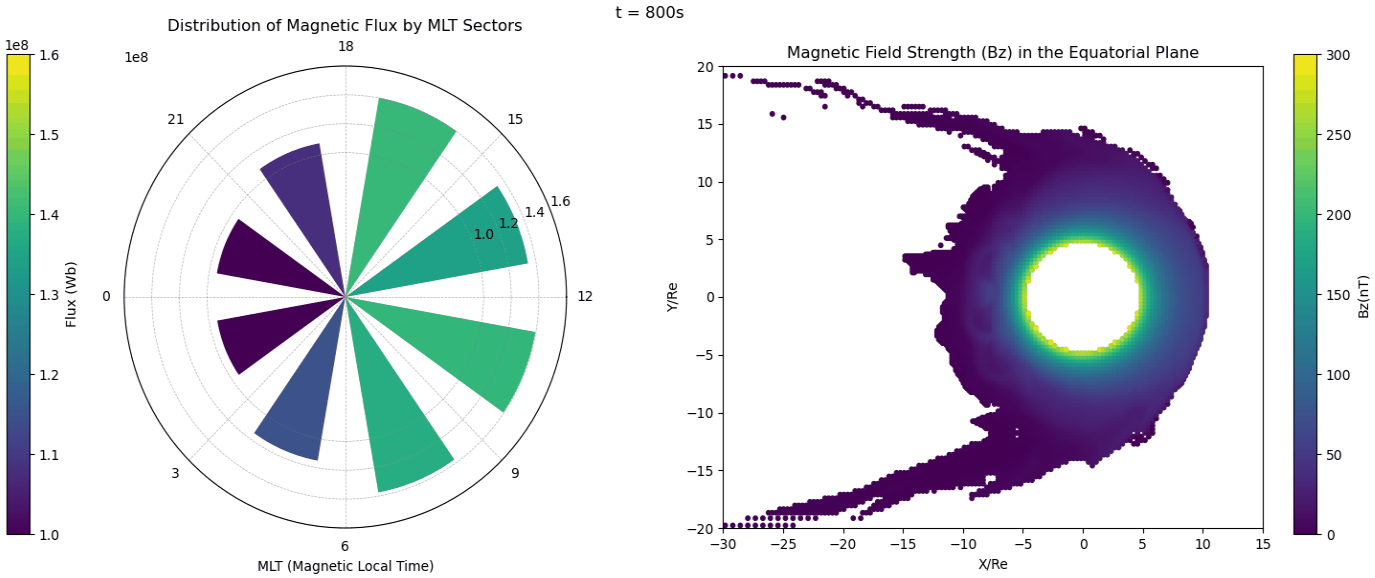
Smith, D. A., & Sojka, J. J. (2019)

Results: Closed Magnetic flux

Direct measurement of reconnection rate by empirical equations is difficult.

Instead, we use an indirect method to calculate the change rate of magnetic fluxes that are opened/closed.

Time step after 800s, make sure that the nightside reconnection has happened.

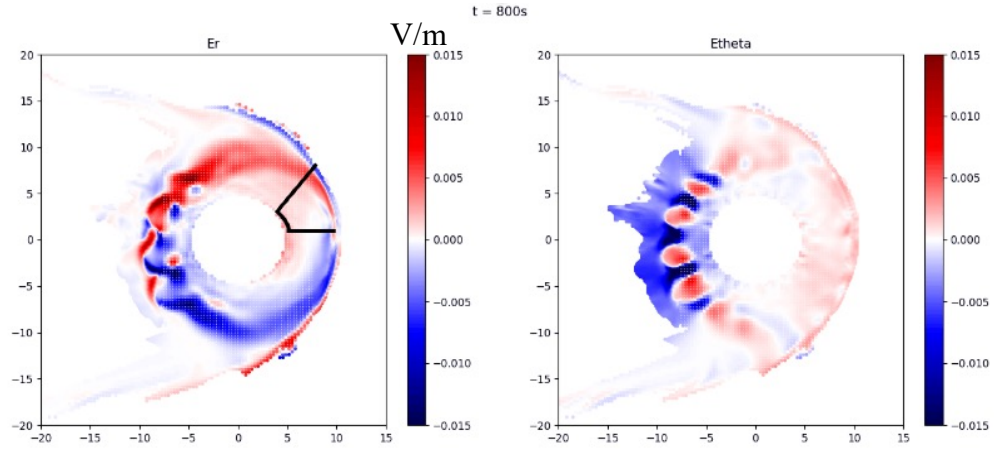


Left panel: Magnetic closed flux in different MLT (Magnetic Local Time) sectors
Righ panel: (Closed field line region)Bz in the equatorial plane.

Results: Convection Rate

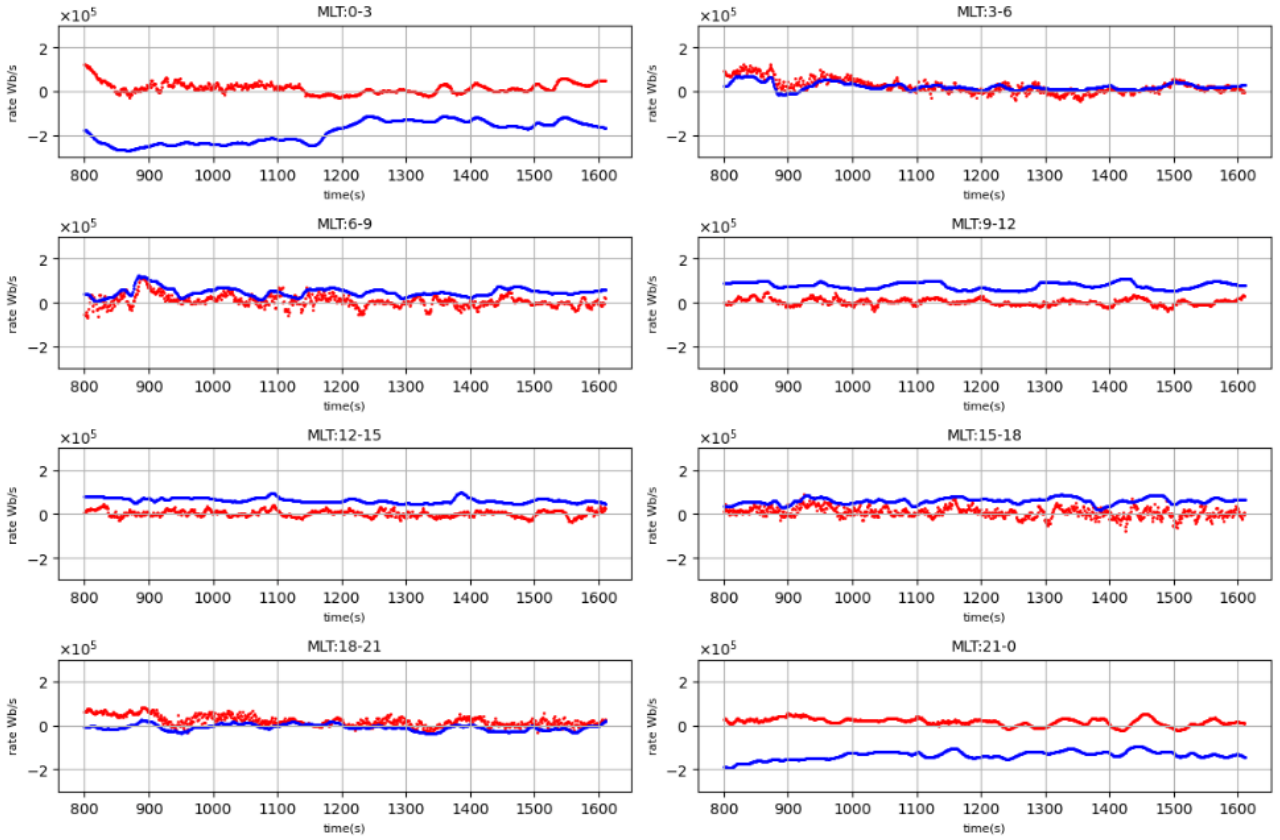
The Convection inside the closed field line region includes the azimuthal and radial direction.

The electric potential accounts for the magnetic flux change rate.



Electric field Er and Etheta

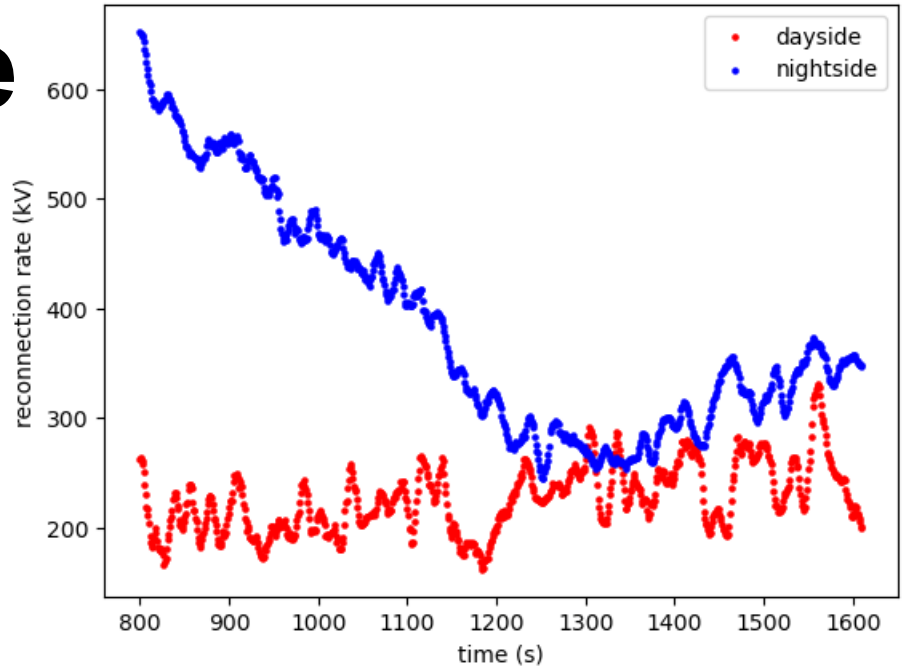
Closed Flux change rate vs Convection rate in different MLT sectors

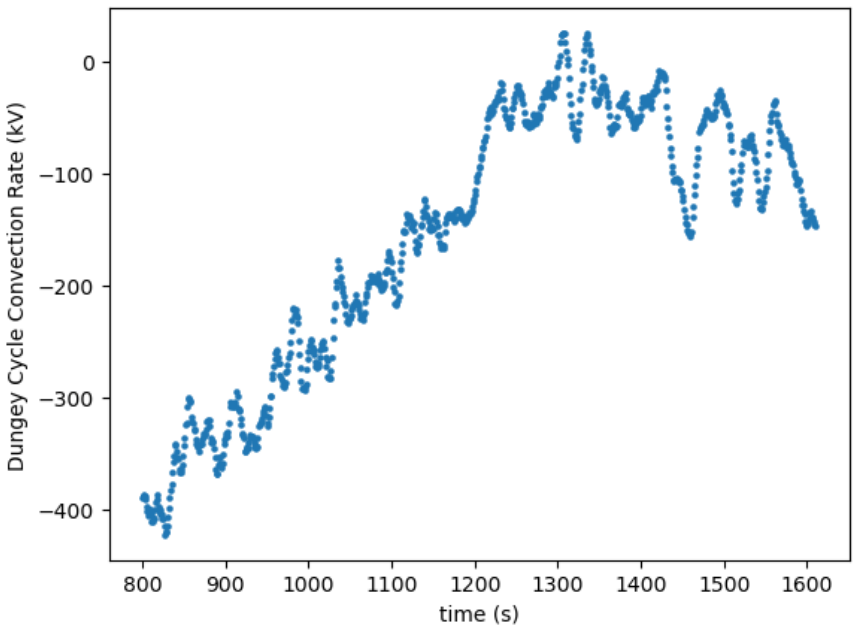


Results: Reconnection Rate

Dayside and nightside reconnection rate can be calculated by the subtraction of the total closed flux change rate and convection rate.

The Dungey cycle convection rate shows most negative values after 800 seconds, which indicates a constantly contracting polar cap OCB(open-closed field line boundary).

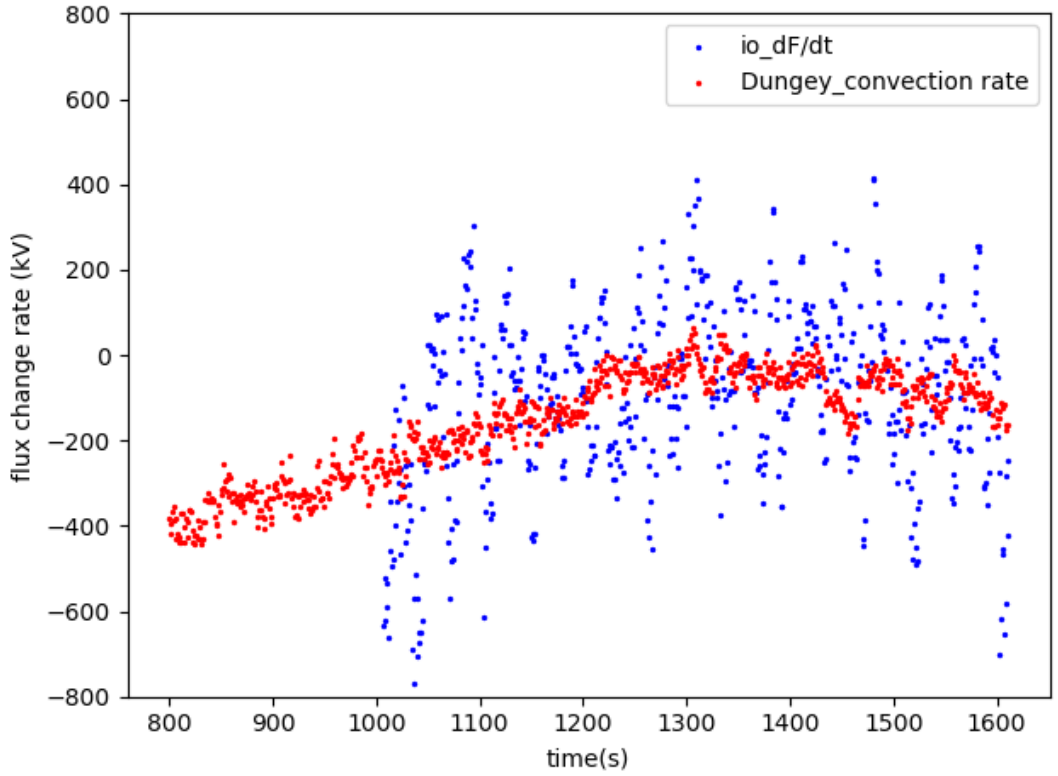




Discussion: ionospheric point of view

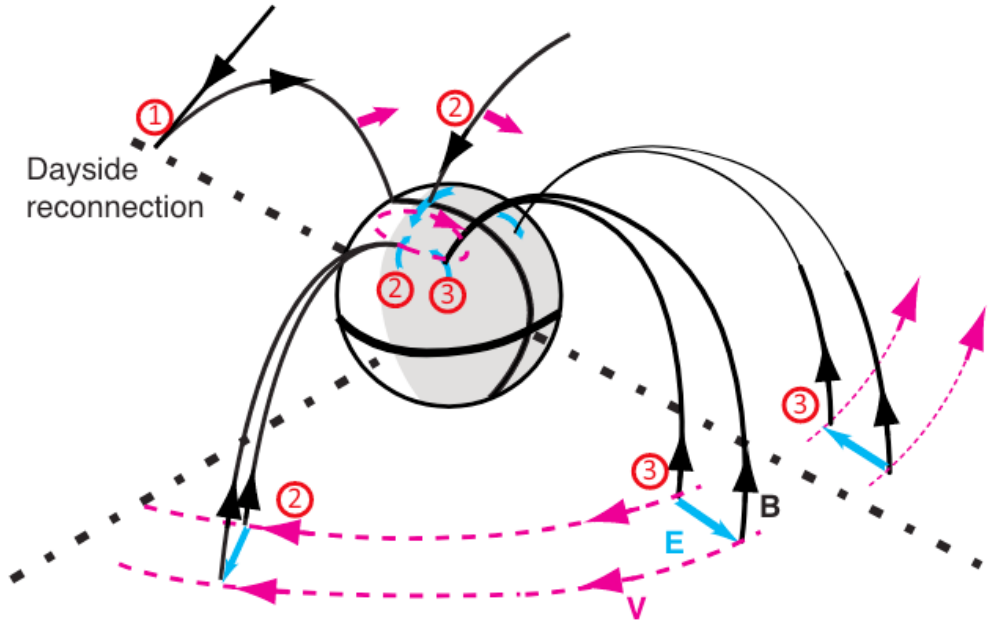
Recall that the Magnetosphere and ionosphere coupling, the flux change rate should be consistent.

Calculate the open flux change rate in the ionosphere, but they are noisy.



Discussion: a new convection pattern

Dayside-driven convection is a newly(relatively) discovered convection mechanism that can also cause the convection in the magnetosphere.



Schematic of dayside-driven convection

black arrows: magnetic field lines;
pink arrows: convective flow;
blue arrows: convection electric fields.
(Dai. et al., 2024)

Summary

- Dungey Cycle is a crucial convection pattern in the Earth's magnetosphere
- Two ways to quantify the intensity of the convection
  - Dayside and nightside reconnection rate
  - Ionospheric open flux change rate
- In practice, the dayside and nightside reconnection rate should be calculated by using an indirect method.
- Future work includes
  - Calibrating the ionospheric open flux
  - Compare the results with other simulations/ observations
  - Extend the convection study to earlier time steps (study dayside-driven convection)

Thank you!