Inner Magnetosphere Effects

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Inner Magnetospheric Effects:
Inner Magnetosphere Effects

• Historical Background
• Main regions and transport processes
  – Ionosphere
  – Plasmasphere
  – Plasma sheet
  – Ring current
  – Radiation belt
• Geomagnetic Activity
  – Storms
  – Substorm
• Models
Inner Magnetospheric Effects:  

Historical Background: Space in 1950
Historical Background

Whistlers revealed unexpected plasma

1952
L. R. Owen Storey
Cavendish Laboratory
University of Cambridge

Inner Magnetospheric Effects:

Historical Background
Historical Background

Explorer 1
January 31, 1958

Radiation Belts Discovered
Pickering Van Allen von Braun

Counting Rate (c.p.s.)
Time from Previous Interrogation (mins)

Radiation Belts Discovered
Ionosphere

**Photoionization**
\[ \text{O} + \text{hv} = \text{O}^+ + \text{e}^- \]

- Ionosphere: ionized portion of upper atmosphere
  - Extends from around 60 to beyond 1000 km
  - Completely encircles the Earth
  - Main Source: photoionization of neutrals
    - Other production processes may dominate in certain ionospheric regions
- Loss Mechanism: ionospheric outflow
Ionosphere outflow

• Main cause
  – Ambipolar electric field
  – pressure gradients
  – Mirror force due to gyration of charged particles
• Polar wind: Ionospheric loss at polar latitude
  – Along essentially open geomagnetic field lines
• At mid-latitudes the plasma may bounce to the conjugate ionosphere or become the plasmasphere
Plasmasphere Formation: Diffusive Equilibrium

\[ H_j = \left( \frac{kT_i}{m_j g} \right) \left( 1 - \frac{m_a T_e}{m_j T_t} \right)^{-1} \]

Titheridge (1972)

- \( H_j \) = scale height
- \( k \) = Boltzmann constant
- \( m_j \) = \( j \)'th ion mass
- \( g \) = gravitational constant
- \( m_a \) = mean ion mass
- \( T_e \) = electron temperature
- \( T_t = T_i + T_e \) = total temperature

Inner Magnetospheric Effects:
Inner Magnetospheric Effects:

Global convection

- In the Late 50s, ground-based measurements revealed the plasma flow pattern in the polar and auroral ionosphere
  - Anti-sunward flow over the polar cap and
  - Return flow equatorward of the auroral oval
- In 1959 Gold introduced the term convection
  - Resemblance to thermally driven flow cells

Main regions and transport processes
Inner Magnetospheric Effects:

- Highly conducting plasma in the solar wind flows across polar geomagnetic field lines
  - Induces an electric dynamo field
  - Frozen-in flux concept

Main regions and transport processes
Reconnection

- If the polar geomagnetic field lines are open
  - The electric field produces an anti-sunward $E \times B$ drift of solar wind and magnetospheric plasma across the polar cap
  - Reconnection occurs down tail
  - Closed geomagnetic field lines flow back towards Earth at lower latitudes
Plasma sheet

- Plasma sheet: population of ionospheric and solar wind particles being accelerated Earthward
- Neutral current sheet: large-scale current flow from dawn to dusk across the plasma sheet
  - Separates the two regions of oppositely directed magnetic field in the magnetotail
  - Accelerates particles towards Earth
- Direct access to night side auroral oval
  - Can collide with ionosphere producing aurora

Inner Magnetospheric Effects: Main regions and transport processes
Adiabatic Invariants

• Energetic plasma near the center of the plasma sheet gyrates closer to the Earth
  – Become trapped on closed dipole-like field lines
  – Encounter increasing magnetic field strength
  – Bounce between hemispheres

  \[ \mu = \frac{W_i}{B} = \frac{mv_i^2}{2B} \]

  \[ \int_{\text{bounce}} \mathbf{v} \cdot d\mathbf{l} = \int_{\text{bounce}} v_\parallel d\mathbf{l} \]

  \[ \Phi = \int_{\text{drift}} \mathbf{B} \cdot d\mathbf{A} \]

  – Gradient and curvature drift
    • Divert ions and electrons in opposite directions
    • Form the ring current and radiation belts

Inner Magnetospheric Effects: Main regions and transport processes
Ring Current

- Hot (1-400 keV)
  - tenuous (1-10s cm⁻³)
- Diamagnetic current produced by motion of plasma trapped in the inhomogeneous geomagnetic field
  - Torus-shaped volume extending from ~3 to 8 RE
  - Main Source: plasma sheet particles
  - Loss Mechanisms: charge exchange, coulomb collisions, atmospheric loss, pitch angle (PA) diffusion, and escape from magnetopause

\[
\Delta B(r) = \frac{\mu_0}{4\pi} \int J(r') \times (r-r') \frac{dr'}{|r-r'|^3}
\]
Radiation Belt

• Very Hot (100s keV - MeV)
• Extremely tenuous: <<1 cm⁻³
  – Outer belt: very dynamic region
    ♦ Mostly elections located at 3-6 Rₑ
  – Inner belt: fairly stable population
    ♦ Protons, electrons and ions at 1.5-2 Rₑ
• Source: injection and energization events following geomagnetic storms
• Loss Mechanisms: Coulomb collisions, magnetopause shadowing, and PA diffusion
Plasmasphere

- Cool (<10 eV)
- High density (100s-1000s cm\(^{-3}\))
- Co-rotating plasma
  - Torus-shaped, extends to 4-8 \(R_E\)
  - Plasmapause: essentially the boundary between co-rotating and convecting plasma
- Main Source: the ionosphere
- Loss Mechanism: plasmaspheric erosion and drainage plume

Inner Magnetospheric Effects:

Main regions and transport processes
Geomagnetic storms

• Large (100s nT)
• Prolonged (days)
• Magnetospheric disturbances
  – Caused by variations in the solar wind
  – Related to extended periods of large southward interplanetary magnetic field (-IMF Bz)
    ✋ Increasing the rate of magnetic reconnection
    ✋ Enhancing global convection
Geomagnetic storms

- Enhanced convection
  - Increased rate of injection into the ring current
    - The ring current then expands earthward
    - Induced current can reduce the horizontal component of the geomagnetic field (100s nT)
  ✶ Used to calculate Dst

Inner Magnetospheric Effects: Geomagnetic Activity
Plasmaspheric Plumes

• Enhanced convection also causes the co-rotating plasmaspheric material to surge sunward
  – Decreasing the night-side plasmapause radius
  – Extending the dayside plasmapause radius

• Creates a plume extending from 12 to 18 MLT

• For continued enhanced convection less material remains to feed the plume and it narrows in MLT
  – Dusk edge remains almost stationary
  – Western edge moves eastward
Substorms

• A relatively short (hours) period of increased energy input and dissipation into the inner magnetosphere
  – Events may be isolated or occur during a storm
  – Associated with a flip from northward to southward IMF Bz

• Increased rate of reconnection

• Increased flow in magnetospheric boundary layer

• Energy accumulates in the near-Earth tail
Substorms

- Additional magnetic flux in the tail lobes causes the cross-tail current sheet thickness to decrease
  - When the current sheet thickness reaches its threshold reconnection occurs
  - The cross-tail current is disrupted
- The substorm current wedge closes the cross-tail current through the ionosphere
- Particle precipitation increases Auroral activity
Models – Empirical: IRI

Inner Magnetospheric Effects:

![Graphs depicting Inner Magnetospheric Effects](Image)
Models – Empirical: GCPM

Inner Magnetospheric Effects:
Models – Physics Based: BATS-R-US

Inner Magnetospheric Effects:
Coupling Models

Inner Magnetospheric Effects: