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
Historical Background: Space in 1950

Inner Magnetospheric Effects:

- Heavyside layer
- Shell of Solar Electrons

Historical Background
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

Radiation Belts Discovered
Ionosphere

Photoionization
\[ O + h\nu = O^+ + e^- \]

- 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

Inner Magnetospheric Effects:
Main regions and transport processes
**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:
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
Solar wind dynamo

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

• If the polar geomagnetic field lines are open
  – The electric field produces an anti-sunward ExB 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
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

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

\[ \mu = \frac{\frac{W}{B}}{2B} = \frac{mv^2}{2B} \]

\[ J = \oint v \cdot dl = \oint v || dl \quad \text{bounce} \]

\[ \Phi = \int B \cdot dA \quad \text{drift} \]

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 \(\sim 3\) to \(8\ R_E\)
  - Main Source: plasma sheet particles
  - Loss Mechanisms: charge exchange, coulomb collisions, atmospheric loss, pitch angle (PA) diffusion, and escape from magnetopause

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

• Very Hot (100s keV - MeV)

• Extremely tenuous: <<1 cm^{-3}
  – Outer belt: very dynamic region
    ‣ Mostly elections located at 3-6 R_E
  – Inner belt: fairly stable population
    ‣ Protons, electrons and ions at 1.5-2 R_E

• Source: injection and energization events following geomagnetic storms

• Loss Mechanisms: Coulomb collisions, magnetopause shadowing, and PA diffusion

Inner Magnetospheric Effects:

Main regions and transport processes
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
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
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:
Models – Empirical: GCPM

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

Inner Magnetospheric Effects:
Coupling Models

Inner Magnetospheric Effects: