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

- Heavyside layer
- Shell of Solar Electrons
- Exosphere
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

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
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'\text{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

Inner Magnetospheric Effects:
Main regions and transport processes
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

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

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

\[ J = \oint v \cdot d\vec{l} = \oint v_{\parallel} d\vec{l} \]

\[ \Phi = \int B \cdot d\vec{A} \]
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: \(<\!\!<\!\!\!<\!\!\!1\text{ cm}^{-3}\)
  - 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
Plasmasphere

• Cool (<10 eV)
• High density (100s-1000s cm⁻³)
• Co-rotating plasma
  – Torus-shaped, extends to 4-8 Rₑ
  – 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

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:
Models – Empirical: GCPM

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Coupling Models

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