STORM TIME EFFECTS ON THE LOW- TO MID-LATITUDE IONOSPHERE: PENETRATION ELECTRIC FIELDS

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How do penetration electric fields evolve in the low- to mid-latitude ionosphere as a function of longitude and latitude during geomagnetic storms?

What is the response of the ionosphere to penetrating electric fields as a function geophysical parameters (e.g., geomagnetic conditions, solar EUV, longitude, latitude, etc.)?

The first self-consistent study of the impact of storm-time penetration electric fields on the low- to mid-latitude ionosphere

Based on an electrodynamically coupled inner magnetosphere model (RCM) and an ionosphere model (SAMI3)
OVERVIEW OF SAMI3

- Magnetic field: Offset, tilted dipole model / IGRF-like
- Interhemispheric / Global
- Nonorthogonal, nonuniform fixed grid
- Seven (7) ion species (all ions are equal): $\text{H}^+, \text{He}^+, \text{N}^+, \text{O}^+, \text{N}_2^+, \text{NO}^+$, and $\text{O}_2^+$
  - Solve continuity and momentum for all 7 species
  - Solve temperature for $\text{H}^+$, $\text{He}^+$, $\text{O}^+$, and e⁻
- Plasma motion
  - $\mathbf{E} \times \mathbf{B}$ drift perpendicular to $\mathbf{B}$
    (both vertical and longitudinal in SAMI3)
  - Ion inertia included parallel to $\mathbf{B}$
- Neutral species: NRLMSISE00 and HWM93
- Chemistry: 21 reactions + recombination
- Photoionization: Daytime and nighttime
The fundamental coupling of RCM and SAMI3 is through the solution of the potential equation

$$\nabla \cdot \sum_{\text{SAMI3}} \cdot \nabla \Phi = J ||$$

→ SAMI3 provides the ionospheric conductance to RCM
→ RCM solves the potential equation to determine $\Phi$
→ RCM provides the $\Phi$ to SAMI3
→ SAMI3 and RCM use $\Phi$ to calculate the electric field
→ Transport the plasma

The coupled model provides a self-consistent electrodynamical description of the ionosphere/inner magnetosphere system
Codes cover different spatial regions
  - RCM covers $-72^\circ < \theta < -10^\circ$ and $72^\circ > \theta > 10^\circ$ (green and blue regions)
  - SAMI3 covers $\pm 60^\circ$ (green and yellow regions)
- RCM uses IRI for latitudes above $60^\circ$ and a fitting algorithm to match to SAMI3 (blue)
- SAMI3 assumes the potential is latitudinally independent below $10^\circ$ (yellow)
Codes use different grids and we must interpolate data (Φ and Σ) from one grid to the other
→ We set up a uniform, intermediate grid that we interpolate data to in order to pass data between RCM and SAMI3

RCM uses a fixed time step while SAMI3 uses a variable time step (in general) – fortunately, both codes use similar time steps
→ We run both codes on the same time step (\(dt = 2\) sec)

An MPI version of SAMI3 has been developed to run on a Linux cluster (e.g., 16 node dual processor Opteron and Xeon systems) but RCM is not parallelized
→ Coupled code runs \(\sim 1.5\) real time
STORM TIME MODEL

Time dependent polar cap potential used in RCM

[Graph showing polar cap potential over time with cases labeled Case 0, Case 1, and Case 2.]
RESULTS

TEC and TEC differential
RESULTS

$E \times B$ drift velocity

**Graphs:**
- **Longitude: 0°**
  - Altitude: 598 km
- **Longitude: 180°**
  - Altitude: 598 km

Case 0: solid
Case 1: ◆
Case 2: □

100 UT
Altitude: 598 km

230 UT
Altitude: 598 km

**Axes:**
- Vertical $E \times B$ velocity (m/s)
- Time (UT)
- Time (MLT)
Coupled RCM/SAMI3 model developed: idealize storm-model study

Penetration field modifies low- to mid-latitude ionosphere

Upward drift enhanced daytime
  Downward drift enhanced nighttime
  - TEC changes by ±35%
  - NmF2 changes by ±20%
  - HmF2 changes by 15% (raised by ~ 100 km)
  - $E \times B$ drift velocity can increase by a factor of 2

Enhanced 'fountain effect' and increased TEC in afternoon, mid-latitude ionosphere: qualitatively consistent with observations

Time dependence of polar cap potential important

SAMI3 has been upgraded: single global ionosphere model