Ionospheric/Thermospheric Space Weather Issues

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CEDAR Tutorial
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Outline

- Applications
- Weather Features
- Causes of Weather
- Status of Weather Modeling
- Requirements for Forecasting
Applications

Weather disturbances in the ionosphere-thermosphere system affect the following:

- Over-The-Horizon (OTH) Radars
- Communications
- GPS Surveying
- Navigation Systems (GPS and VLF)
- Satellite Drag
- Spacecraft Charging (in Trough)
- Surveillance
  - Optical Emissions
  - Radar Altimetry
- Induced EMF at Ground
  - Pipelines
  - Power Grids
  - Long Telecommunications Cables
Weather Features

- Sun-Aligned Arcs
- Auroral Arks
- Plasma Patches
- Boundary Blobs
- Flux Transfer Events
- Traveling Convection Vortices
- SAID Events
- SAR-arcs
- Anomalous $T_e$ in E-region
- Sporadic E
- Spread F
- Equatorial Bubbles
- Descending Layers
- Magnetic Storms
- Substorms
- Gravity and Tidal Waves
- Scintillations
11 NOVEMBER 1981

0442:33 TO 0457:16 UT

0529:36 TO 0544:19 UT

0553:08 TO 0607:51 UT

0616:40 TO 0631:23 UT

GEOMAGNETIC NORTH DISTANCE FROM CHATANIKA — x 10^2 km

Rino et al (1983)
Tsunoda (1988)

- Chatanika radar scan
- On-going precipitation
- Evidence for rapid ionization in F-region
DE-2 Satellite
Northern Hemisphere
Winter

Northward IMF
Multicell Pattern
Killeen et al (1985)
Sporadic - E

Stuszczywicz
Causes of Weather

- Structured Precipitation
- Structured Electric Fields
- Structured Downward Heat Fluxes
- Time Varying Electric Fields
- Time Varying Precipitation
- Plasma Instabilities
- Upward Propagating Gravity and Tidal Waves
Figure 18. An implied convection pattern consistent with observed optical emissions and plasma convection velocities measured by DE 2. The flow lines describing cells III, IV, and V are at the same potential and may be connected 'fingers' or separate convection cells. From Carlson et al. [1988].
Electric Field Structure

ION DRIFT METER, DE-2
UNIVERSITY OF TEXAS AT DALLAS
OCTOBER 17, 1981
1634-1646 UT

Frank et al (1986)
Magnetospheric Parameters

Parameters

- Convection
- Precipitation
- Birkeland Currents
- Heat Flows

Dependence

- IMF \((B_x, B_y, B_z)\)
- Kp

Issues

- Statistical Patterns
- Instantaneous Patterns
- Spatial Structure
- Temporal Variations
- Transition Time-Scales
Statistical Patterns

Southward IMF

- 2-Cell Convection
- Precipitation

Northward IMF

- 4 2-Cell Convection
- 3-Cell Convection
- Distorted 2-Cell Convection
- Turbulent
- Sun-Aligned Arcs
- θ-Aurora
- Uniform Precipitation (in polar cap)
- Precipitation in Classical Oval
Heppner-Maynard Convection

DE

$B_y < 0$
Northern Hemisphere

BC

$B_y > 0$
Northern Hemisphere
Northward IMF

By > 0

B_y > 0

North

B_y < 0

South

B_y = 0

Potemra et al. (1984)

Dusk-to-dawn

Toward sun

ΔB

Dusk

Dawn

FIGURE 5
Figure 10. Distorted two-cell convection patterns for a strongly northward IMF and for $B_y > 0$ (left dial) and $B_y < 0$ (right dial) in the northern hemisphere. From Heppner and Maynard [1987].
Figure 11. Schematic illustration of sun-aligned arcs in the polar cap for a northward IMF. From Buchau et al. [1983].
Status of Northward IMF Convection

Rich and Hairston (1994)

- Comprehensive Study Using DMSP F8 and F9 Satellites

- The development of more than 2 convection cells for northward IMF is either uncommon or nonexistent. A distorted 2-cell pattern occurs, not a 4-cell pattern.

Weimer (1995)

- Comprehensive Study Using DE 2 Satellite Data

- For northward IMF, evidently there are 4 convection cells, rather than a distortion of the 2-cell pattern.
Figure 21. Variation of the interplanetary magnetic field \( B_x, B_y, B_z, B_T \) versus universal time for a representative 14-hour period. From Roble et al. [1987].
Status of Weather Modeling

- Climatology
- Sun-Aligned Polar Cap Arcs
- Traveling Convection Vortices
- Plasma Patches
- Tides and Gravity Waves
- SAID Events
- Storms and Substorms
GLOBAL IONOSPHERE MODEL

• 3-dimensional, time-dependent

• 100-1000 km altitude range

• Densities & velocities for electrons and
  NO+, O2+, N2+, O+, N+, He+

• Ion and electron temperatures

Inputs Needed

• Magnetospheric electric field

• Auroral oval

• Neutral atmosphere

• Neutral wind

• Magnetospheric Heat Flow
108 RUNS OF USU IONOSPHERIC MODEL

• Season - Equinox
  - June Solstice
  - December Solstice

• Solar Activity - High  $F_{10.7} = 210$
  - Mid  $F_{10.7} = 130$
  - Low  $F_{10.7} = 70$

• Geomagnetic Activity
  - High  $Kp = 6.0$
  - Mid  $Kp = 3.5$
  - Low  $Kp = 1.0$

• Heppner-Maynard Convection ($Bz < 0$)
  - $By > 0$
  - $By < 0$

• Northern and Southern Hemispheres

Sojka and Schunk (1994)
Model Inputs

- Heppner-Maynard Convection
- Hardy Auroral Oval
- MSIS Atmosphere
- Hedin Winds
- Displaced Poles

Diurnally Reproducible Results
"Climatology"
O+ 300 km

NPDE04  UT 0500  NPDE04  UT 1700

3.5  130  84357  3.5  130  84357
O+  300 km

NPDE13  UT 1700  NPDE22  UT 1700

$K_p = 1$  $K_p$ variation  $K_p = 65$
O+ 300 km

NPDE04  UT 1700

3.5  130  84357

NPDE05  UT 1700

3.5  130  84173

Seasonal Variation
**Ionospheric Structure**

**TYPE 1 SUNALIGNED ARCS**
DAWN-DUSK DRIFT (PREDOMINANT)
100 - 250 M/s

**TYPE 2 PATCHES**
ANTI-SUNWARD DRIFT
0.1 - 1 Km/s

Buchau et al (1983)
Plasma Patch Formation

Sojka et al (1993)
Heppner-Maynard Convection

- Southward IMF
- "A" yields uniform flow at 500 m/s
- "DE" yields strong flow in dusk sector at 1 km/s
- Change every 1/2 hour
NCAR-TGCM Simulation

- Equinox Transition Study
  - September 18-19, 1984

- Parameterized Convection and Precipitation Models for Entire Period
  - NOAA & DMSP Particle Data
  - AMIE Technique for Convection
  - Semi-diurnal Tides

- Several Quiet Days Followed by Storm

Crowley et al. (1989)
Magnetic Storm (Sept. 19, 1984)

(a) AE
(b) Joule Heating
(c) HP
(d) Potential Difference (kV)

ΔΦ (kV)
Neutral Winds and Temperatures

9 UT
(Pre-storm)

Active Day
300 km

13 UT

12 UT

18 UT
Meridional Neutral Wind

1800 UT; 70° West Longitude

No Tides

Tides

Geographic Latitude

Height
Forecasting: What's Needed?

- Requirements range from hours to 30 or 90 days forecast of the ITM system.

- The latter arise from the need to define optimal usable communication links.

- Typically, 12 hours to a day is a good forecast for severe weather related problems, i.e., satellite drag, spacecraft damage, etc.

- How can we do this?

  An example on 14 April 1994, from Murray Dryer, SEL, NOAA, shows forecasters had no evidence of a CME ejection. However, soft x-ray images from YOHKOH (Japanese satellite) were FAXed to SEL. They showed a very extended short-lived filament. Forecast was made ~ 2-3 days to reach Earth and 7 days to reach Ulysses.
Forecasting: Science Issues

- When a CME arrives at the Earth, how do you convert this knowledge into convection and precipitation patterns? How long will the storm last?

- For non-storm conditions, how do you forecast $K_p$ and $Dst$ variations? That is, how do you forecast convection and precipitation pattern variations?

- Models of convection and precipitation do not exist for severe storms. A cross-tail potential of 216 kV was observed, but this corresponds to a $K_p = 14$.

- The ‘average’ convection pattern for northward IMF has not been clearly identified.

- The spatial structure seen in the ionosphere-thermosphere system needs to be incorporated into the forecast models. Multi-grids or nested models are required.

- More work needs to be done on establishing how the convection and precipitation patterns vary with time.
  - AMIE approach is the state-of-the-art, but needs validation.
  - PCO is important.

- Need to predict substorm onset.

- Real-time monitoring is important to update forecast models.

- Need a specification of upward propagating gravity and tidal waves.