Statistical Aspects of Subauroral/Auroral Convection and Ionospheric features

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Outline

ISR based ionospheric models

• ISR Local Ionospheric Models
• ISR Regional Ionospheric Models
• ISR Convection Model
  – By dependence
  – Kp dependence
  – Seasonal dependence
• Summary
Existing Long-term Data

• **The European Chain:**
  EISCAT Svalbard Radar (1997-), in polar cap, the highest latitude
  EISCAT Tromsø UHF radar (1984-) and VHF radar (1990-),
  St. Santin Radar (1973-1986)

• **East America Chain**
  Sondrestrom Radar (1990-)
  Millstone Hill Radar (1970-)
  Arecibo Radar (1966-)

• **East Asia**
ISR Empirical Models

- Local Models: Ne, Te and Ti
- Regional Models: Ne, Te and Ti
  - Millstone Hill Subauroral Model
  - Millstone Hill / Sondrestrom Subauroral-Auroral Model
  - Millstone Hill / Sondrestrom / Arecibo American Regional Model
- High-latitude Convection Model
Local Ionospheric Models
Binning and Fitting technique

- Data are binned according to local time and month.
- Piece-wise linear height profile is used for initial data binning with 17-19 height nodes.
- Solar activity dependency is determined by a least-squares fit to a linear function to F107.
- Magnetic activity dependency is a linear function to ap index for the previous 3 hours.
- Median filter (3 months x 3 hours) is applied to the fitting coefficients.
Analytic representations of bin-fit results

- Seasonal variations: harmonics with 12, 6 and 3 month components
- Local time variations: harmonics with 24, 12, 6 and 3 hour components
- Height variations: cubic B-spline with 17 breaks and gradient controls at upper and lower boundaries.
Local Model Results
Latitudinal and Longitudinal features

- Semiannual components start to occur at lower midlatitudes.
- Strong semiannual components, asymmetry appears at midlatitudes.
- Semiannual components, longitudinal differences are observed at mid- and high-latitudes.

Examples of locations:
- Svalbard
- Tromsø
- Millstone Hill
- Shigaraki
- Arecibo
- St. Santin
Virtual ISRs
IRI and ISR Models
Sondrestrom Ne profile
ISR Regional Ionospheric Models

Subauroral ionospheric variations in Ne, Te and Ti based on Millstone Hill ISR data

Geodetic 35-55° from Millstone Hill Radar
ISR Regional Ionospheric Models

Subauroral - Auroral Ionospheric Models

• A combination of ISR observations from Millstone Hill and Sondrestrom (and Arecibo)
  – MH: zenith local measurements; elevation and azimuth scans
  – Sondrestrom: local, northward and southward
• Cubic B-splines used for latitudinal variations and height variations
• Harmonics for seasonal and local time variations
• Linear to F107 and ap3
Regions of Stagnation

$B_y = 3 \pm 4 \text{nT}$  
$B_z = -2 \pm 4 \text{nT}$
Auroral Heating

By = $3 \pm 4$ nT
Bz = $-2 \pm 4$ nT

Summer

Equipotential + Ion Temperature (K)
at 210 km

Cross Polar Cap Potential, KV

0 20 40 60 80 100 120

600 700 800 900 1000 1100
By = 3 ± 4 nT
Bz = -2 ± 4 nT

Equi-potential + Electron Temperature (K)
at 450 km

Cross Polar Cap Potential, KV

WINTER
00APLT
ISR Convection Model

• Millstone Hill – LOS
  – Extra-wide coverage
  – MISA moves slowly and continuously either in AZ or EL, followed by zenith antenna sounding
  – Assumptions: LOS only from perpendicular drifts for MH low EL scans (ignoring parallel drifts well to the north of MH)

• Sondrestrom – resolved velocities
  – Comp-scan
IMF Data

- NSSDC OMNI 2 system
- Hourly averages
- Time-shifted data “at Earth” (propagation time correction)
- Response time = communication time + reconfiguration time
  – about 20 min: recent estimate
GLOBAL SEARCH: LOS, GEOPHYS INDEXES (By and Bz OR Kp and By)

MADRIGAL

LOS DATA BINNING ACCORDING TO APLT, APLAT, INDICES
VECTORS $V$ BASED ON LOS BIN AVERAGE
VECTORS $V$ DATA FOR EACH BIN

$V$ DEPENDENCIES ON INDICES
$V$ MODEL

$V$ FOR GIVEN APLT, APLAT, INDICES (further binning)

VELOCITY TO POTENTIAL FITTING

Periodic Bi-cubic spline
**IMF Data histograms**

**By**
within +/- 5 nT
more positive (away)

**Bz**
within +/- 4nT
most likely 0nT
more negative (southward)
Overview: Convection Patterns

Note changes in:
1. the shape of each cell
2. polar cap potential drop

By Movie
Overview

-4nT  0  +4nT

By = -4 ± 2 nT  Bz = 4 ± 2 nT

By = 0 ± 2 nT  Bz = 4 ± 2 nT

By = 4 ± 2 nT  Bz = 4 ± 2 nT

ANNUAL

| -18(Dusk) - 6(Dawn) | = 25 kV |

| -16(Dusk) - 4(Dawn) | = 20 kV |

| -24(Dusk) - 9(Dawn) | = 33 kV |

| -25(Dusk) - 11(Dawn) | = 36 kV |

| -23(Dusk) - 10(Dawn) | = 33 kV |

| -30(Dusk) - 15(Dawn) | = 45 kV |

| -36(Dusk) - 25(Dawn) | = 61 kV |

| -38(Dusk) - 24(Dawn) | = 60 kV |

| -42(Dusk) - 22(Dawn) | = 64 kV |
When $K_p$ increases

- Cell expansion
- Enhanced potentials with $B_y$ dependent:
  - $\phi(B_y^+)$ > $\phi(B_y^-)$
  - $B_y^+$ penetrates to lower latitudes
  - $B_y^-$ rotates to later MLT
Seasonal Variations

\[ B_z = [-8 \ 0] \text{ nT} \]
\[ B_y = [0 \ 8] \text{ nT} \]

Larger potential drops in solstice than in equinox

Cell rotation in summer relative to winter
Seasonal Variations

$B_z = [-8 \ 0] \ nT$

$B_y = [-8 \ 0] \ nT$

Larger potential drops in solstice than in equinox.

Cell rotation and antisunward move in summer relative to winter.
Winter-Summer Differences

Kp = [0 5]

Cell rotation and antisunward move in summer relative to winter

de la Beaujardere et al. (1991)
- Field-line geometry
- Ionospheric conductivity

φ_{wt}^- < φ_{sm}^-
φ_{wt}^+ > φ_{sm}^+
Lobe cells resulting from dipole tilt are added to round cells in the summer patterns. The dusk cells are made stronger than the dawn cells by adding an extra convection contour. The round and crescent shapes are distorted in the By-patterns by the tendency for the flow contours to concentrated on the dawnside of the polar cap.
Winter-Summer Differences

Polar cap potential drops (difference between dawn and dusk potentials)

Dawn-dusk similarity scale (sum of dawn and dusk potentials)

Lobe cell generation in summer (Crook and Rich, 1994)

Most equal potentials for $B_y -$;

Least equal potentials for $B_y +$.

Day-night conductivity gradient effects
By direction and convection (Bz-)

Hemispheric difference in solstice during By +:

$$\phi_{summer}^{By^+ (N)} - \phi_{winter}^{By^+ (S)} = \phi_{summer}^{By^+ (N)} - \phi_{winter}^{By^- (N)}$$
“Hemispheric” difference

<table>
<thead>
<tr>
<th></th>
<th>By +</th>
<th>By -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solstice</td>
<td>6 kv</td>
<td>8 kv</td>
</tr>
<tr>
<td>Equinox</td>
<td>8 kv</td>
<td>7 kv</td>
</tr>
</tbody>
</table>

$K_p < 5$

$\phi_{\text{winter}}^{\text{By+ (S)}} = \phi_{\text{winter}}^{\text{By- (N)}}$?
3 Types of ISR-based Models have been developed that can provide specifications on a range of ionospheric variations of various spatial scales.

In particular, for the convection patterns, our results show:

- Asymmetric effects of By + and By – on convection cell shapes and cross-polar cap potentials, with By + resulting in higher polar cap potential drop than By -;
- Convection pattern expansion toward lower latitudes for enhanced Kp, which has a dependency on the By sign;
Summary - II

• Higher polar cap potential drops in equinox than in solstice;
• Antisuward move and rotation of the cells’ axis toward earlier local times, as it turns from winter to summer;
• Higher dusk-dawn cell similarity in summer for By - and low for By – than in winter, in supportive of lobe-cell generation in summer;
• “Hemispheric” differences.