Low Latitude Storm Time Ionospheric Electrodynamics

Bela G. Fejer
Center for Atmospheric and Space Sciences
Utah State University
Logan, UT 84322-4405

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OUTLINE

1. Properties and electrodynamic effects of storm-time low latitude electric fields.

2. Generation Mechanisms
   • Magnetospheric dynamo and prompt penetration electric fields.
   • Ionospheric disturbance dynamo.
   • Traveling atmospheric disturbance (TAD) dynamo.

3. An equatorial storm-time dependent empirical zonal electric field (vertical plasma drift) model.
   • Long and short term average signatures of equatorial disturbance electric fields.
   • Comparison with results from the Rice Convection model, and from the ionospheric disturbance dynamo model.
   • Comparison of empirical model results with individual observations.

4. Disturbance dynamo effects on the Jicamarca and Arecibo zonal plasma drifts.

5. Conclusions.
INTRODUCTION

The equatorial ionospheric zonal electric field, which drives the vertical electrodynamical plasma drift, plays a dominant role on:

- The equatorial electrojet current system
- The distribution of ionization on the equatorial and low latitude ionosphere and protonosphere
- The dynamics of the equatorial ionosphere
- The generation of plasma instabilities in the equatorial E region
- The generation of equatorial spread F and scintillation which affects low latitude communication, surveillance and radio positioning systems.

During geomagnetically quiet conditions, the mid- to low-latitude electric fields are generated by ionospheric dynamo effects, but during disturbed conditions they are also affected by the magnetospheric dynamo.
DATA

F region vertical plasma drifts measured with the incoherent scatter radar at the Jicamarca Radio Observatory (12°S, 77°E, magnetic dip 2°S), near Lima, Peru.

Over Jicamarca, an upward (eastward) drift velocity of 40 m/s corresponds to an eastward (downward) electric field of 1 mV/m.

The accuracy is about 1-2 m/s (0.025-0.05 mV/m) for the vertical drift and 10-20 m/s for the zonal drift. The integration time is 1-10 minutes.
Jicamarca Equinox

AE ≤ 250 nT
Φ_{adj} = 130

Vertical Drift (m/s)

Local Time
18-19 JANUARY 1984

AU/AL (nT)

B_z (nT)

ΔH (nT)

Eastward Electric Field (mV/m)

HUANCAYO

JICAMARCA

Quiet time average

Feyer et al. (1990)
JICAMARCA, PERU
ELECTRON DENSITY
SEP 13-14, 1972

HEIGHT (Km)

0 200 400 600 800

TIME (75°W)

08 10 12 14 16 18 20 22 00 02 04 06 08

Log$_{10}$ $N_e$

Sp "F"
FEBRUARY 17-18, 1976

B_z (SM)

AU

AL

WESTWARD AURORAL E-FIELD

TRIVANDRUM

EASTWARD EQ. E-FIELD

Gonzales et al. (1979)
UPWARD/NORTHWARD DRIFT VELOCITY (m/s)

EASTWARD ELECTRIC FIELD (mV/m)

18-19 JANUARY 1984

IMF

AU/AL (nT)

MILLSTONE HILL

Δ = 64°

MILLSTONE HILL

Δ = 55°

ARECIBO

JICAMARCA

U.T. 00 08 16 00 08 16 00

Feyer et al. (1990)
Large electric field (plasma drift) perturbations are often observed at the equator during disturbed conditions.

![Graph](image1)

August 8-10, 1972

Jicamarca

Local Time

The average equatorial drifts during geomagnetically quiet and disturbed conditions are essentially identical!

![Graph](image2)

Jicamarca

Local Time

\[ \Phi_{adj}=130 \]

Mar-Apr

Sep-Oct

May-Aug

\[ \bullet \ AE \leq 250 \text{ nT} \]

\[ \circ \ AE \geq 250 \text{ nT} \]
DAY/NIGHT ASYMMETRY IN CONDUCTIVITY

UNIFORMLY CONDUCTING IONOSPHERE

ENHANCED AURORAL CONDUCTIVITY

(d) = (b) + (c)

Riley et al. 1993
Figure 11. Model results of the initial time equatorial zonal electric fields corresponding to an increase in the polar cap potential drop by 100 kV (from FEJER et al., 1990a).
POSITIVE IONOSPHERIC STORM

TRAVELING ATMOSPHERIC DISTURBANCE

MIDDLE LATITUDES

LOW LATITUDES $t = 3.5h$

HIGH LATITUDES $t = 0$

MAGNETOSPHERIC SUBSTORM

$\Delta hp$ $\Delta Np$

GEOMAGNETIC ACTIVITY EFFECT

$N_2$

Prölss (1993)
Fig. 1. Storm-time variations at 45° latitude of the equatorward wind $u_\theta$ and of the eastward wind $u_\phi$ at four different altitudes within the dynamo region, and of the eastward F region plasma drift velocity $v_\phi$, for our two longitudinally symmetric simulations of an auroral heat input event.

Blanc and Richmond (1980)
DATA

We use about 15,000 Jicamarca drift measurements and AE indices with a time resolution of 15 min from 1968 to June 1988, to study the effects of convection changes and high latitude energy deposition on the equatorial electric fields.

For comparison with theoretical model results, we use the relationships between the polar cap potential drop, the global energy injection and the AE index [e.g., 1992, 1983] i.e.,

\[ \Phi (kV) = 36 + 0.082 \ AE \ (nT) \]

\[ U(W) = 2.9 \times 10^9 \ \ AE \ (nT) \]
Initial study [Fejer and Scherliess, GRL 1995]

$$\Delta V(t) = \sum_{i=1}^{q} \left[ a_{i,1} \Delta AE(t) + a_{i,2} \Delta AE(t-1 hr) \right]$$

Magnuspheric dynamo effects

$$+ a_{i,3} \overline{AE^*}(2-4hrs) \right] N_{i,4}(t)$$

Ionospheric storm time dynamo effects
JICAMARCA 1968-87

Local Time

Storm-Time (Hours)

Δ Vertical Drifts (m/s)

Feyer and Scherliess, 1995
Equatorial Zonal Electric Field
(Vertical Plasma Drift)

Empirical Storm Time Model

- based on about 15000 measurements

- based on 9 normalized cubic B-splines to describe local time dependence

Model can be expressed as:

\[ v(t) = \sum_{i=1}^{9} \left[ a_{i,1} \Delta AE(t - 7.5m) + a_{i,2} \Delta AE(t - 30m) + a_{i,3} \Delta AE(t - 75m) \right] \]

Prompt Penetration

\[ + a_{i,4} AE^*(2 - 6h) + a_{i,5} \alpha AE^*(7 - 12h) + a_{i,6} \beta AE^*(22 - 28h) \right] N_{i,4}(t) \]

Disturbance Dynamo Splines

\[ \alpha \} \text{ short-long term} \]

\[ \beta \} \text{ interference parameters} \]
Prompt Penetration Electric Fields

**Graph 1:**
- **AE (nT):** 700, 500, <300, 100
- **Storm-Time (Minutes):** 0, 30, 60, 90
- **T** marks specific time points:
  - $t_e$, $t_{7.5}$, $t_{10}$, $t_{60}$

**Graph 2:**
- **Vertical Drift (m/s):**
  - Empirical Model
  - RCM
- **Eastward Electric Field (mV/m):**
- **Local Time:**
  - 02, 06, 10, 14, 18, 22
- **Initial Time Response**
- **$\Delta \Phi = 33kV$**

Feyer and Scherliess, 1996
Empirical and Theoretical Storm-Time Dynamo Model Results

\[ AE(1-9h) = 400 \text{ nT} \]
\[ U(W) = 1.2 \cdot 10^{11} \text{ W} \]

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**Graphs:**

- **Top Graph:**
  - X-axis: Storm-Time (Hours)
  - Y-axis: AE (nT)
  - Data points and lines indicating AE values over time.

- **Bottom Graph:**
  - X-axis: Local Time
  - Y-axis: Vertical Drift (m/s)
  - Data points and lines indicating vertical drift over local time.
  - Legends include Jicamarca, Empirical Model (\( \tau = 2-9\text{hrs} \)), and Blanc-Richmond (1980) models.

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**Citation:**
Schepfliess and Fejer, 1996
Scherliess and Feyer, 1996
July 2-3, 1968

Jicamarca

Data
Model
quiet

Dist. Dynamo
Prompt Penetr.

Fejer and Schorliess, 1996
Vertical Drift (m/s) AE (nT)

Aug 8-9, 1972

Aug 9-10, 1972

Jicamarca

Aug 8-9, 1972

Aug 9-10, 1972

Scherliess and Feyer, 1996
CONCLUSIONS

Experimental and model studies have shown conclusively that the low latitude ionosphere is strongly affected by prompt penetration electric fields driven by magnetosphere dynamo effects as well as by storm time ionospheric dynamo effects which can take up to about 30 hours to reach equatorial latitudes.

The response of the low latitude ionosphere to high latitude forcing can only be understood taking storm-time effects into account.

Large databases of high quality measurements, and close collaboration between modeling and experimental studies are necessary for the full understanding and predictability of ionospheric electrodynamic effects.

We have described a time dependent electric field model which takes into account the response of the equatorial zonal electric field to convection changes and storm time dynamo electric field effects.

At the equator, direct penetration and storm time dynamo electric fields from the model are in excellent agreement with results from the Rice Convection Model, and from the Blanc-Richmond disturbance dynamo model, respectively. Case studies also indicate generally good agreement between the model predictions and measurements.
Similar studies are being carried out using plasma drift data from Arecibo, and Millstone Hill, and Fabry-Perot thermospheric wind measurements from Arequipa and Arecibo, and also DE-2 satellite data.

We plan to extend the model to include energy deposition in different local time sectors and in the northern and southern hemispheres, as well as seasonal, By and substorm effects.

Realistic global predictive electrodynamic models should become available in the next few years.