Low Latitude Storm Time Ionospheric Electrodynamics

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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 electrodynamic 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.

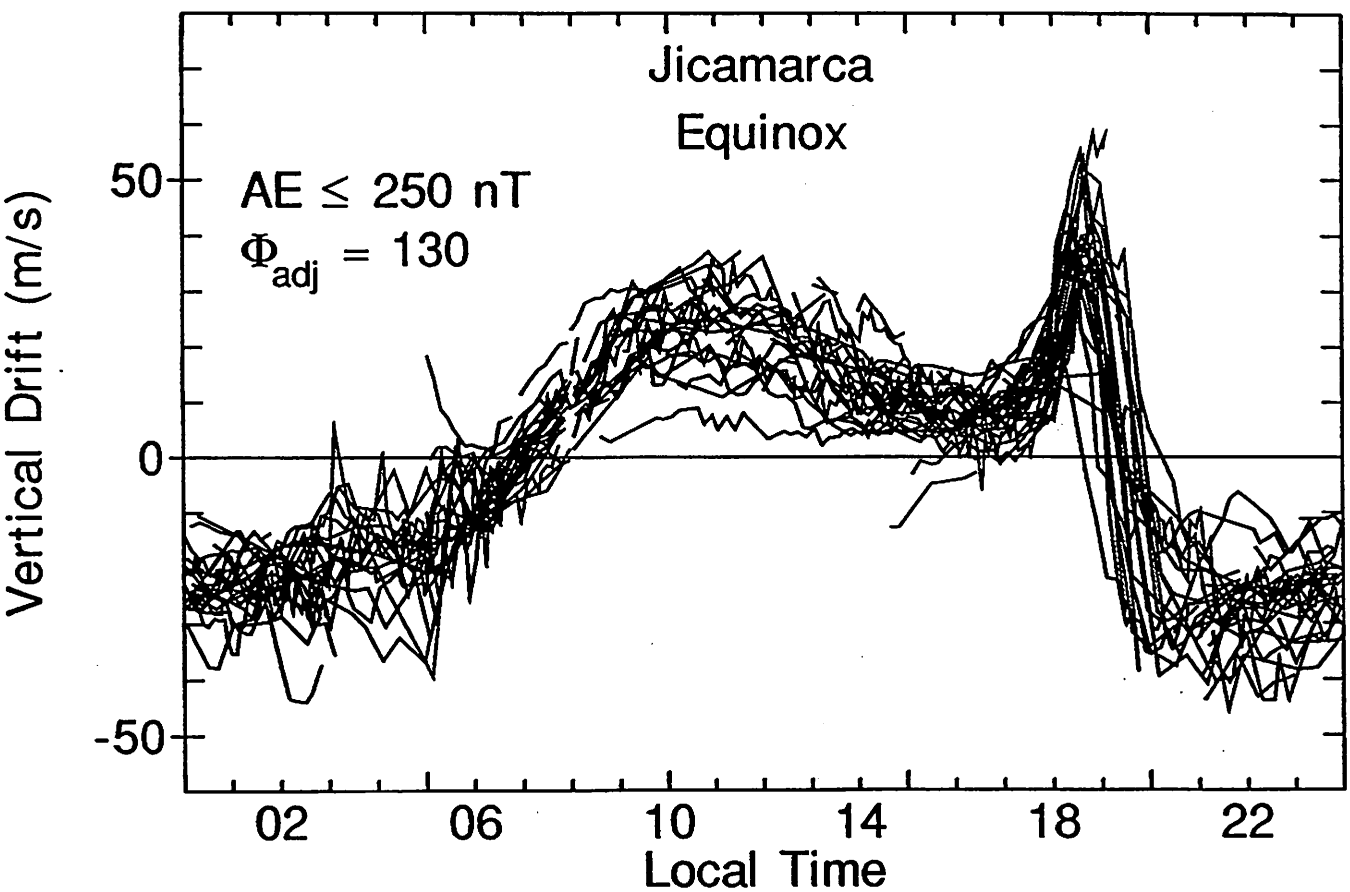
During geomagnetically quiet conditions, the mid- to low-latitude electric fields are generated by ionospheric dynamo effects, but during disturbed conditions they are also affected by the magnetospheric dynamo.

DATA

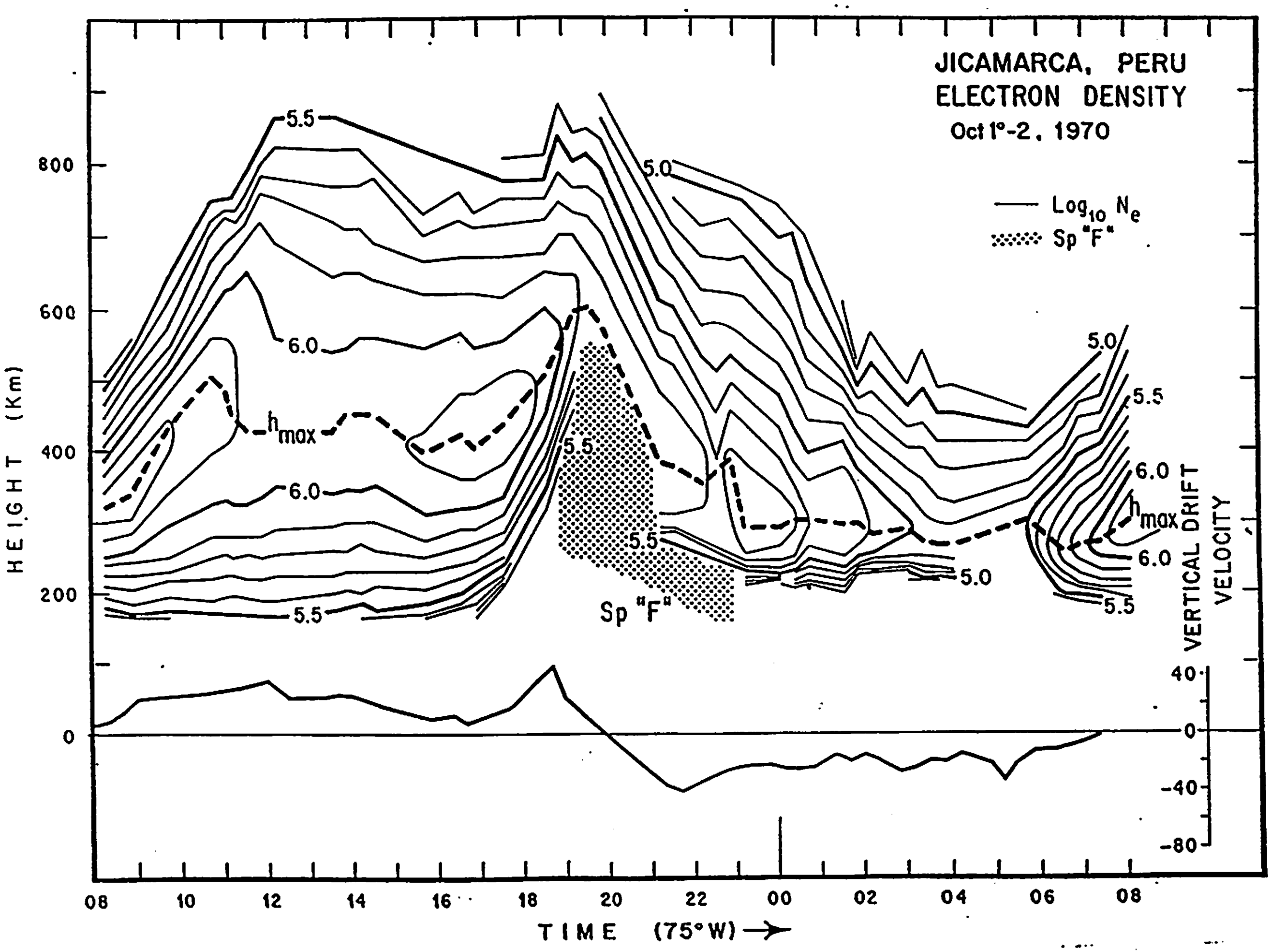
F region vertical plasma drifts measured with the incoherent scatter radar at the Jicamarca Radio Observatory (12°S, 77°E, magnetic dip 2°S), near Lima, Peru.

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

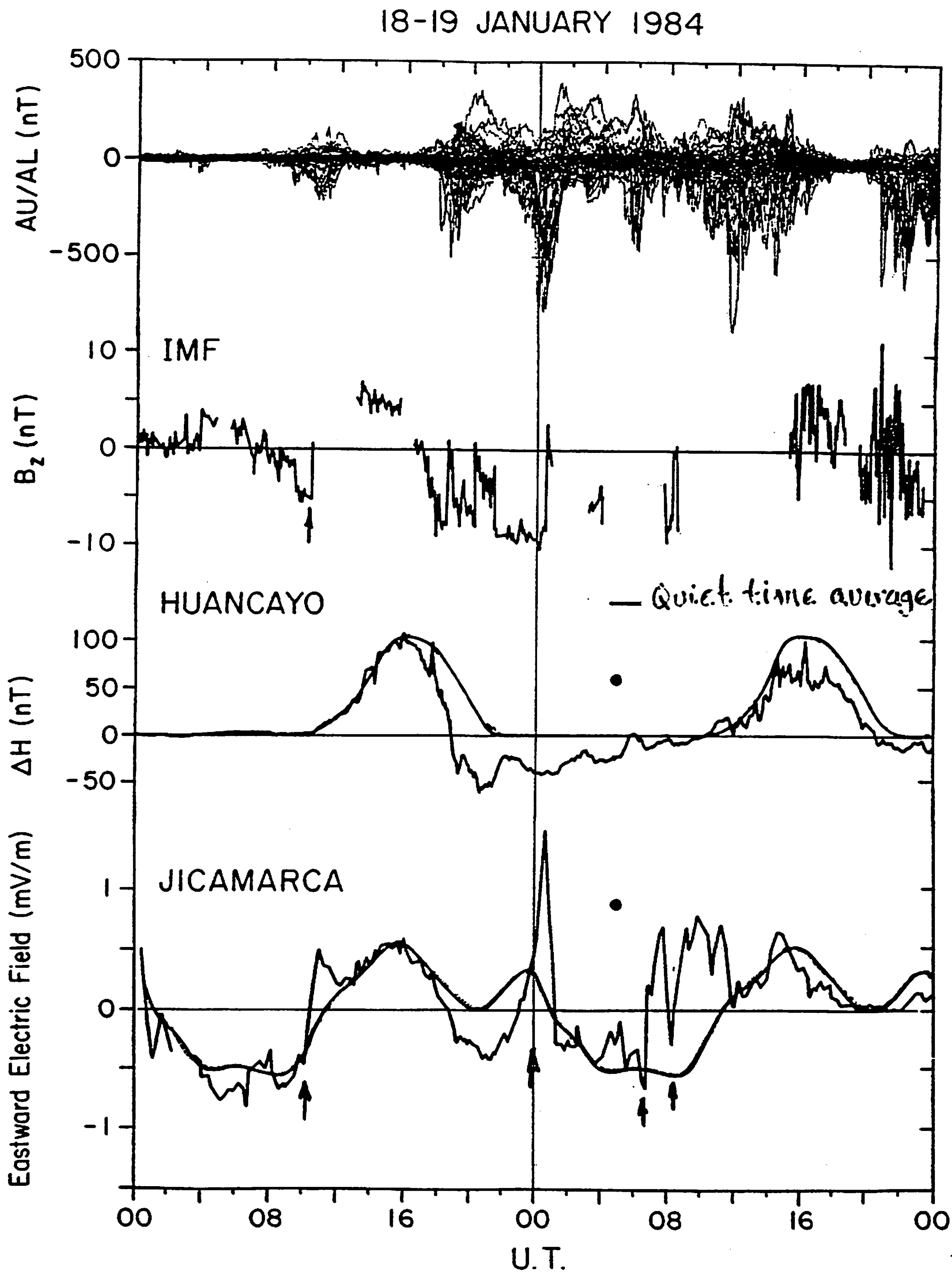
The accuracy is about 1-2 m/s (0.025-0.05 mV/m) for the vertical drift and 10-20 m/s for the zonal drift. The integration time is 1-10 minutes.



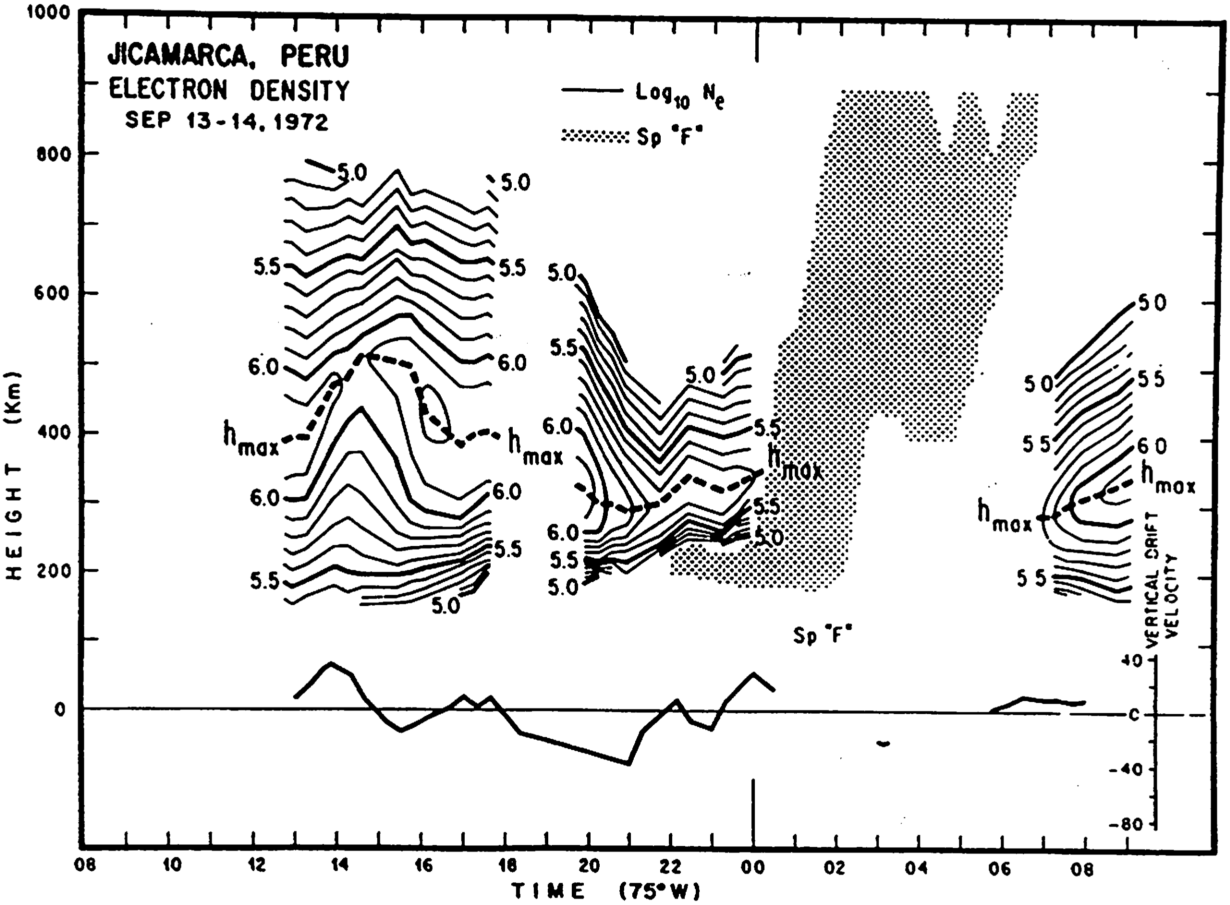
Jicamarca
Equinox
AE ≤ 250 nT
Φ_{adj} = 130
50
0
-50
Vertical Drift (m/s)
02
06
10
14
18
22
Local Time

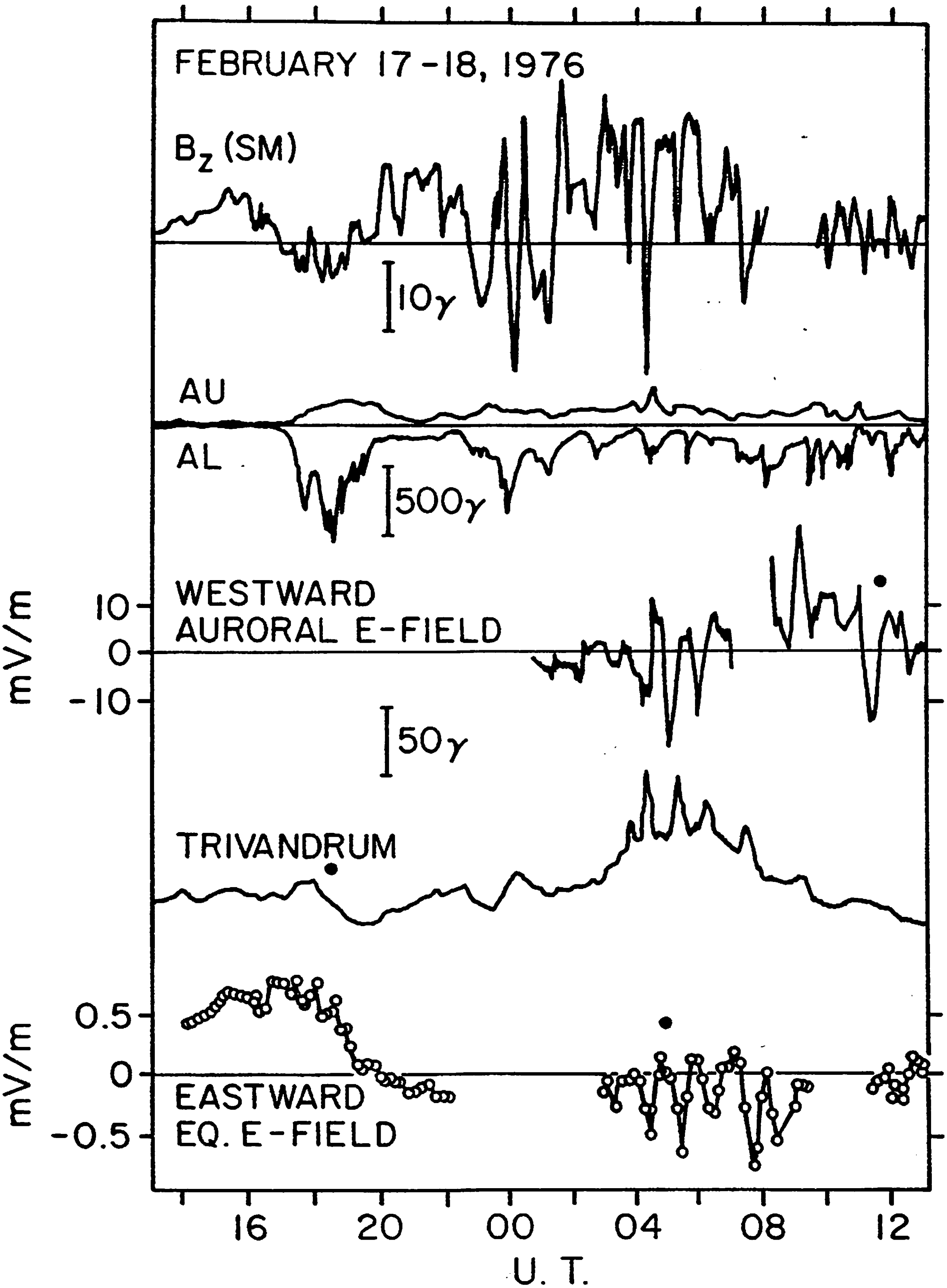


JICAMARCA, PERU
ELECTRON DENSITY
Oct 1°-2, 1970
Log10 Ne
Sp "F"
HEIGHT (Km)
VERTICAL DRIFT VELOCITY
hmax
Sp "F"
TIME (75°W)

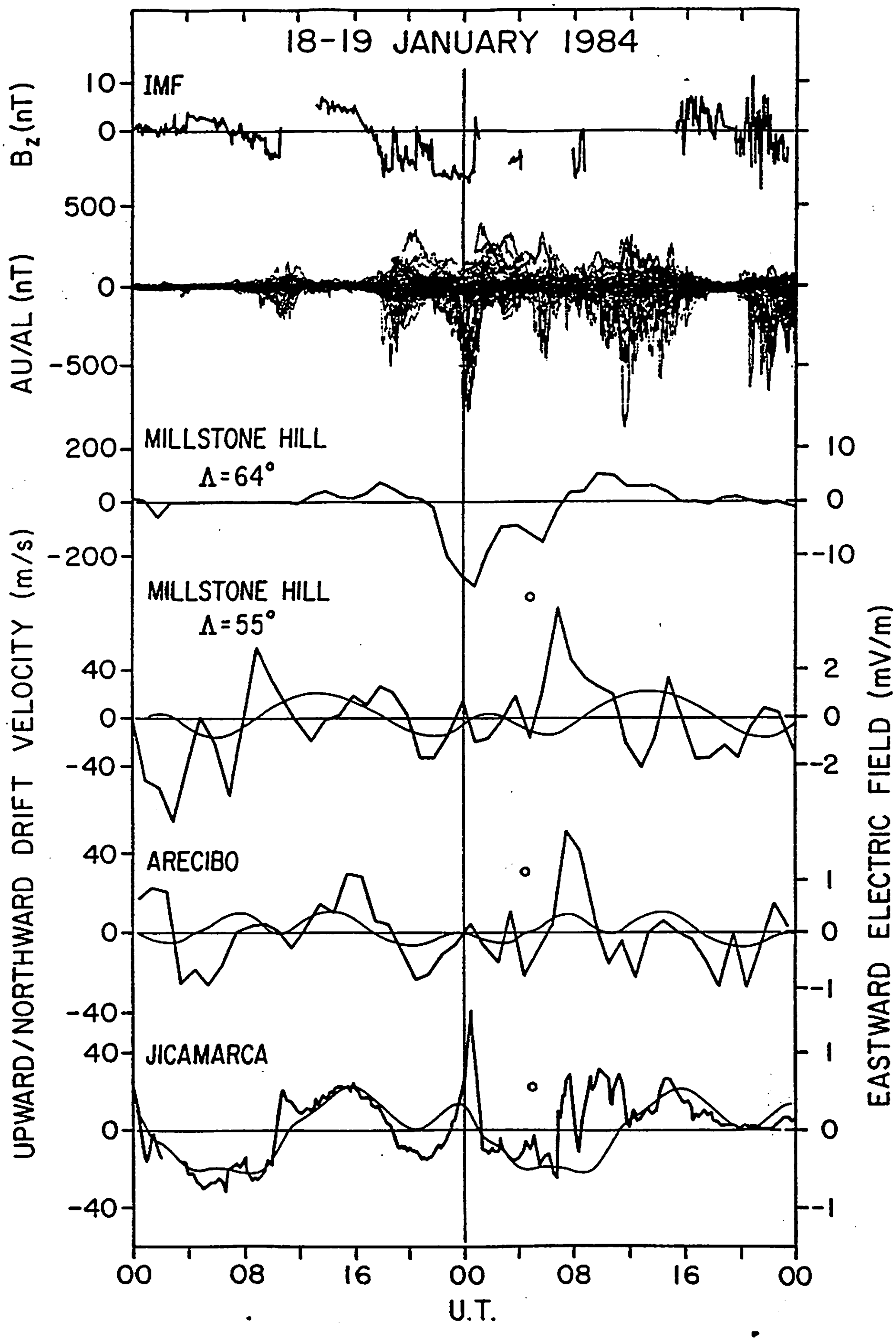


Fejer et al. (1990)


JICAMARCA, PERU
ELECTRON DENSITY
SEP 13-14, 1972
Log10 Ne
Sp "F"
HEIGHT (Km)
TIME (75°W)
VERTICAL DRIFT VELOCITY
hmax
Sp "F"
1000
800
600
400
200
0
08
10
12
14
16
18
20
22
00
02
04
06
08
40
0
-40
-80

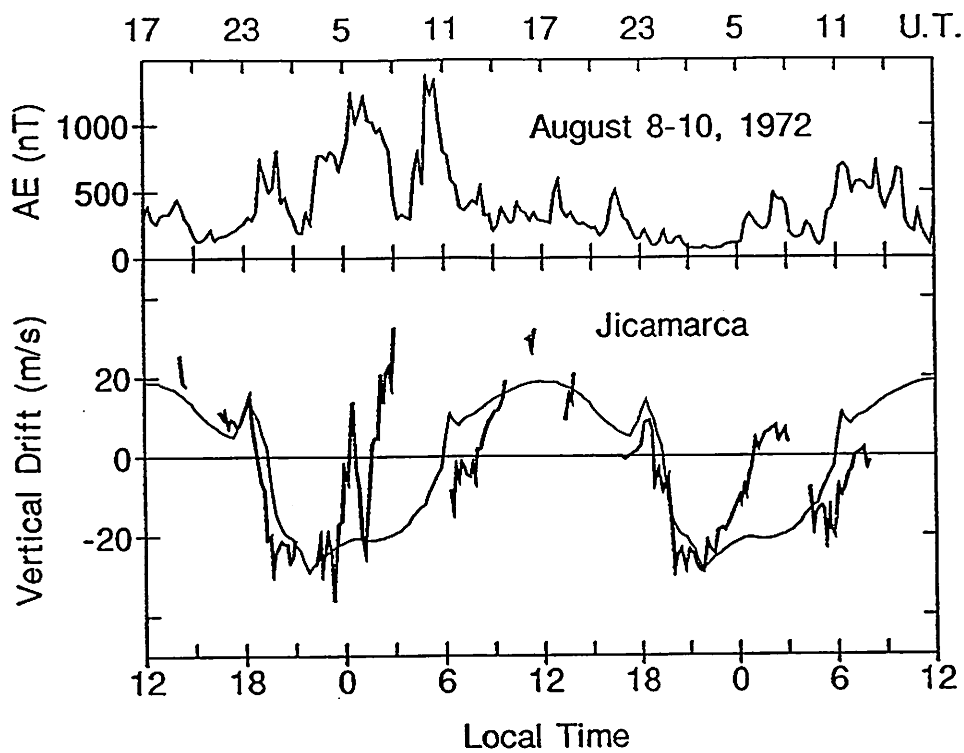


Gonzales et al. (1979)

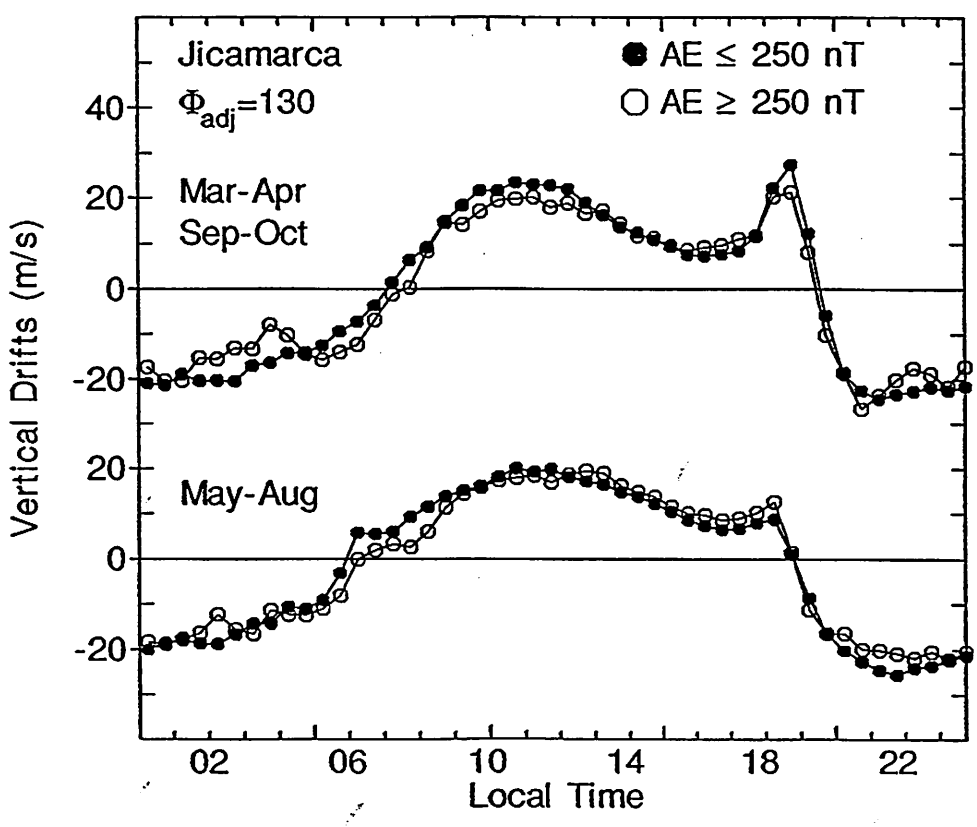


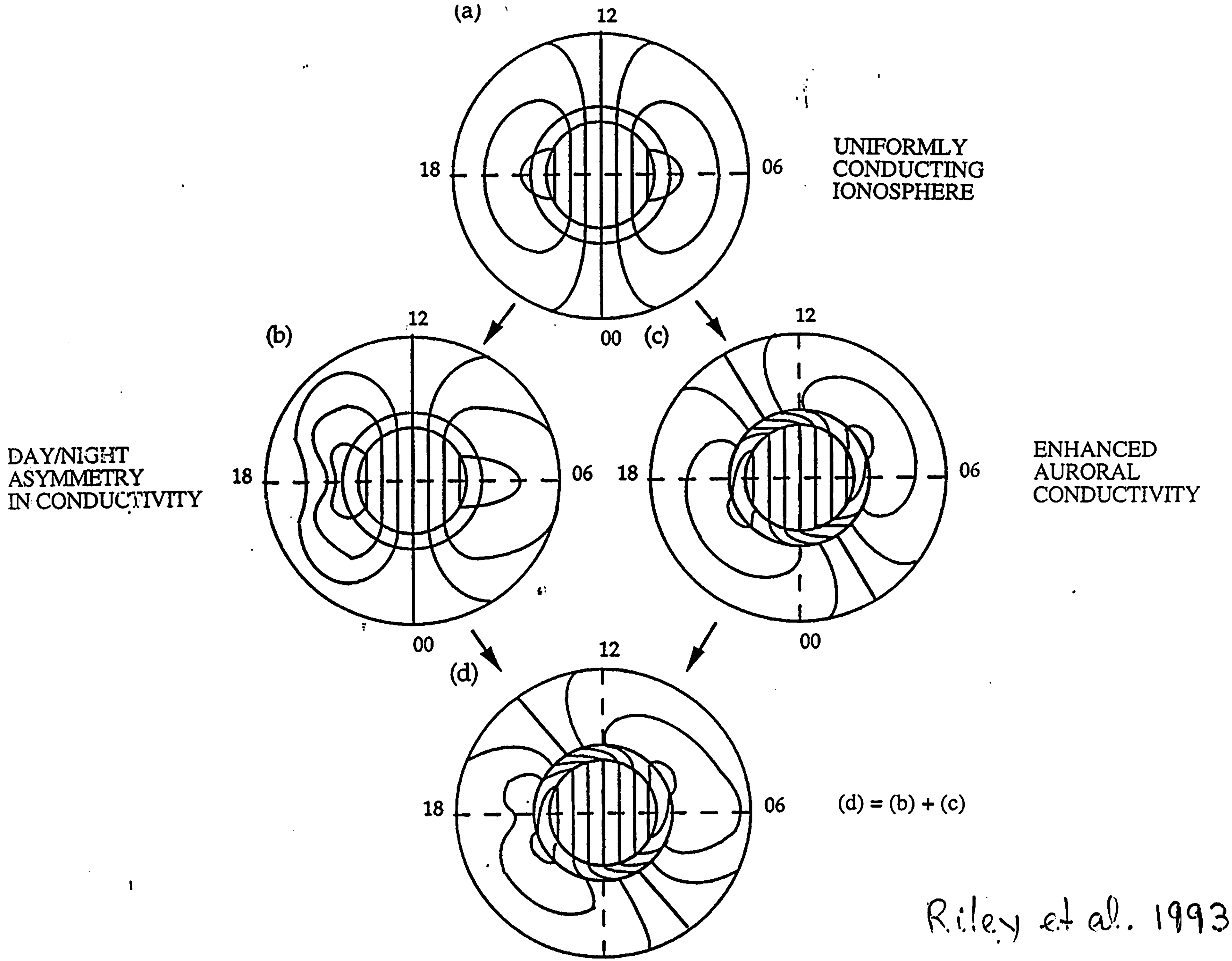
Fejer et al. (1990)

Large electric field (plasma drift) perturbations are often observed at the equator during disturbed conditions



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





(a)
12
18
06
00
UNIFORMLY
CONDUCTING
IONOSPHERE
(b)
12
18
06
00
DAY/NIGHT
ASYMMETRY
IN CONDUCTIVITY
(c)
12
18
06
00
ENHANCED
AURORAL
CONDUCTIVITY
(d)
12
18
06
(d) = (b) + (c)
Riley et al. 1993

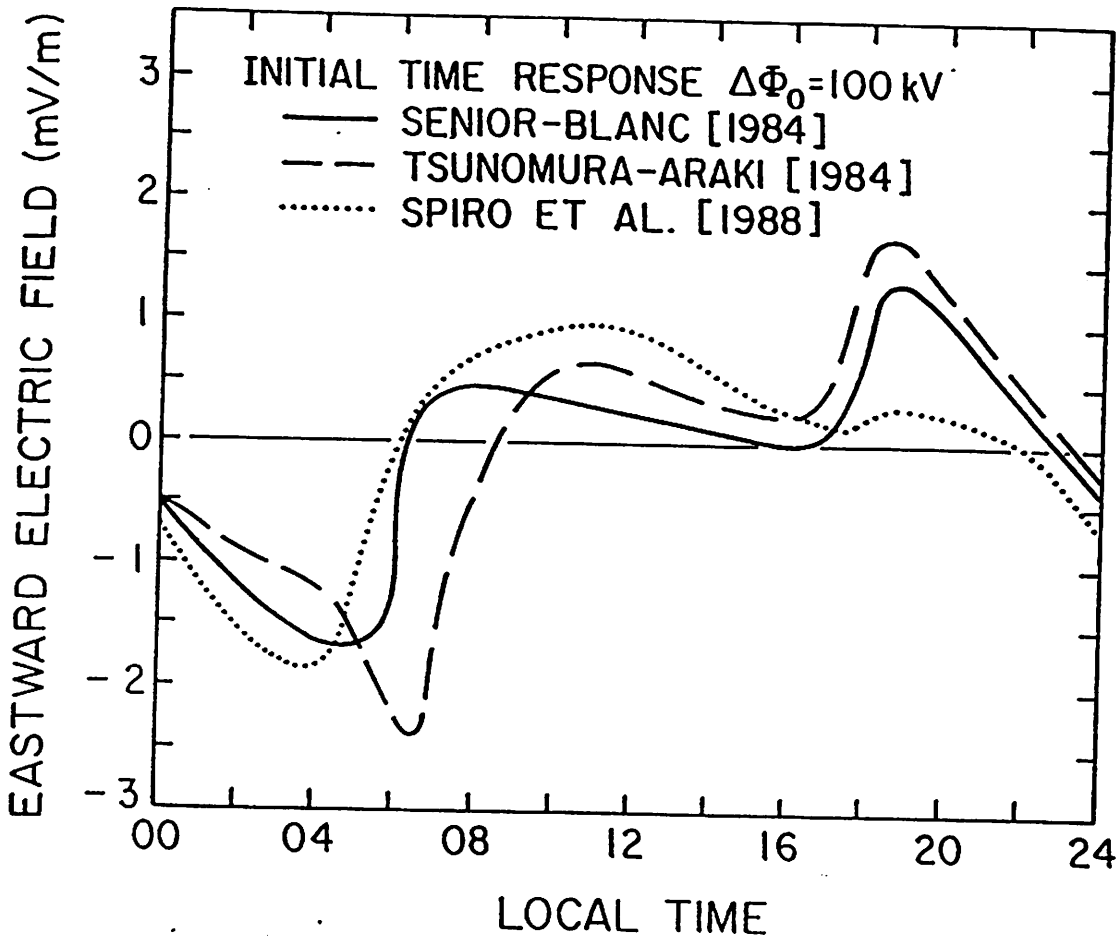
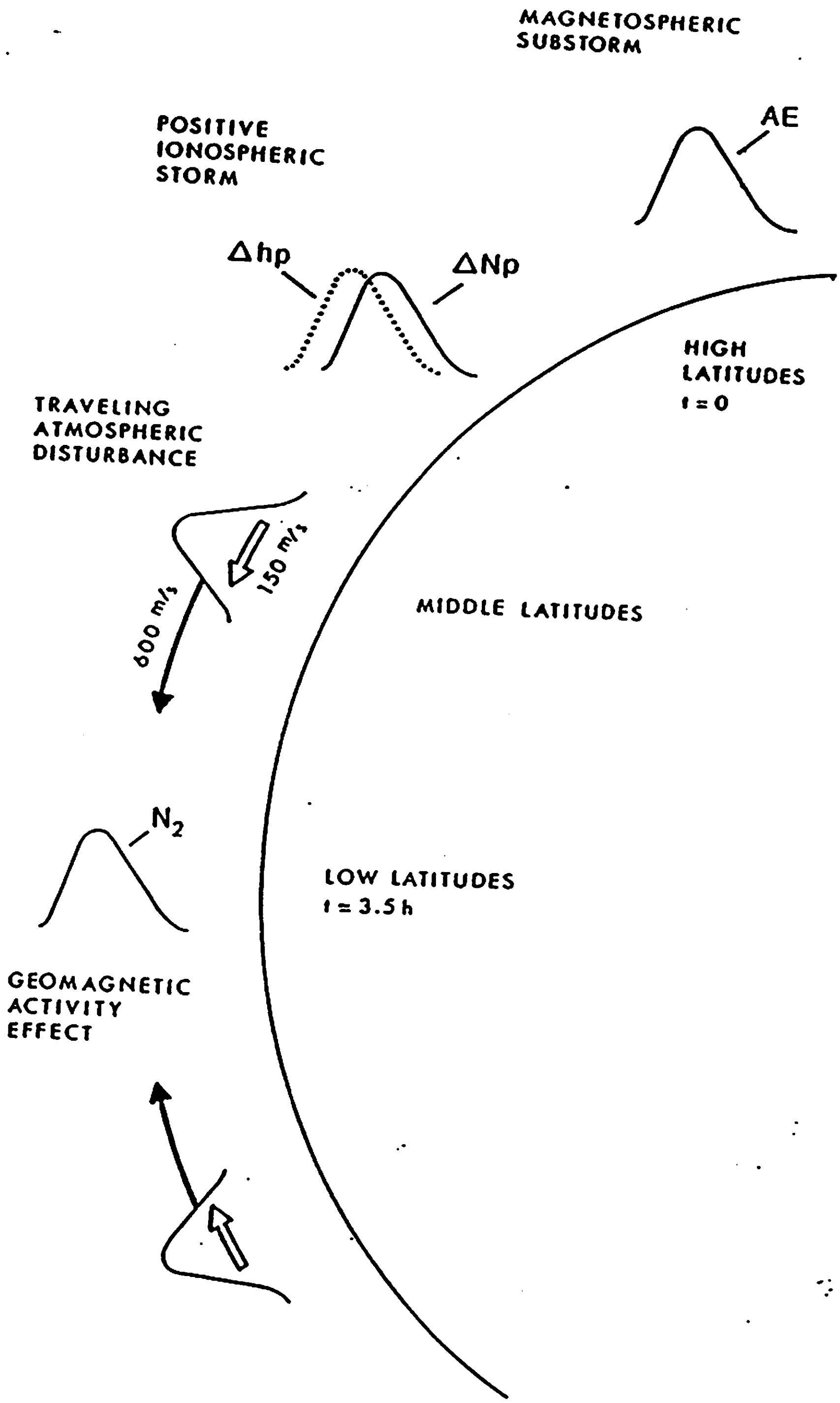


Figure 11. Model results of the initial time equatorial zonal electric fields corresponding to an increase in the polar cap potential drop by 100 kV (from FEJER *et al.*, 1990a).


MAGNETOSPHERIC
SUBSTORM
AE
POSITIVE
IONOSPHERIC
STORM
Δhp
ΔNp
HIGH
LATITUDES
t = 0
TRAVELING
ATMOSPHERIC
DISTURBANCE
150 m/s
600 m/s
MIDDLE LATITUDES
N2
LOW LATITUDES
t = 3.5 h
GEOMAGNETIC
ACTIVITY
EFFECT

Prölss (1993)

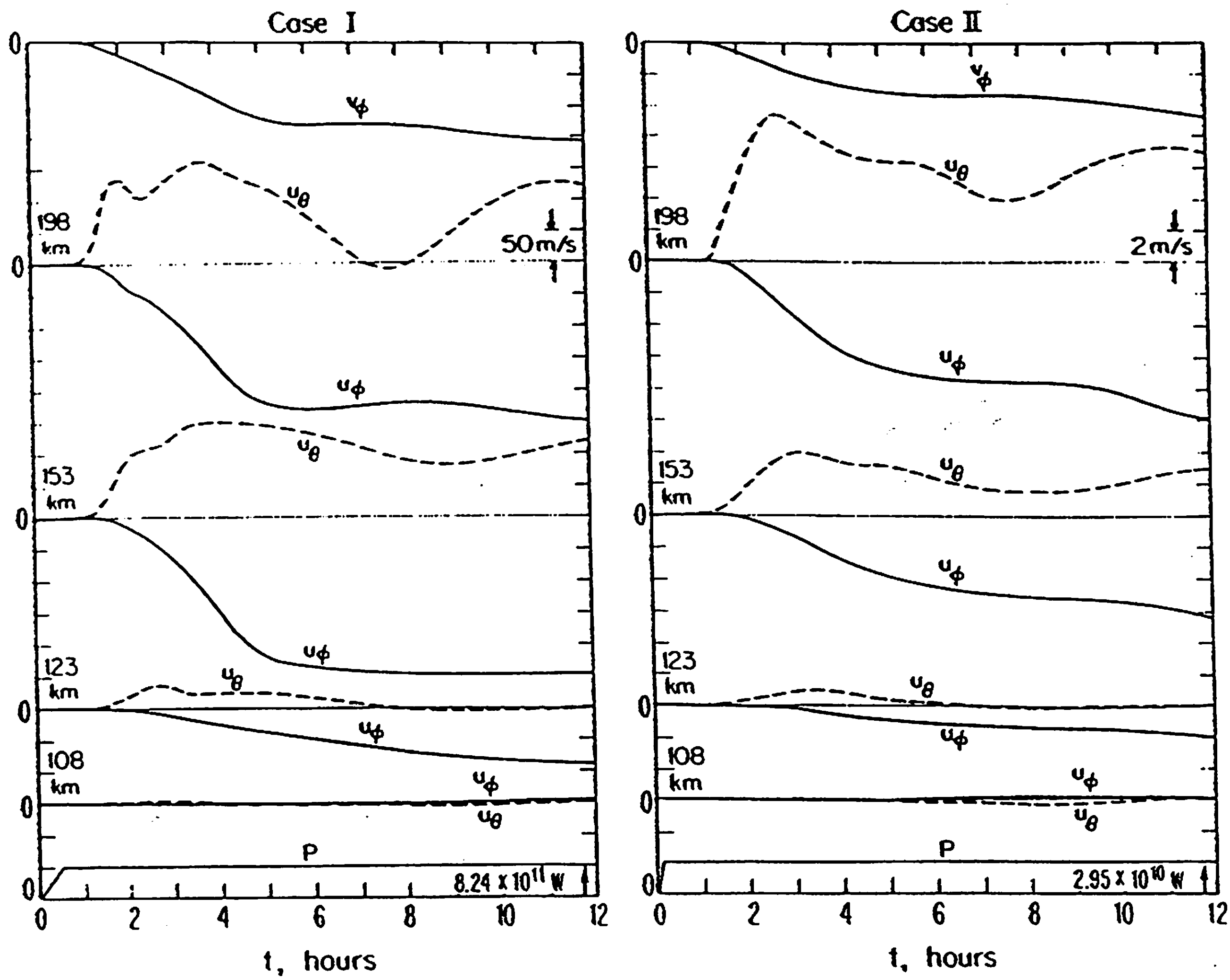


Fig. 1. Storm-time variations at 45° latitude of the equatorward wind u_θ and of the eastward wind u_ϕ at four different altitudes within the dynamo region, and of the eastward F region plasma drift velocity v_ϕ, for our two longitudinally symmetric simulations of an auroral heat input event.

Blanc and Richmond (1980)

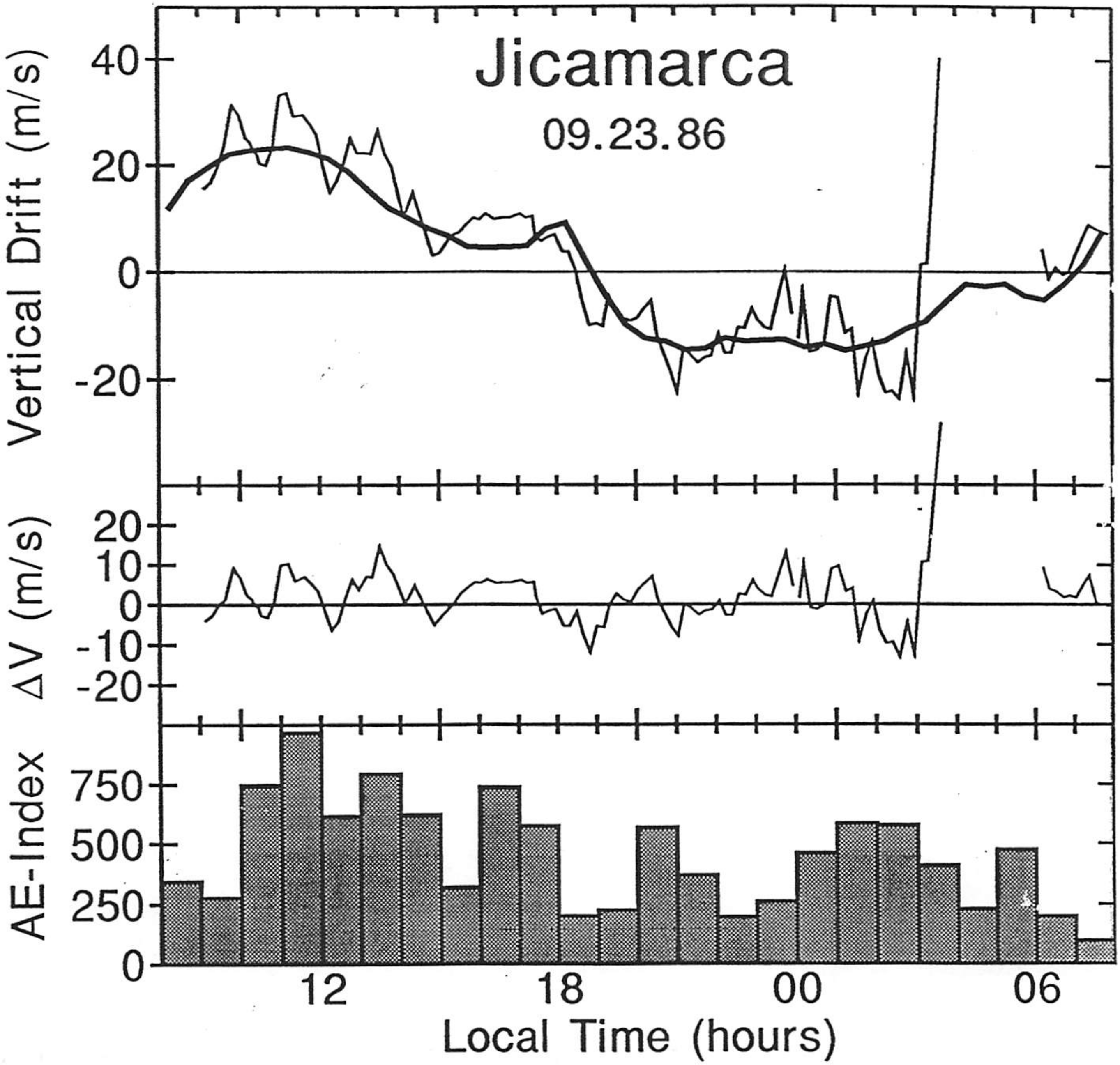
DATA

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.,

$$\Phi\ (kV) = 36 + 0.082\ AE\ (nT)$$

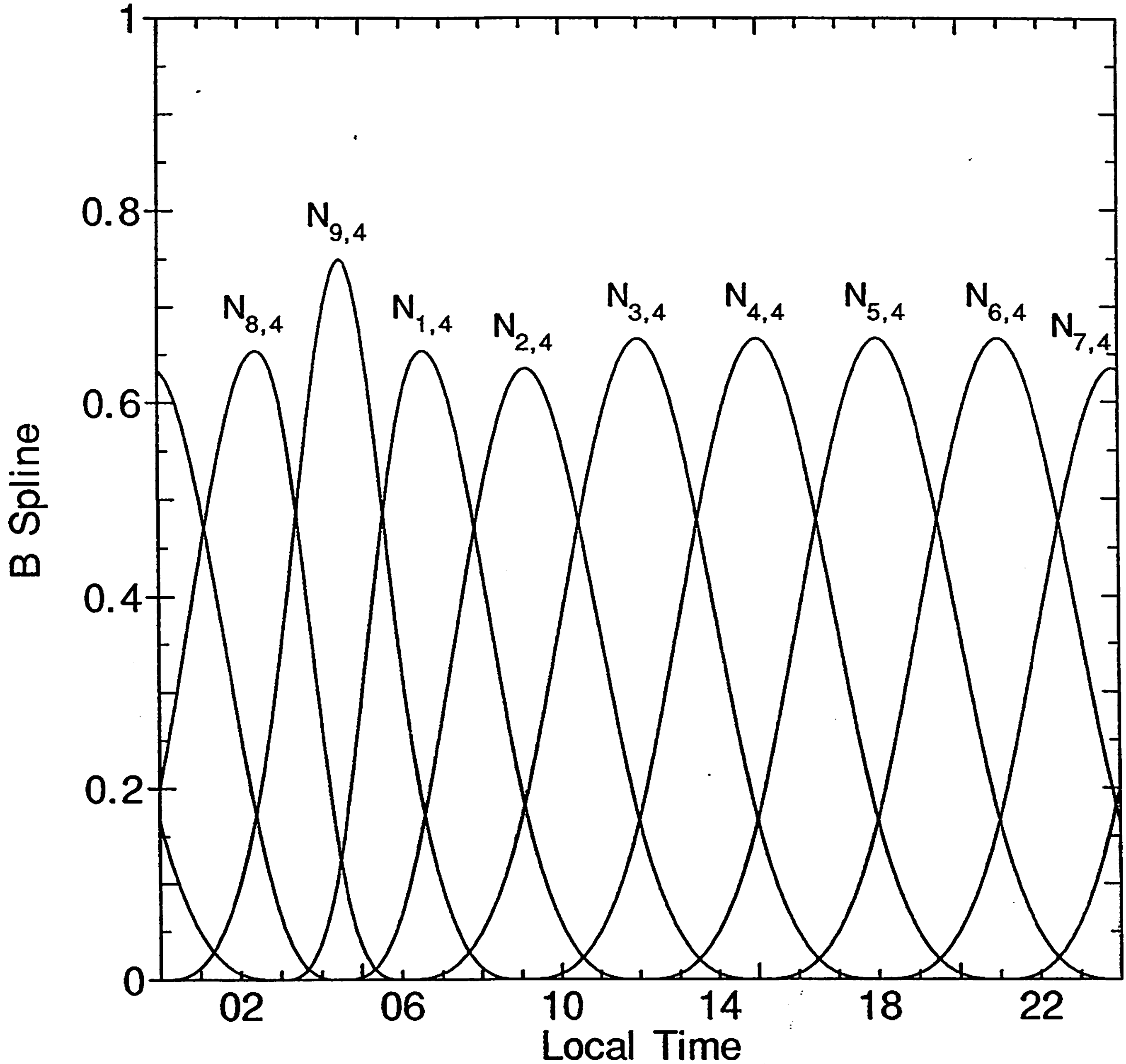
$$U(W) = 2.9\ x10^{9}\ \ AE\ (nT)$$



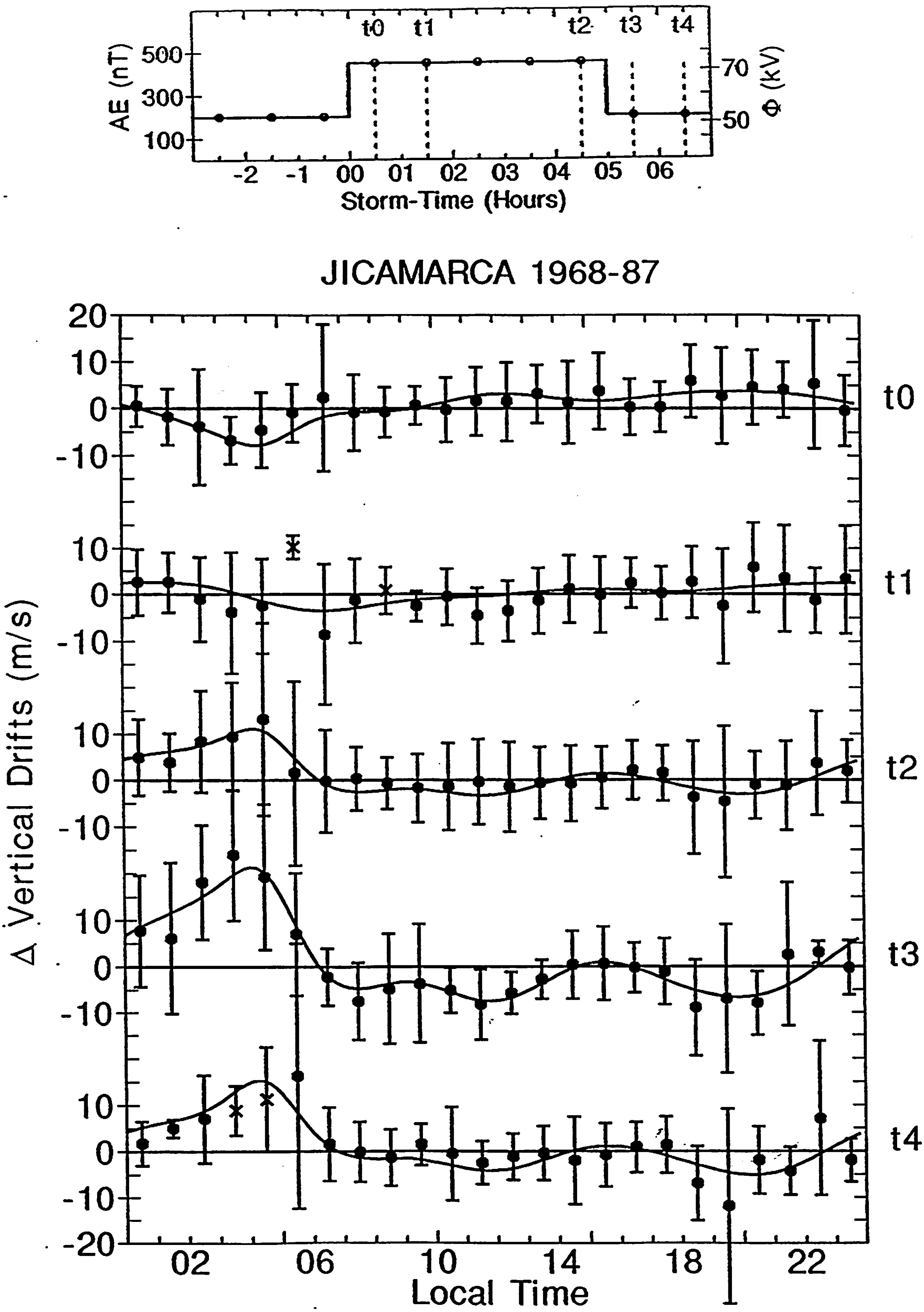
Initial study [Fejer and Scherliess, GRL 1995]

$$\Delta V(t) = \sum_{i=1}^{9} \left[\underbrace{a_{i,1}\, \Delta AE(t) + a_{i,2}\, \Delta AE(t-1\text{hr})}_{\text{Magnetospheric dynamo effects}} \right.$$

$$\left. + \underbrace{a_{i,3}\, \overline{AE}^{*}(2-4\text{hrs})}_{\text{Ionospheric Storm Time Dynamo effects}} \right] N_{i,4}(t)$$



1
0.8
0.6
0.4
0.2
0
B Spline
N9,4
N8,4
N1,4
N2,4
N3,4
N4,4
N5,4
N6,4
N7,4
02
06
10
14
18
22
Local Time



Fejer and Scherliess, 1995

Equatorial Zonal Electric Field (Vertical Plasma Drift)

Empirical Storm Time Model

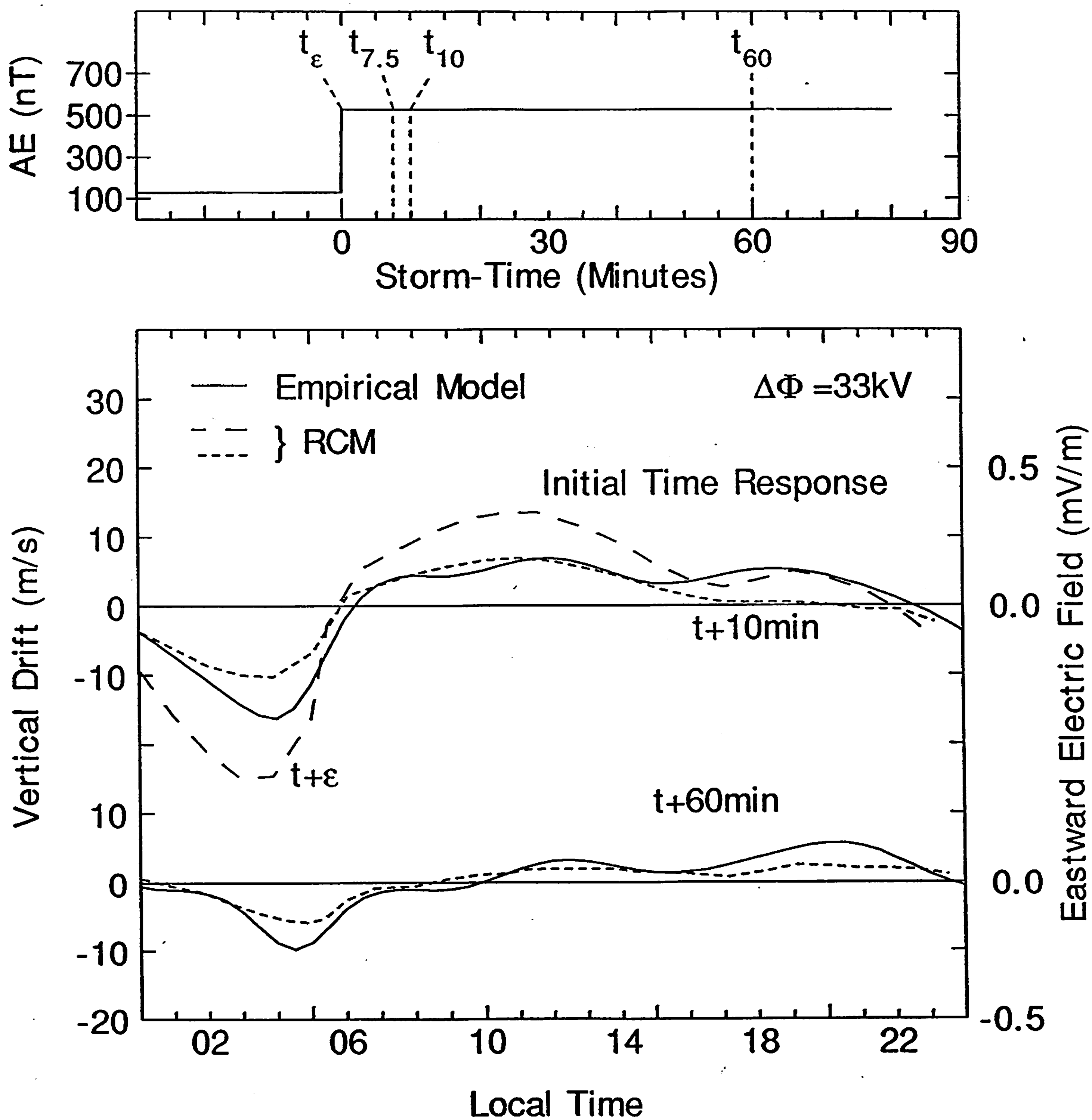
- **based on about 15000 measurements**
- **based on 9 normalized cubic B-splines to describe local time dependence**
- **Model can be expressed as:**

$$v(t) = \sum_{i=1}^{9} [\underbrace{a_{i,1}\Delta AE(t-7.5m) + a_{i,2}\Delta AE(t-30m) + a_{i,3}\Delta AE(t-75m)}_{\text{Prompt Penetration}}$$

$$+ \underbrace{a_{i,4}AE^*(2-6h) + a_{i,5}\alpha AE^*(7-12h) + a_{i,6}\beta AE^*(22-28h)}_{\text{Disturbance Dynamo}}]\underbrace{N_{i,4}(t)}_{\text{Splines}}$$

α, β } **short-long term interference parameters**

Prompt Penetration Electric Fields

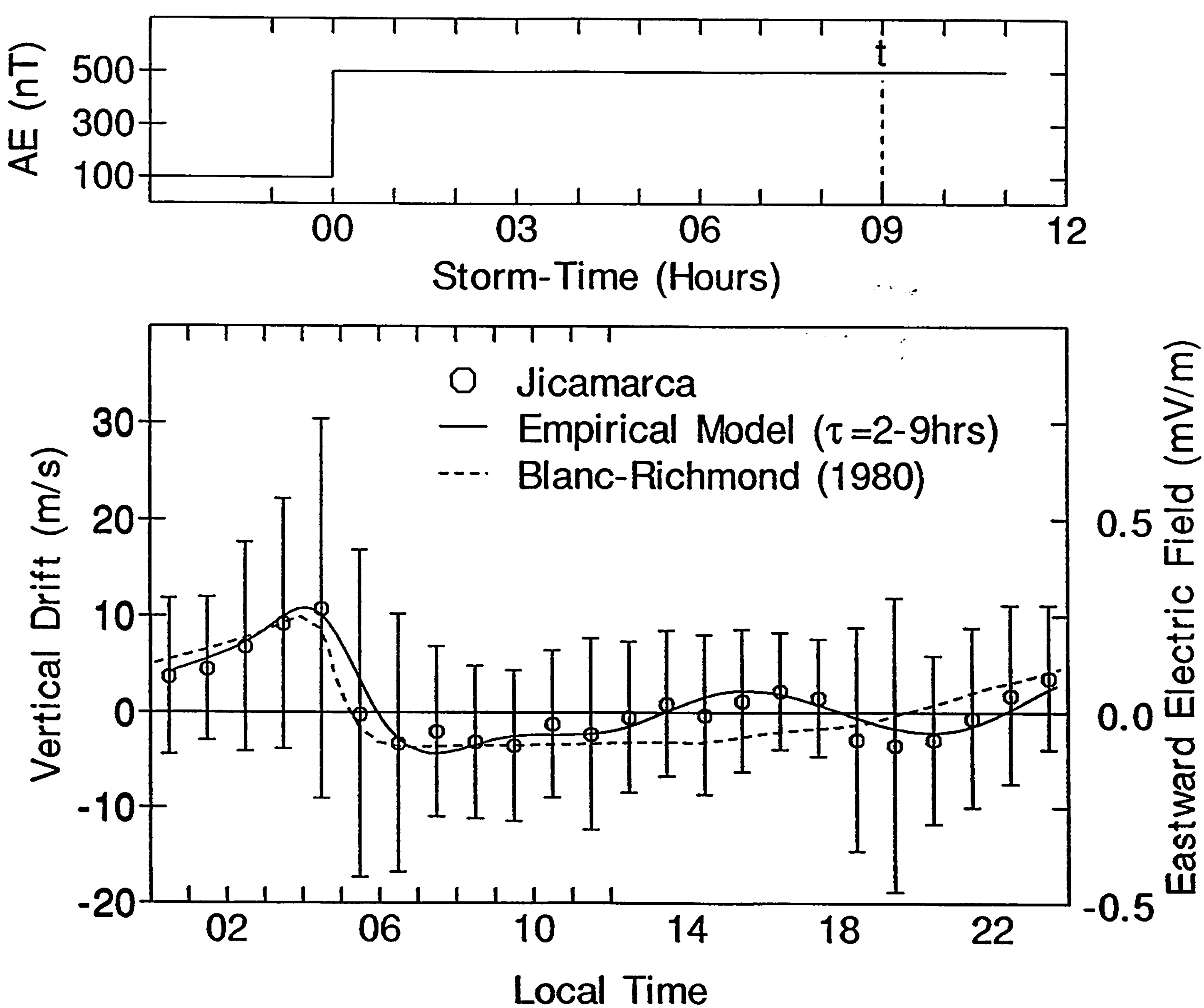


Fejer and Scherliess, 1996

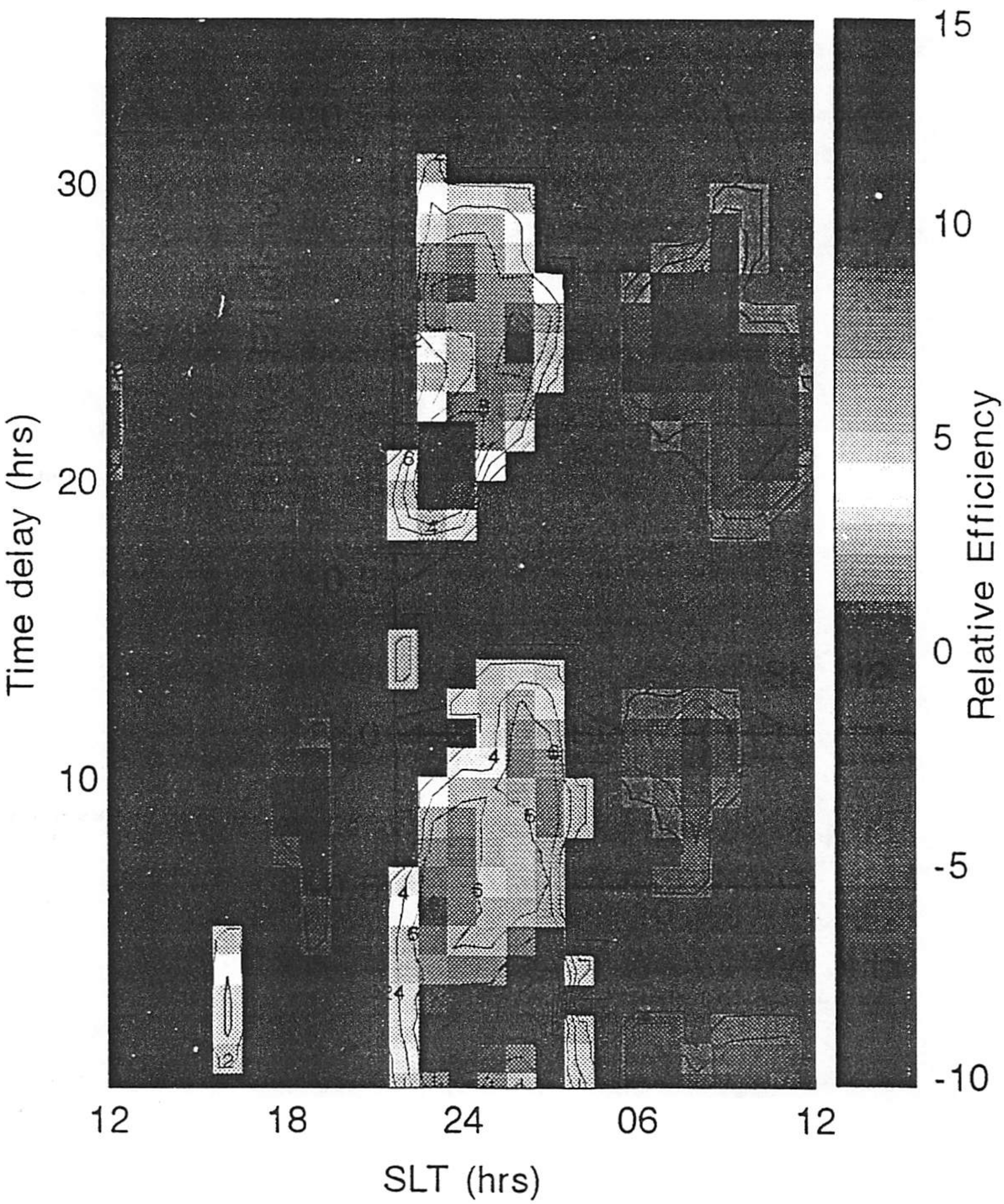
Empirical and Theoretical Storm-Time Dynamo Model Results

AE(1-9h) = 400 nT

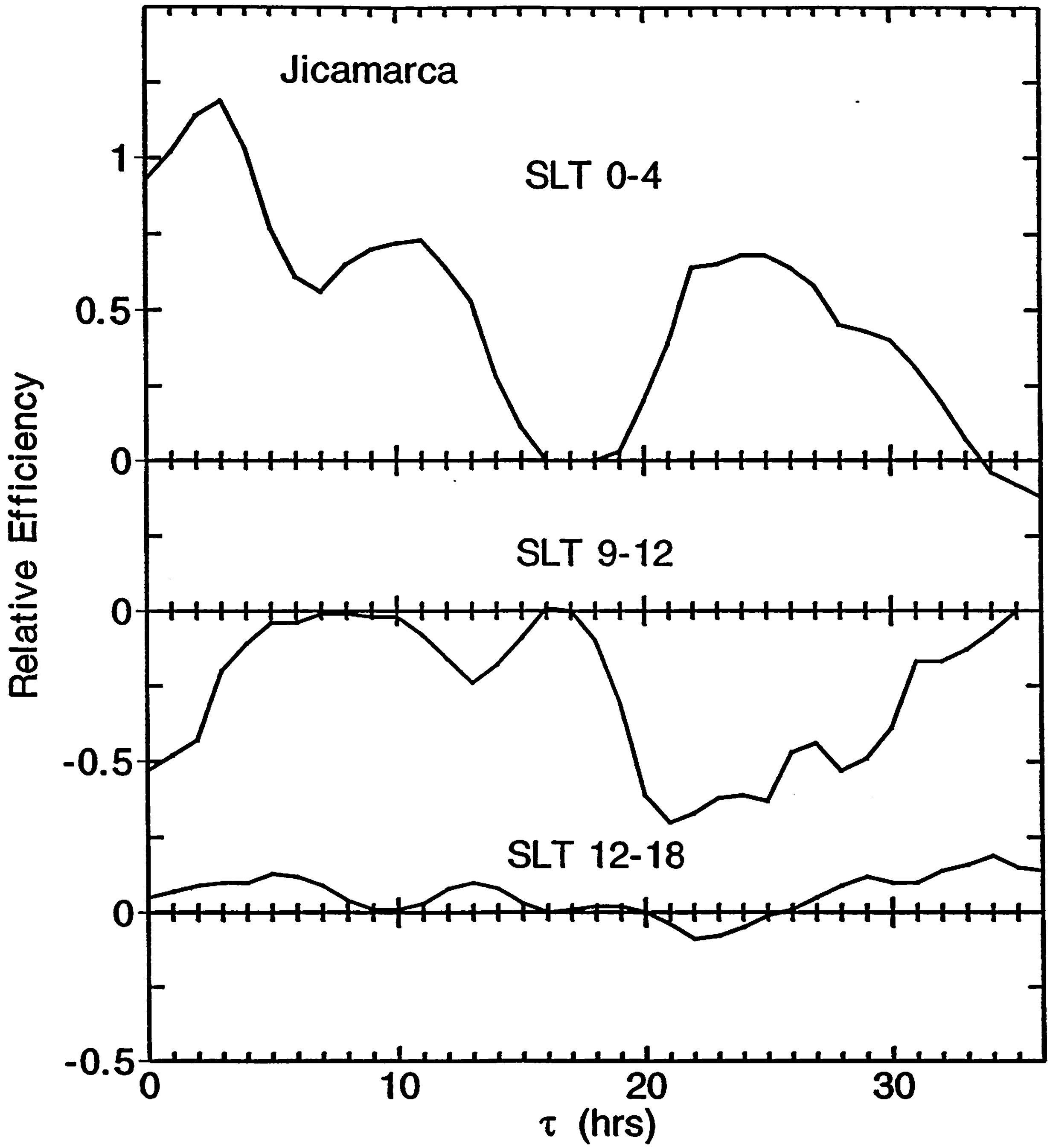
U(W) = $1.2 \cdot 10^{11}$ W



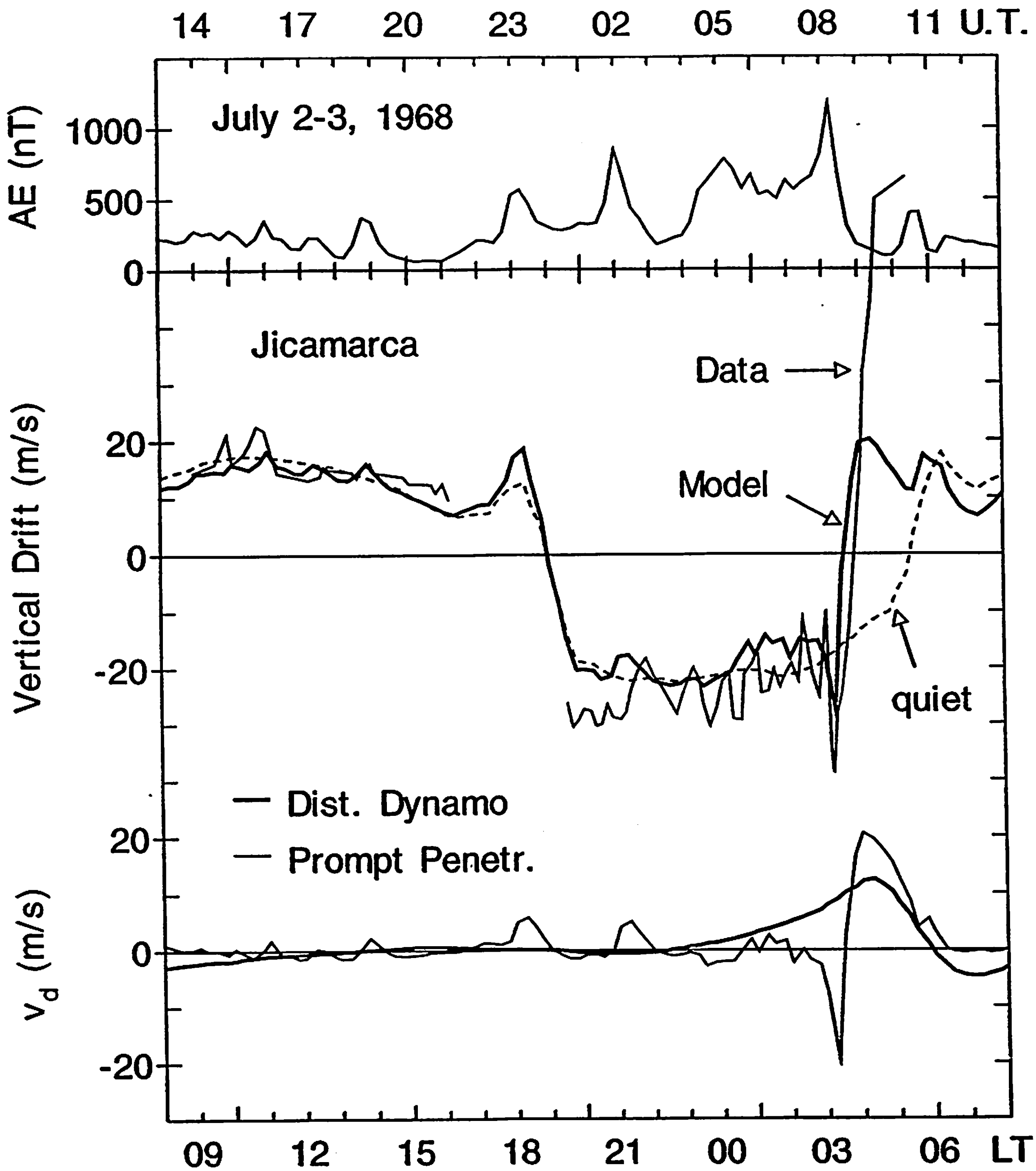
Scherliess and Fejer, 1996



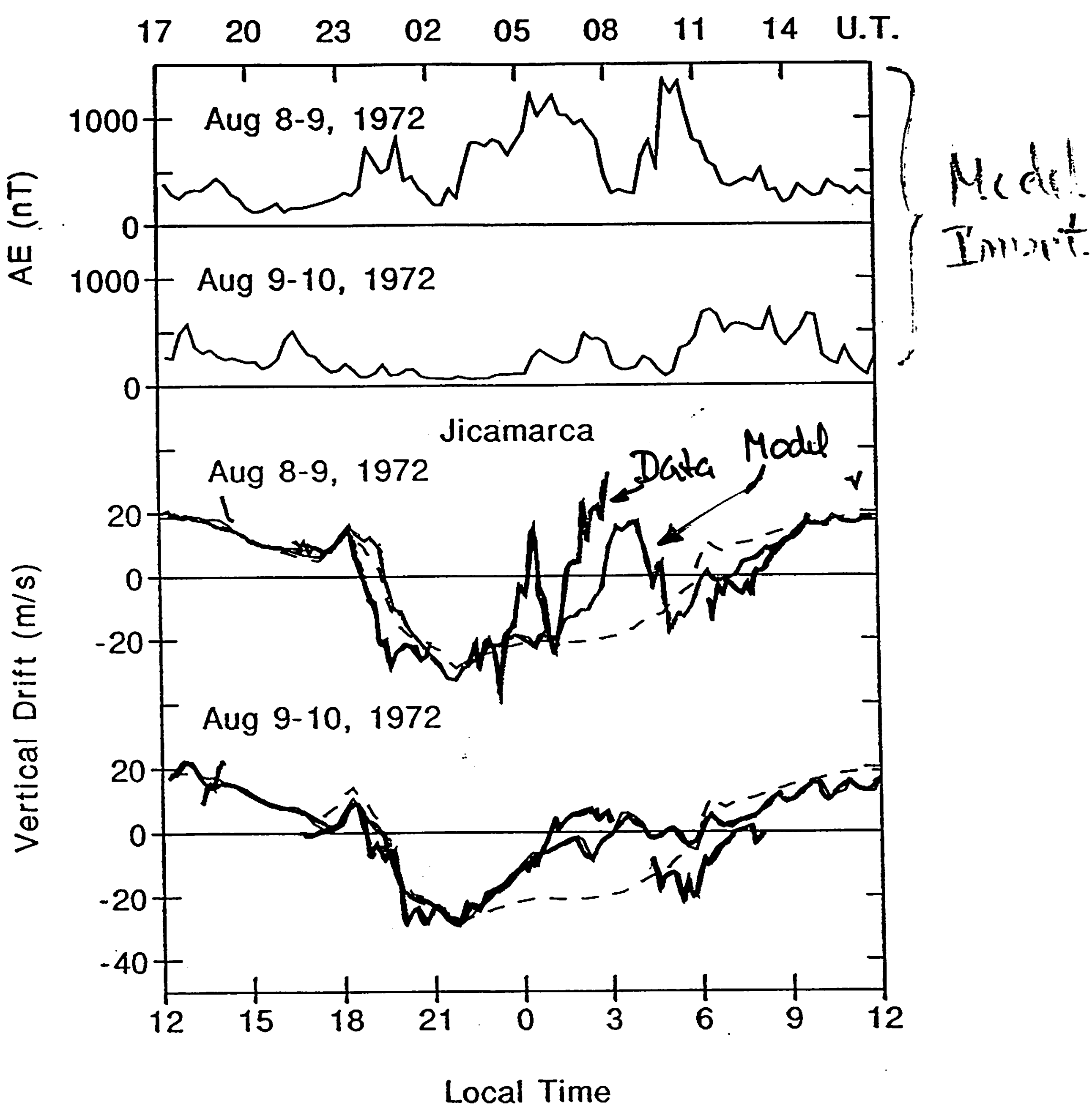
Scherliess and Fejer, 1996



Scherliess and Fejer, 1996



Fejer and Scherliess, 1996



Scherliess and Fejer, 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 satelite 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.