Measuring electron upflow in the polar cap

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IGF 2014

XIV INTERNATIONAL GIRO FORUM · 20–23 MAY

Outline

- Introduction/Background
- Measurements
- Method: Derivation of upflow velocity
- Results
- Conclusion

INTRODUCTION

Rationale

The F2 topside and plasmasphere dominate TEC.

Objectives

1. Develop an empirical electron upflow velocity distribution model in the polar cap ionosphere.

2. Develop a global empirical model of electron density distribution from the F2 peak to several Earth radii.

N_e and electron upflow in the polar cap

- The electron density (N_e) distribution in the polar cap depends largely on
  - the distribution of the electron velocity, which controls the upflow/outflow of charged particles.

- Plasma upflow/outflow at high latitudes plays a vital role in the dynamics of the magnetosphere.

MEASUREMENTS

Database

ISIS 2 and IMAGE/RPI electron density profiles.

Profile Measurements:

IMAGE/RPI

Reinisch et al., Plasma Density Distribution Along the Magnetospheric Field: RPI Observations from IMAGE, *Geophys. Res. Lett.*, 28, 24, December 15, 2001.

Huang et al., Developing an empirical density model of the plasmasphere using IMAGE/RPI observations, *Adv. Space Res., 33*, 829-832, 2004.

Nsumei et al., Polar cap electron density distribution from IMAGE/RPI measurements: The relative importance of solar illumination and geomagnetic activity, *J. Geophys. Res., 113*, A01217, doi:10.1029/ 2007JA012566, 2008.

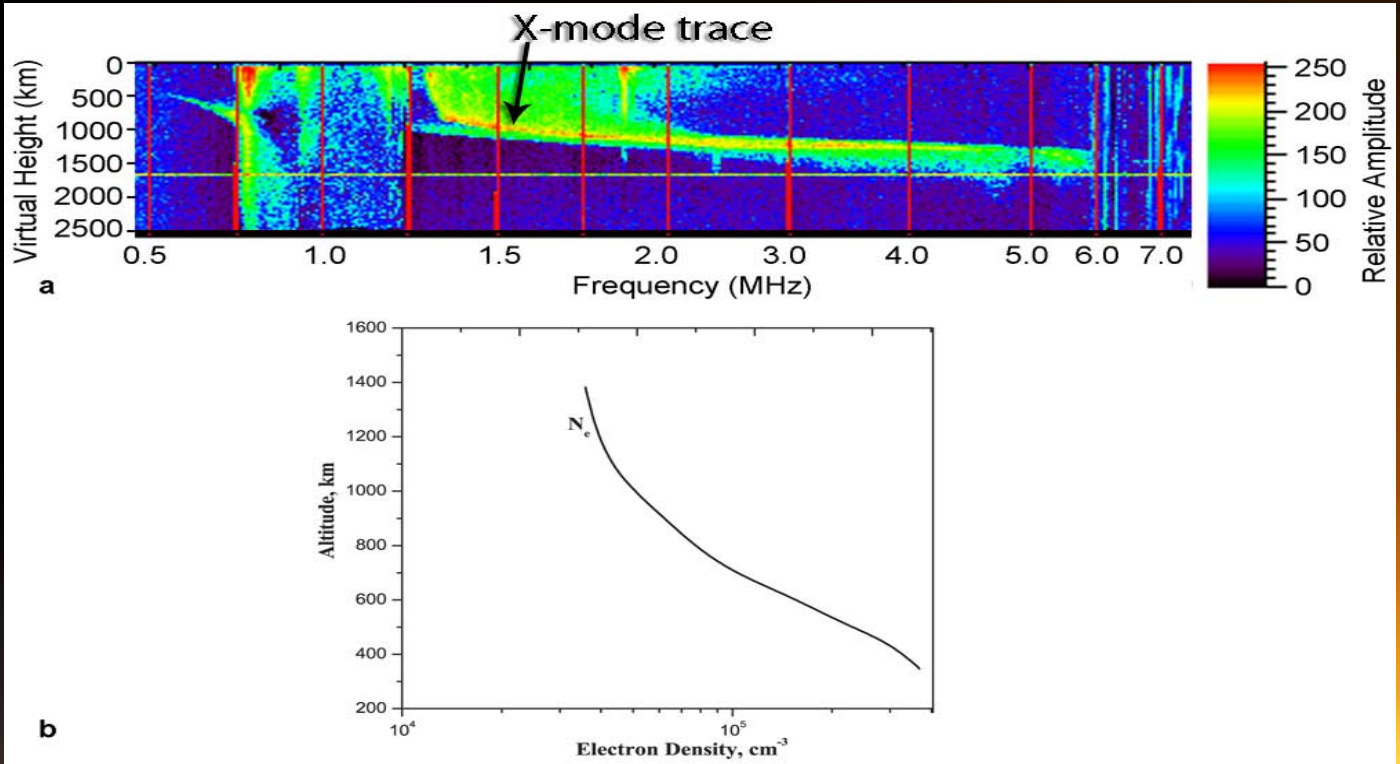
Profile Measurements (contd.)

- **ISIS 2**
  Huang and Reinisch, Electron Density Profiles of the Topside Ionosphere, Annali di Geofisica, 45 (1), 125-130, 2002.

- **Nsumei et al.,** Ionospheric electron upflow in the polar region: Derived from ISIS 2 measurements, *J. Geophys. Res.*, *113*, A03312, doi:10.1029/2007/2007JA012567, 2008.

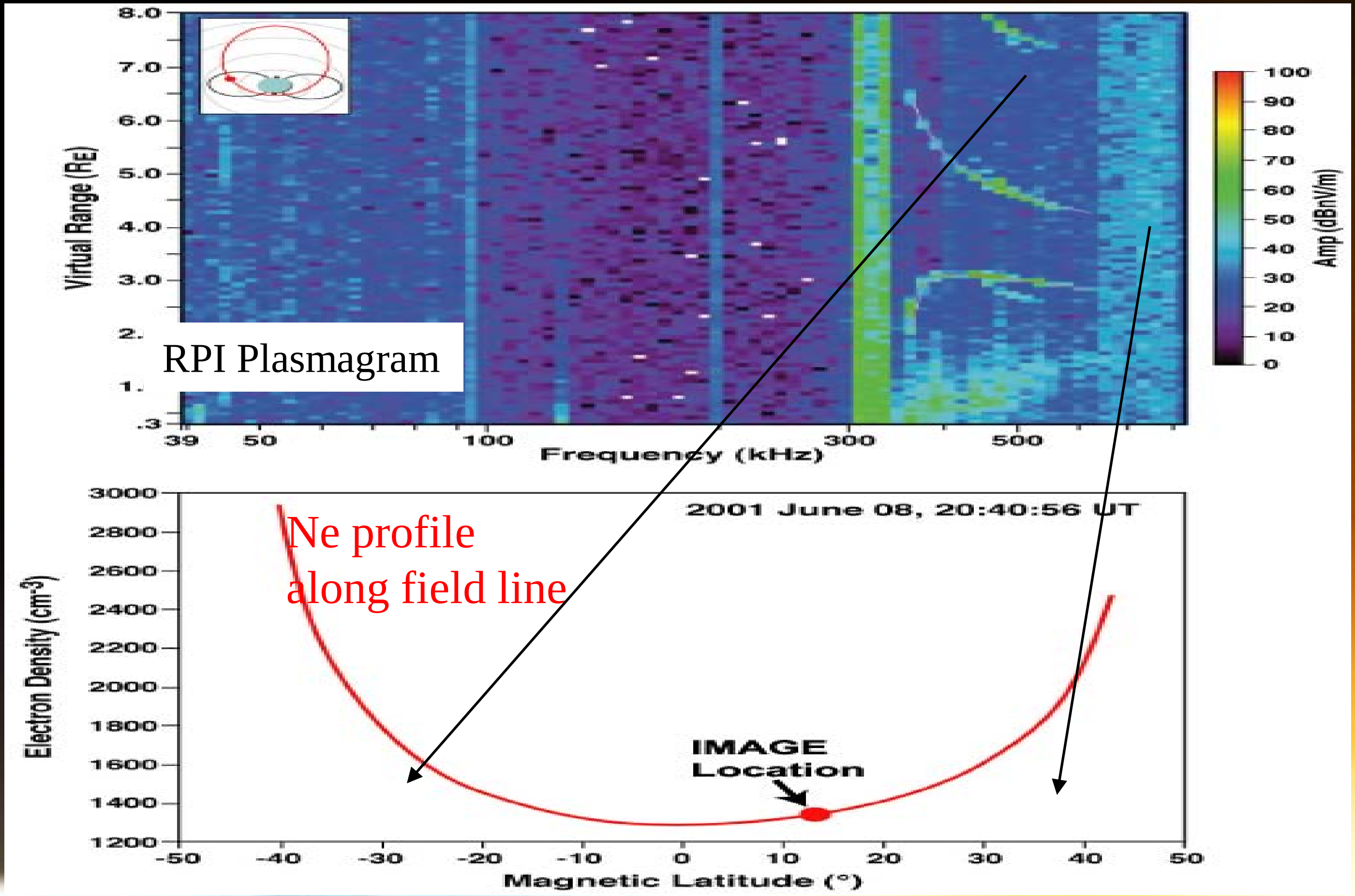
- **Reinisch et al**., Modeling the F2 topside and plasmasphere for IRI using IMAGE/RPI, and ISIS data, *Adv. Space Res*., *39*, 731 – 738, 2007.

ISIS-2 ionograms

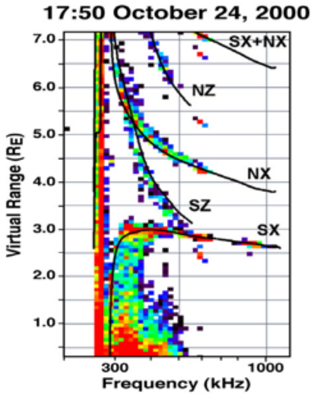


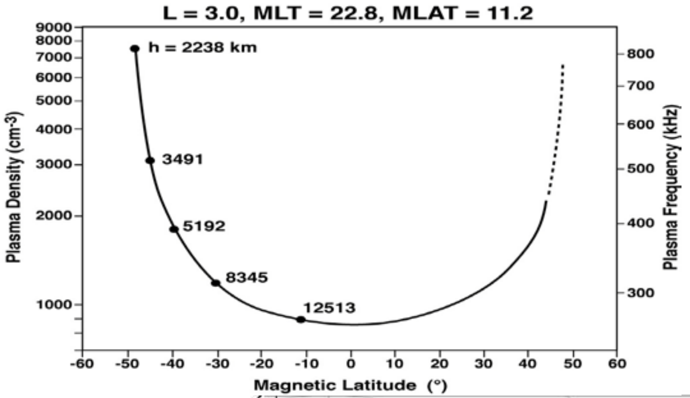
Huang and Reinisch [2002]

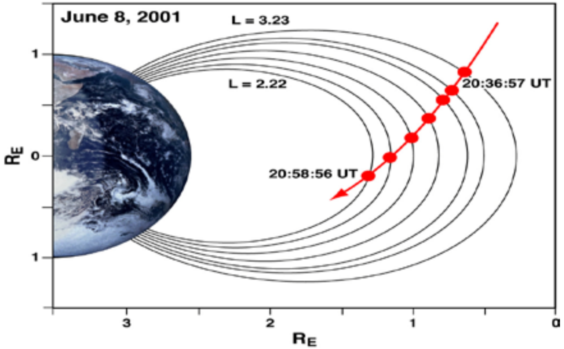
N_e Profiles in Magnetosphere

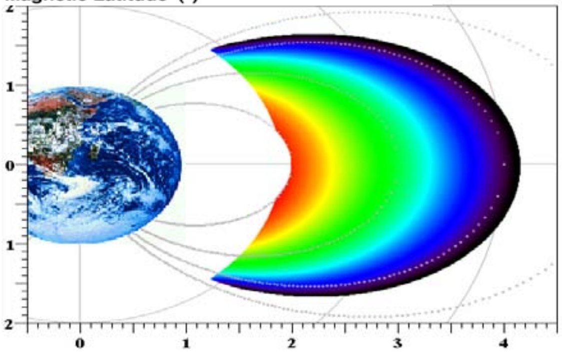


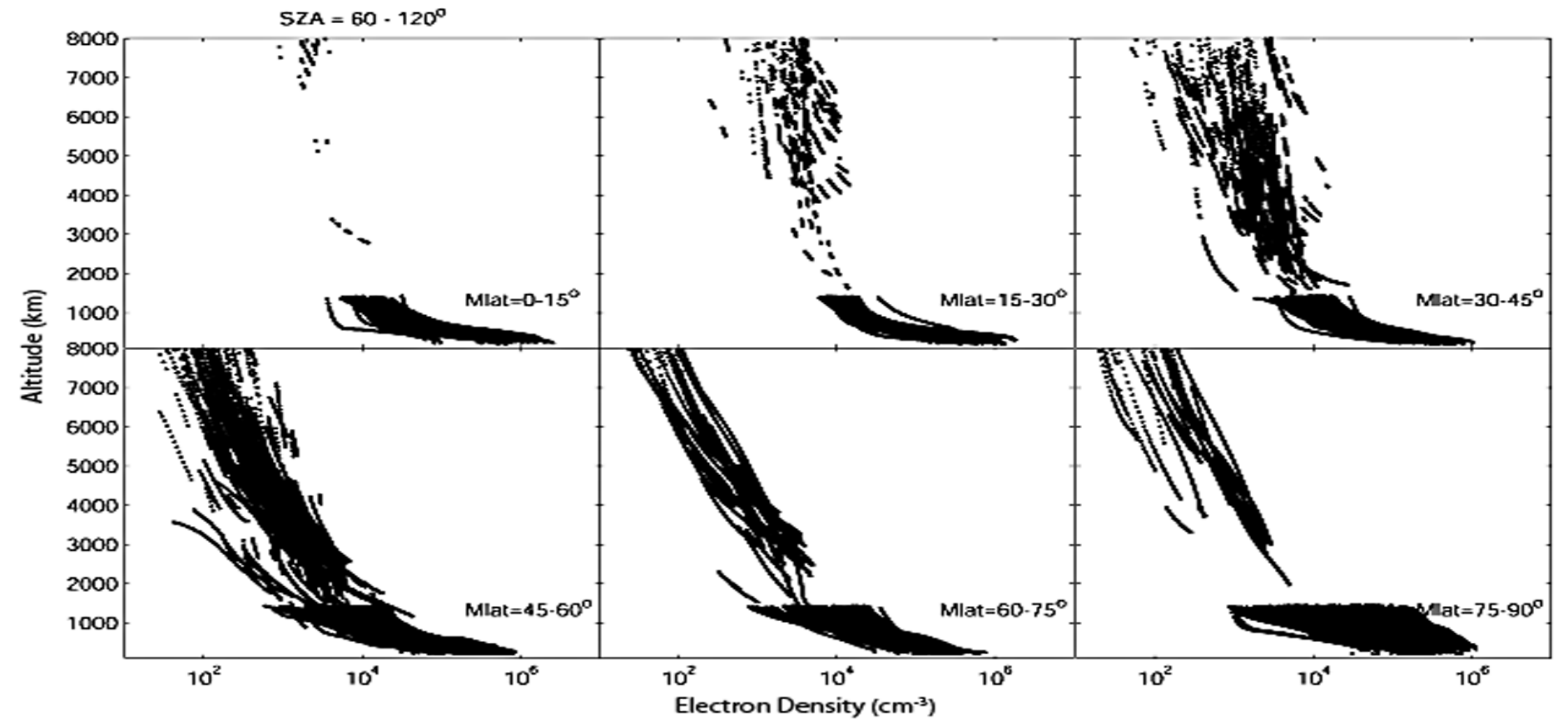
IMAGE/RPI $N_e(s)$ along Fieldline









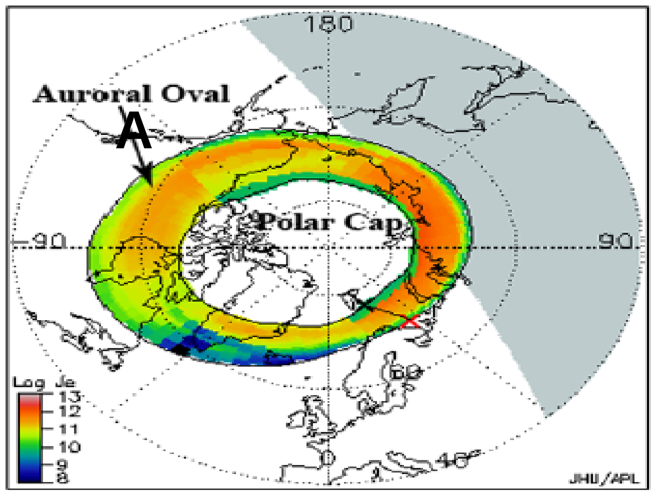


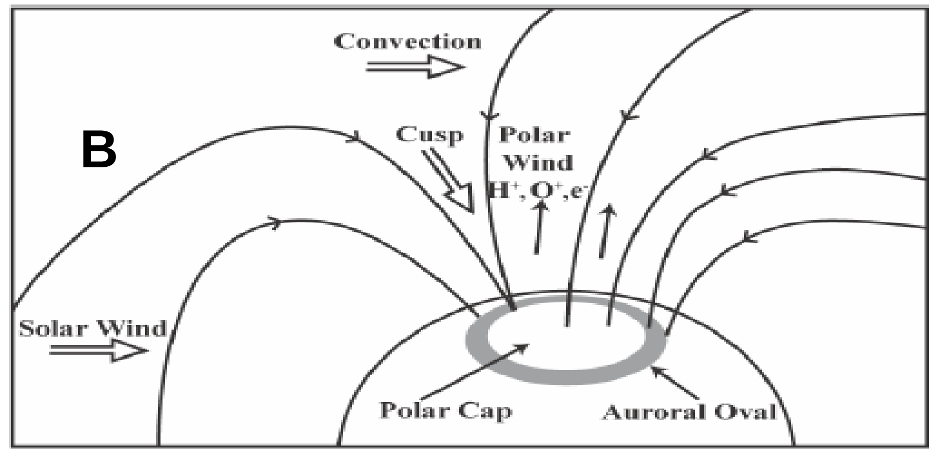
SZA = 60 - 120°
Altitude (km)
8000
7000
6000
5000
4000
3000
2000
1000
Mlat=0-15°
Mlat=15-30°
Mlat=30-45°
Mlat=45-60°
Mlat=60-75°
Mlat=75-90°
10^2
10^4
10^6
Electron Density (cm⁻³)

METHOD

Derivation of Electron Upflow velocity

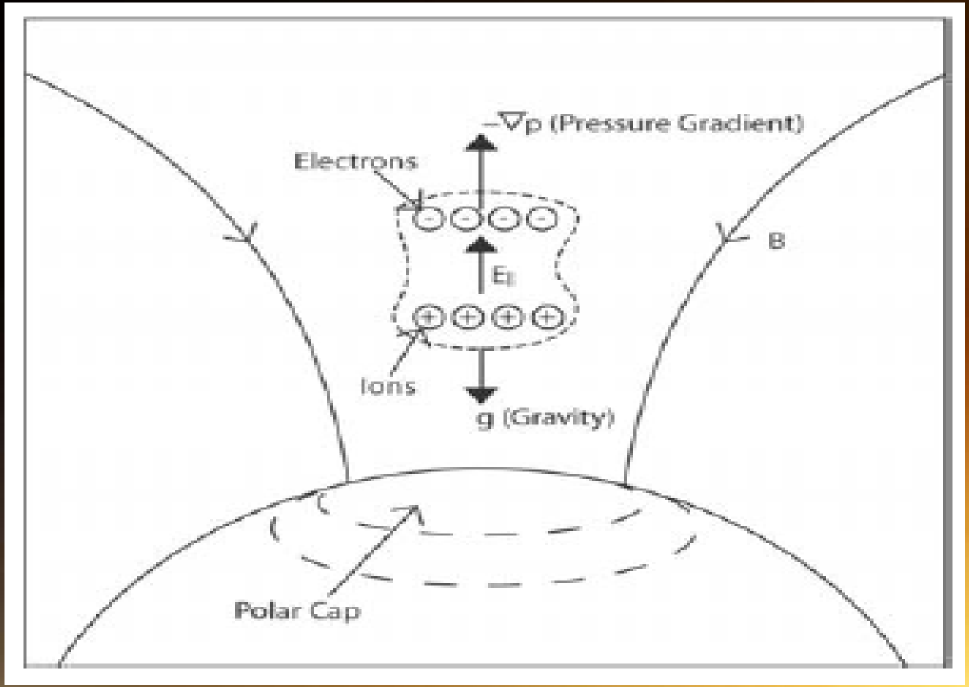
POLAR CAP





(A) Auroral oval (DMSP measurements) and (B) High latitude region and plasma transport (adapted from Tu, 2004)

Major forces acting on plasma species in the polar cap (open field region).

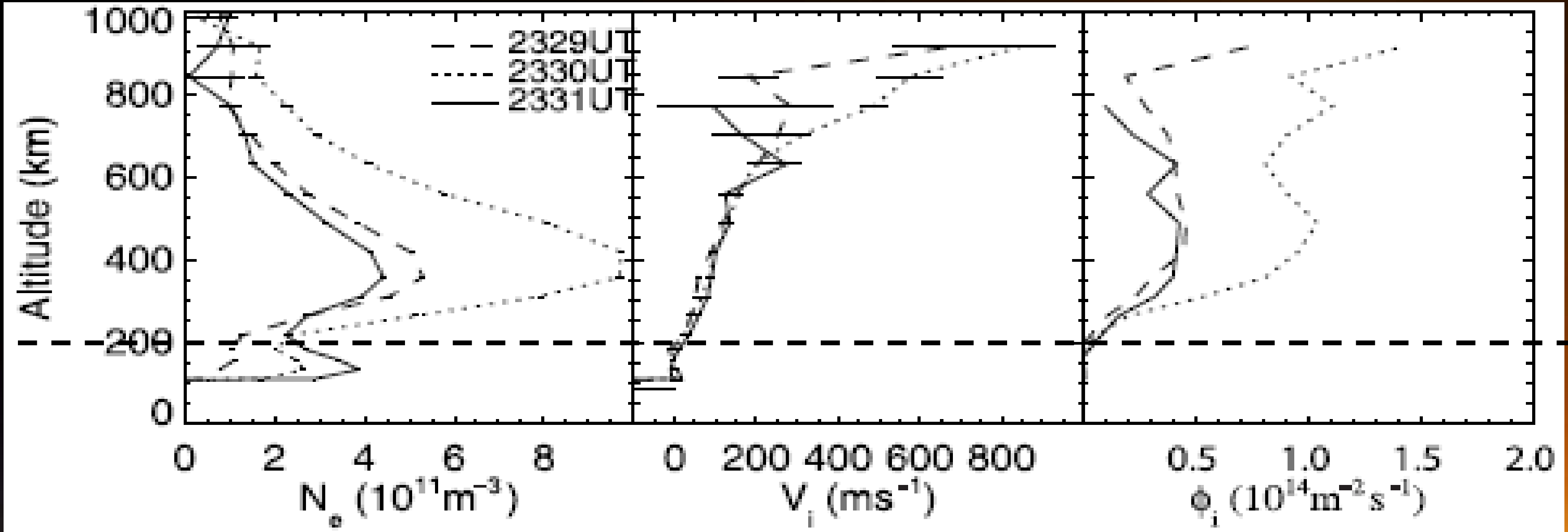


POLAR CAP (EXCLUSIONS)

- Particle heating and acceleration associated with strong field-aligned current, waves and parallel electric field observed in the auroral region NOT considered.

- Cleft ion fountain convected from the cusp/auroral region into the polar cap may affect the polar cap N_e and electron/ion velocities.

SEMETER ET AL.(2003): ION UPFLOW AT THE POLAR CAP BOUNDARY



N_e, V_i, and ϕ_i at one-minute resolution for three intervals: before (dashed), during (dotted), and after (solid) transit of the F-region patch.

SEMETER ET AL.(2003): ION UPFLOW AT THE POLAR CAP BOUNDARY

- The Figure shows one-minute averages of N_e, V_i, and ϕ_i for three intervals:
  - (1) 23:28:30–23:29:30 (before the patch),
  - (2) 23:29:30–23:30:30 (during the patch), and
  - (3) 23:31:30– 23:32:30 (after the patch).
- Note that N_e and ϕ_i both increased by a factor of 2 above 200 km during interval (2).
- The constancy in upflow velocity means that upward ion flux was directly controlled by F-region density for this event.

Derivation of Upflow Velocity

- The electron upflow velocity in the topside ionosphere is derived from the N_e profile using the mass conservation equation.

- The velocity profiles are calculated using the measured ISIS-2 electron density profiles and neutral species density profiles from the MSIS model.

Deriving velocity information from N_e profiles

The electron continuity equation for field-aligned transport along a strong magnetic field $\boldsymbol{B}$ is given by [e.g., Gombosi, 1998]

$$\frac{\partial N_e}{\partial t} + B\frac{\partial}{\partial s}\left(\frac{N_e}{B}u_e\right) = P_e - L_e N_e$$

In the polar region at low altitudes, $\boldsymbol{s} \approx \boldsymbol{r}$ (radial distance). In slow-time varying processes, assuming a dipole magnetic field:

$$\left(N_e u_e r^3 - N_{eb} u_{eb} r_b^3\right) = \int_{r_b}^{r} r^3 \left(P_e - L_e N_e\right) dr$$

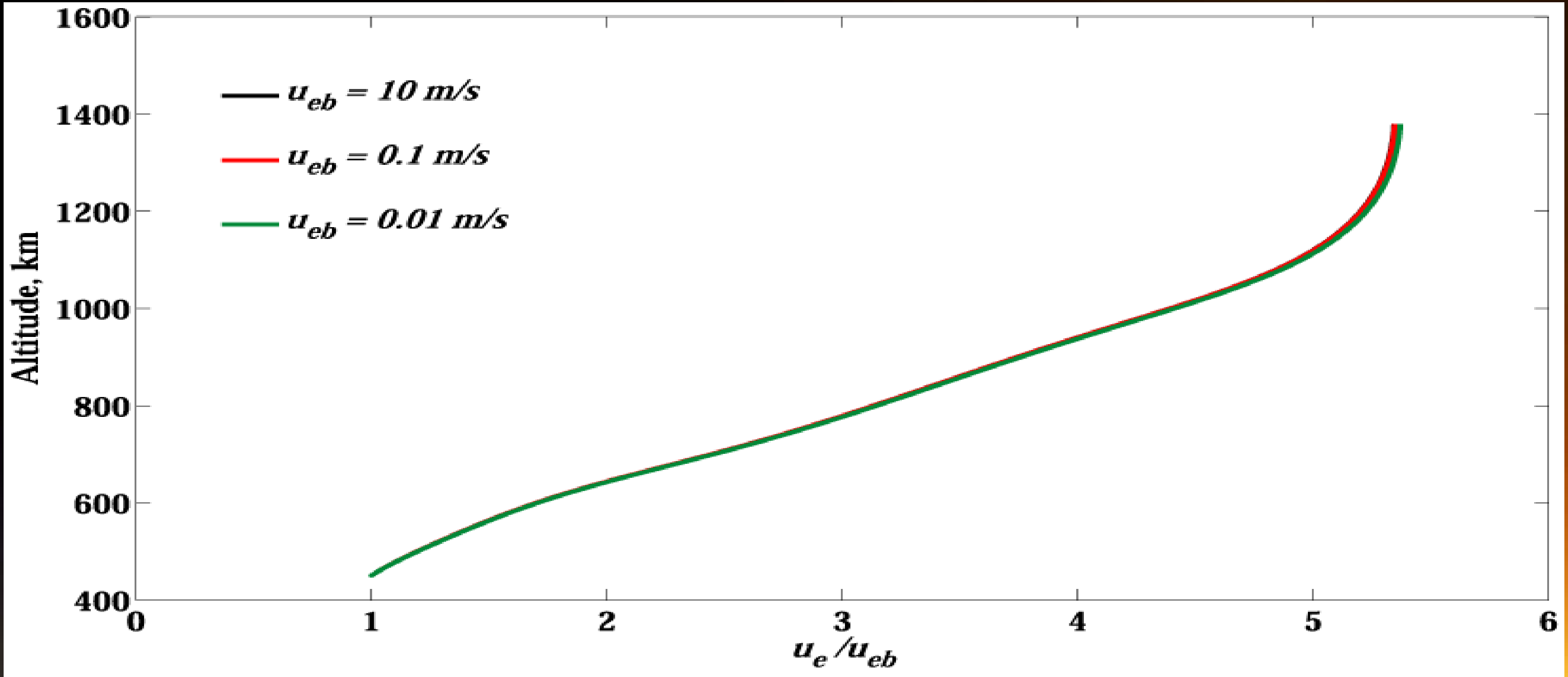
$$\frac{u_e(r)}{u_{eb}} = \frac{N_{eb} r_b^3}{N_e(r) r^3} + \frac{\int_{r_b}^{r} r^3 \left(P_e - L_e N_e\right) dr}{N_e(r) u_{eb} r^3}$$

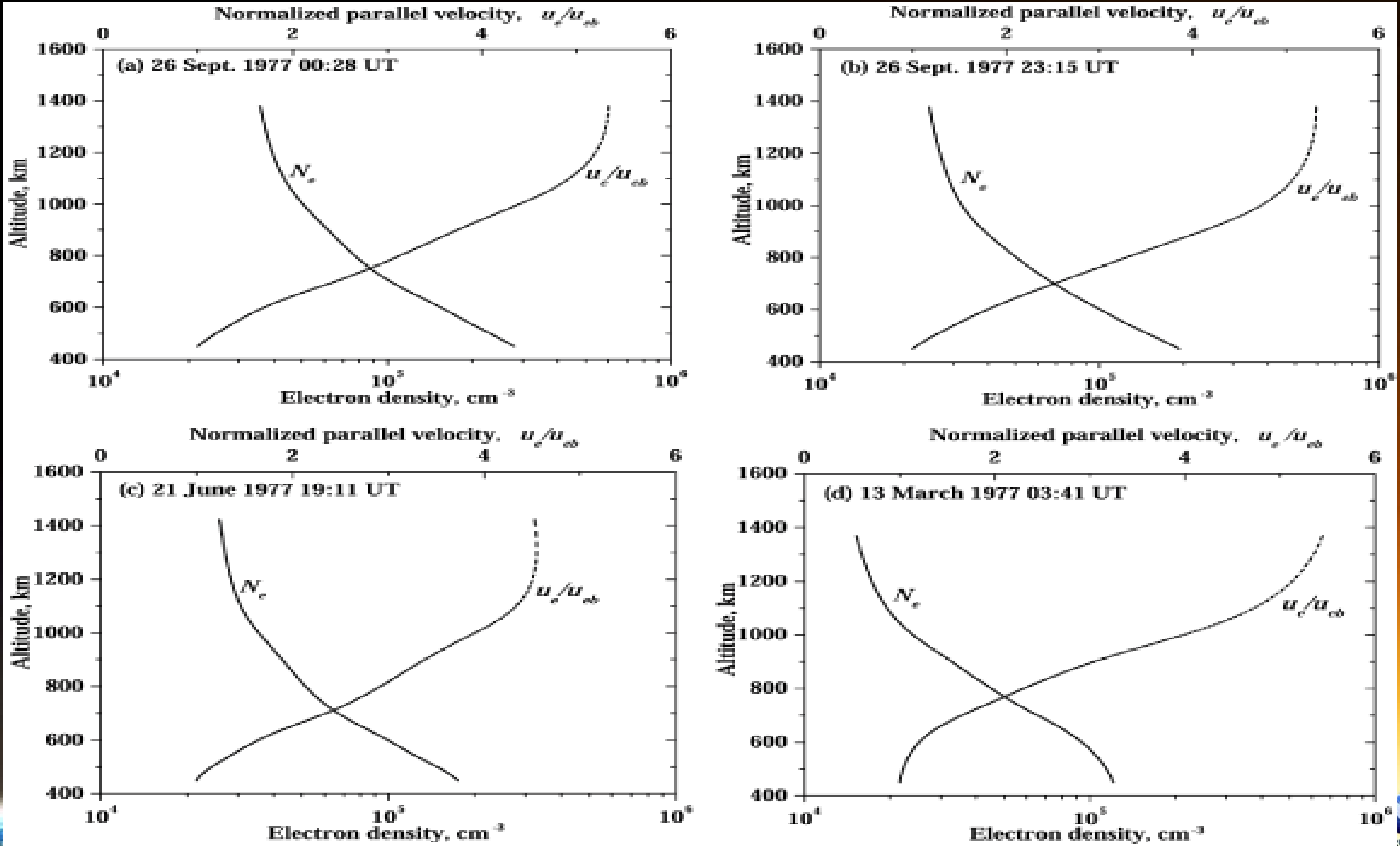
Approximations

- Base height, h_b = 450 km.
- Base velocity, u_{eb} = 0.1 km/s (A few hundred km above hmF2, velocity is subsonic, Loranc et al., 1991).
- Neutral species from MSIS model.
- Model electron temperature profiles [Gulyaeva and Titheridge, 2006] for Polarization electric field calculations.

RESULTS

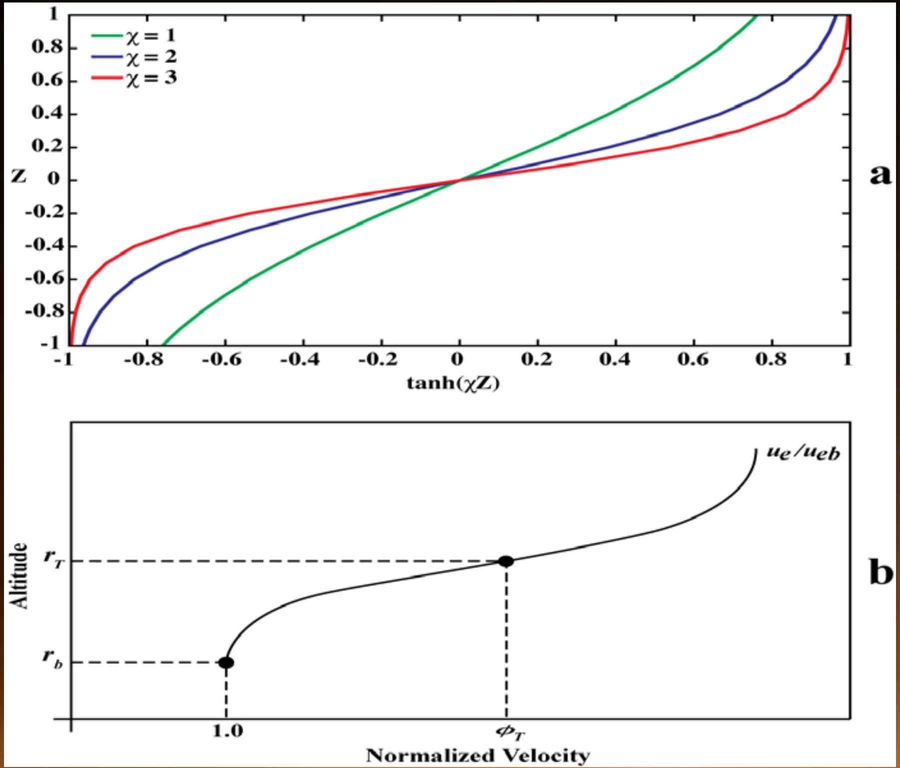
electron velocity for different base





Normalized parallel velocity, u_e/u_{eb}
(a) 26 Sept. 1977 00:28 UT
(b) 26 Sept. 1977 23:15 UT
(c) 21 June 1977 19:11 UT
(d) 13 March 1977 03:41 UT
Altitude, km
N_e
u_e/u_{eb}
Electron density, cm^{-3}

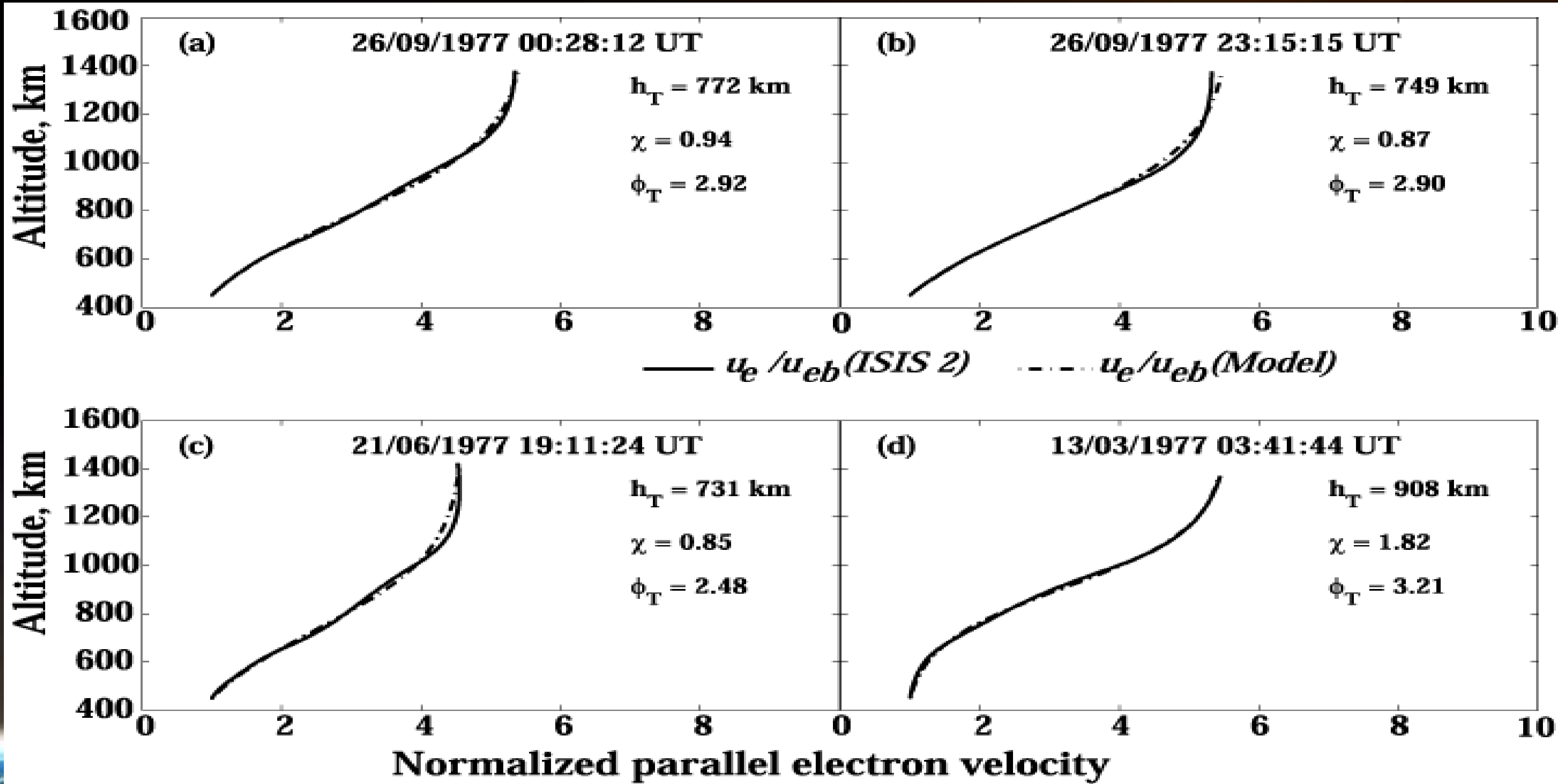
Parameterization of u_e



Model:

$$\phi_e(r) = \frac{u_e(r)}{u_{eb}} = \left\{ \phi_T + (1-\phi_T)\frac{\tanh[\chi(r-r_T)/(r_b-r_T)]}{\tanh\chi} \right\}$$

Fitting of Model Function

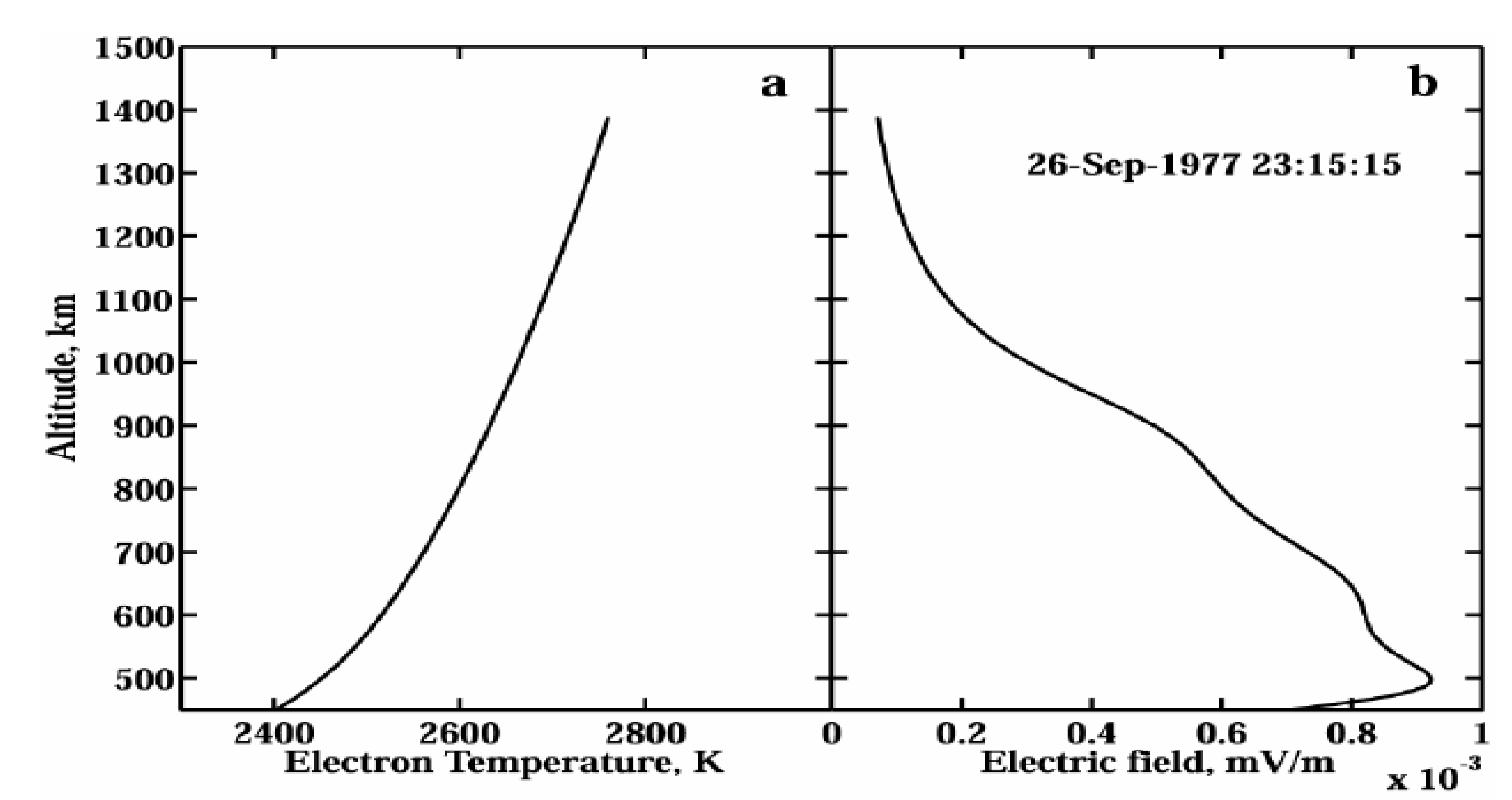


Parallel Electric Calculation

- From the steady-state momentum equation, the parallel electric field may be approxiated.

$$E_s = -\frac{K_B}{e}\left(\frac{dT_e}{dr} + \frac{T_e}{N_e}\frac{dN_e}{dr}\right) - \frac{m_e}{e}\left(\frac{d}{dr}\left(\frac{u_e^2}{2}\right) - g + \sum_{\xi} \nu_{ke}(\mathbf{u}_{\xi} - \mathbf{u}_e)\cdot\mathbf{r}\right)$$

(a) Electron temperature profile [Gulyaeva and Titheridge, 2006] (MLAT =87°) and (b), the calculated polarization electric field profile.



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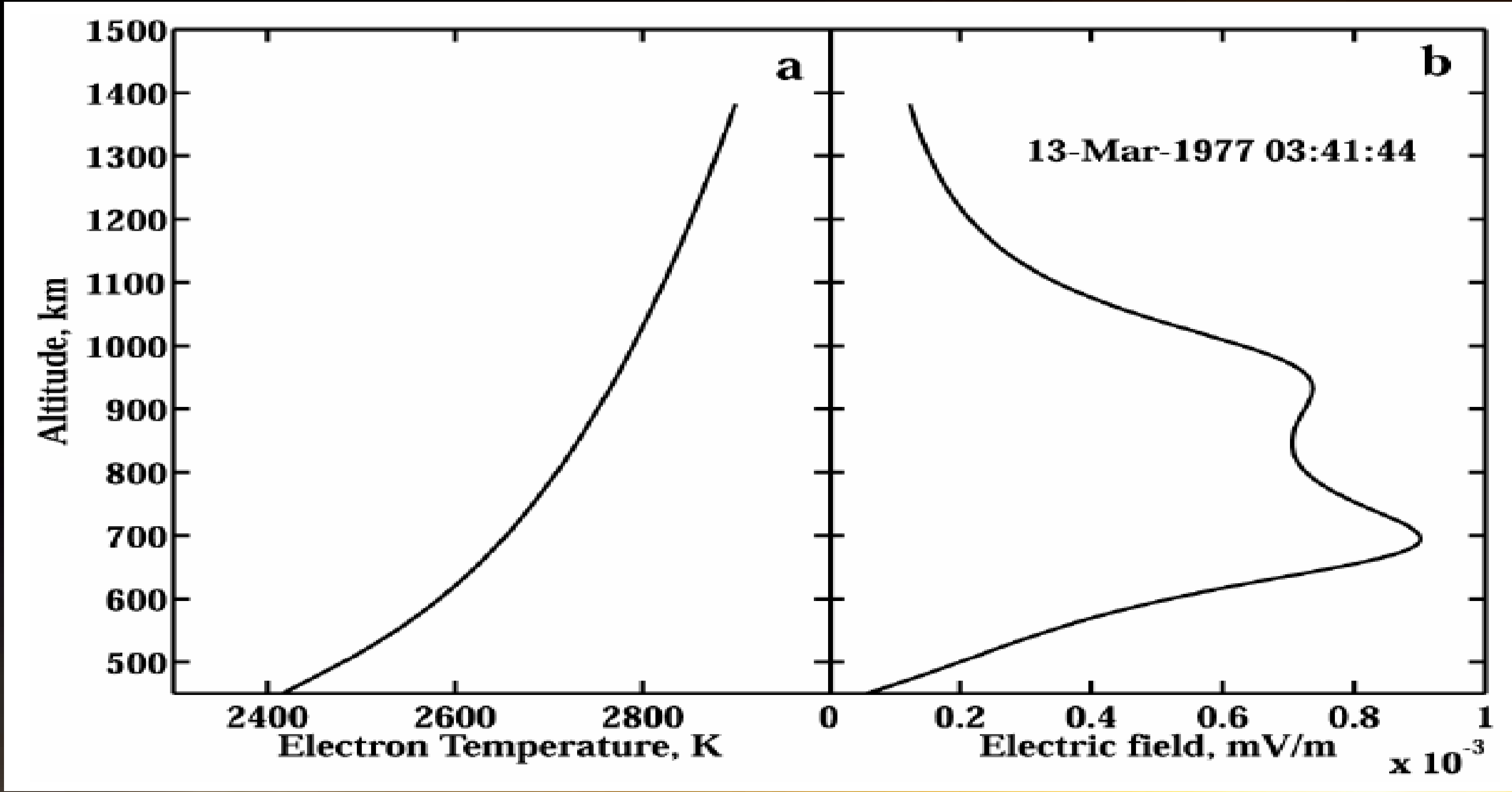
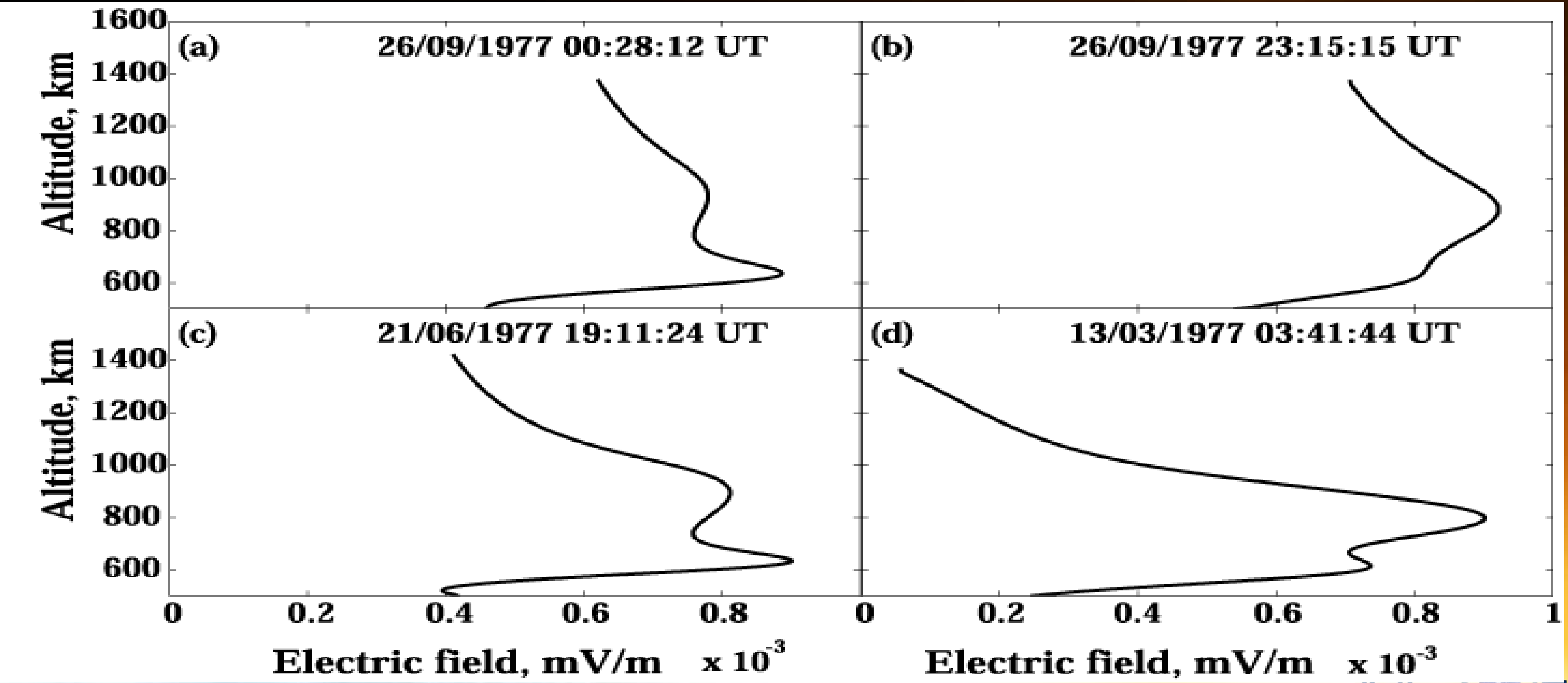

a
b
13-Mar-1977 03:41:44
Altitude, km
1500
1400
1300
1200
1100
1000
900
800
700
600
500
2400
2600
2800
Electron Temperature, K
0
0.2
0.4
0.6
0.8
1
Electric field, mV/m
x 10^-3

Polarization Electric Field



CONCLUSION

Summary

- The normalized parallel electron velocities profiles in the polar cap topside ionosphere has been calculated using measured ISIS 2 and MSIS neutral data.
- Three regions of acceleration identified:
  - a region of slow acceleration from hmF2 to about 150 km above it.
  - a region of fast acceleration from ~ 500 km to 1100 km, and
  - a region of weak acceleration above 1100 km.
- The polarization or ambipolar electric field as a function of altitude, which is the main driver of ion upflow has been estimated.

Acknowledgment

D. Bilitza for ISIS 2 data

Dalu

감사합니다

Gracias Danke Ευχαριστίες

Obrigado

THANK YOU

Köszönöm

Спасибо Dank

ありがとう

Tack Grazie 谢谢 Merci

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