

Ionospheric Response to Intense Interplanetary shocks

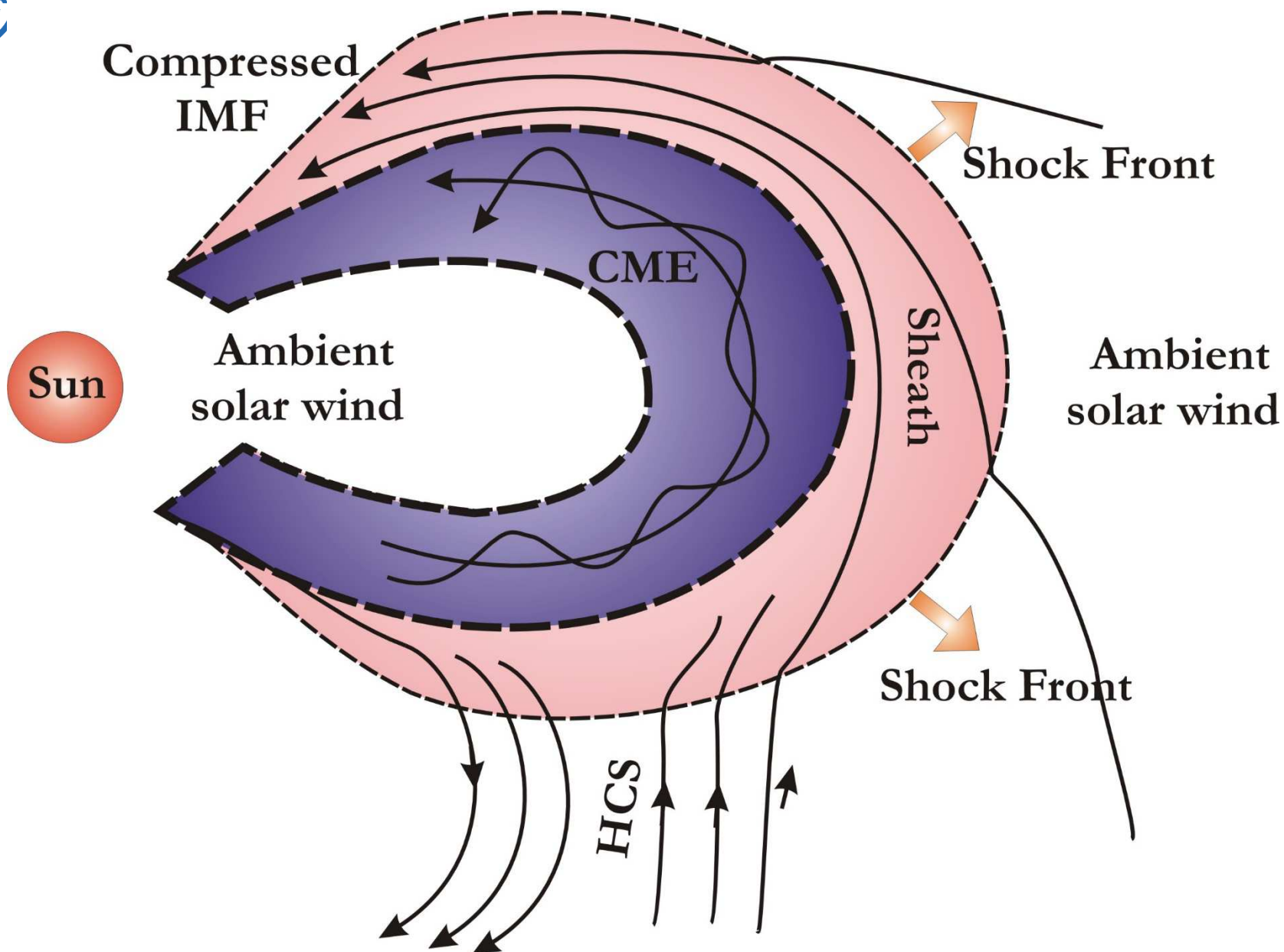
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Interplanetary Shock Structure



Penetration Electric Field Issues

“It should be noted that what is actually observed in the solar wind as well as in the magnetosphere and ionosphere is not the electric field E , but the plasma bulk flow velocity V . The electric field is in most cases inferred by the use of the MHD approximation $E = V \times B$.

The description in terms of E rather than V is, however, traditional and possesses some mathematical and conceptual advantages. For this reason, we refer to the electric field in this paper. It has been argued by Vasyliunas [2001, 2005a, 2005b] that in strictly physical terms, E is merely a consequence of V , the latter being determined by the stress acting on the plasma.”

Tsurutani et al, JGR 2008

Energy input from Solar Wind Ram Pressure -- Tsurutani and Gonzalez, 1995

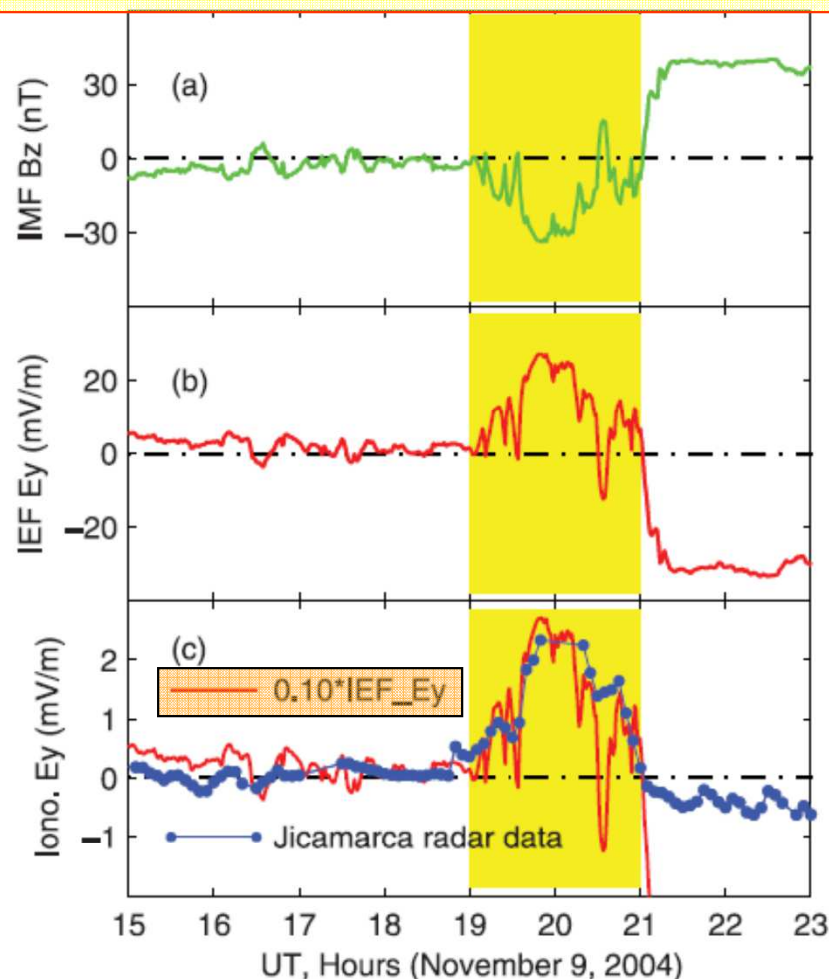
The amount of solar wind energy input into the magnetosphere/ ionosphere has been estimated to be

0.1 to 0.4% of the solar wind ram energy,

that is $1.0\text{--}6.3 \times 10^{20}$ erg/s

[Tsurutani and Gonzalez], 1995, Borovsky and Steinberg [2006]

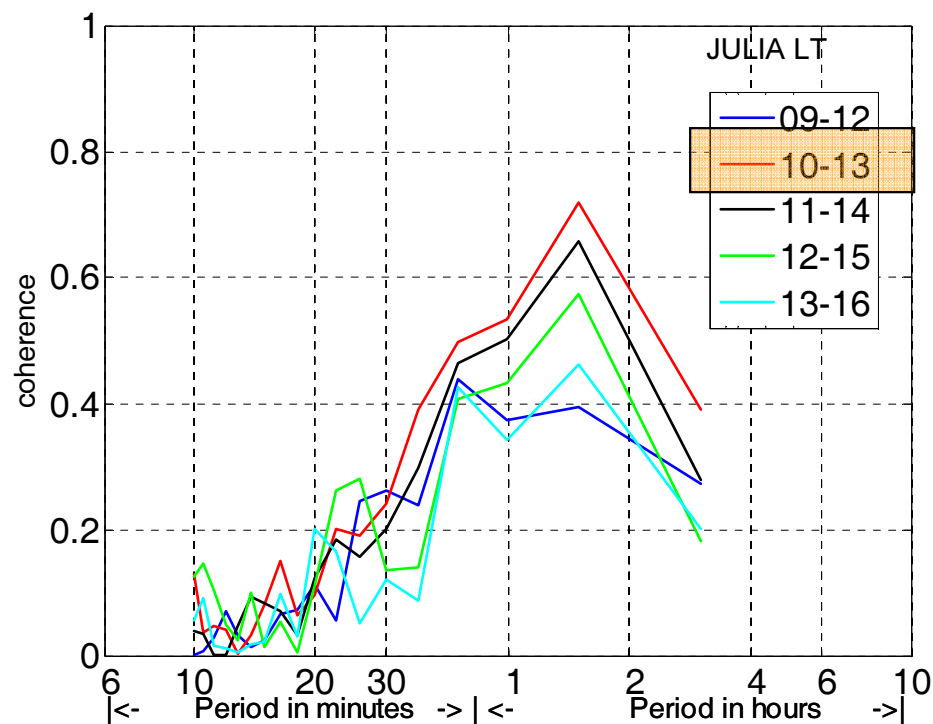
(1) IEF direct penetration -- Huang et al, 2002-2008



$$\Delta E_{y(\text{iono})} \approx 0.1 \times \Delta E_{y(\text{IEF})}$$

Figure 2. Penetration electric fields in the dayside equatorial ionosphere over 2 hours on 9 November 2004. From top to bottom are the IMF B_z , IEF E_y , and ionospheric electric field eastward (E_y) component measured by the Jicamarca incoherent scatter radar. The shaded interval denotes the occurrence of the penetration electric field.

(1) IEF direct penetration -- Penetration Characteristics of the Interplanetary Electric Field to the Day-time Equatorial Ionosphere



Data during 2001 to 2008

Interplanetary electric field (IEF) data, ACE

Equatorial ionospheric electric field (EEF) data

Jicamarca Unattended Long-term
Investigations of the Ionosphere
and Atmosphere (JULIA) radar, Peru

Manoj et al, 2008

(2) IEF via Reconnection Dungey et al, 1964----

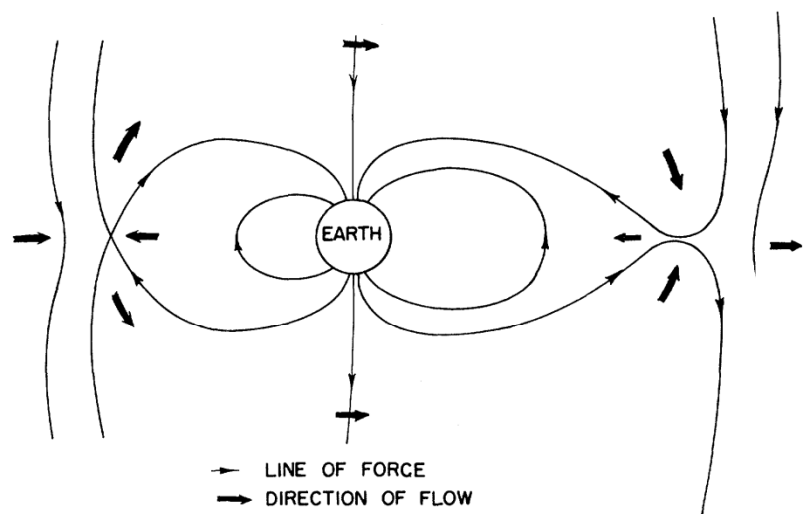


FIG. 1. Interplanetary plasma flow in a plane containing neutral points.

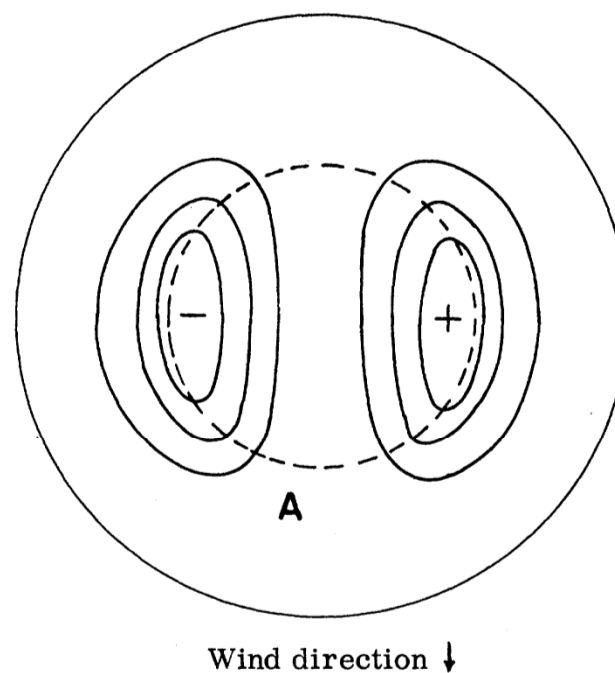


FIG. 2. Equipotentials in northern hemisphere for plasma winds of Fig. 1.

(3) IEF via Reconnection Dungey et al, 1964----

Multiple penetration on November 11-16, 2003

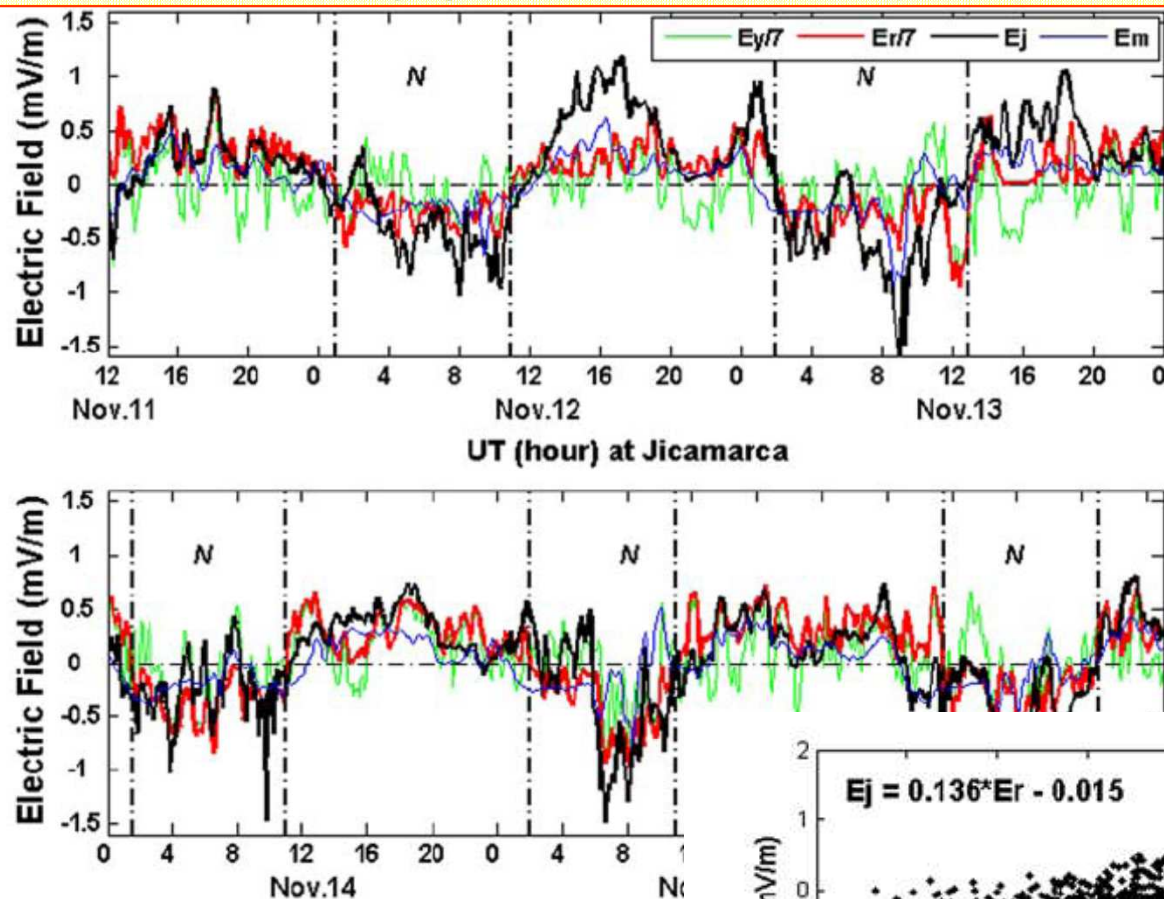


Figure 2. The dawn-dusk component of IEF, E_y (green), reconnect E_j (black), and estimated electric field E_m (blue) by the Fejer and Schlatter (1967) model on November 14–16, 2003, where positive is in dawn-duskward and negative is on the nightside, in which the E_y and E_r have been reversed. The time-sh

Wei et al, GRL 2008

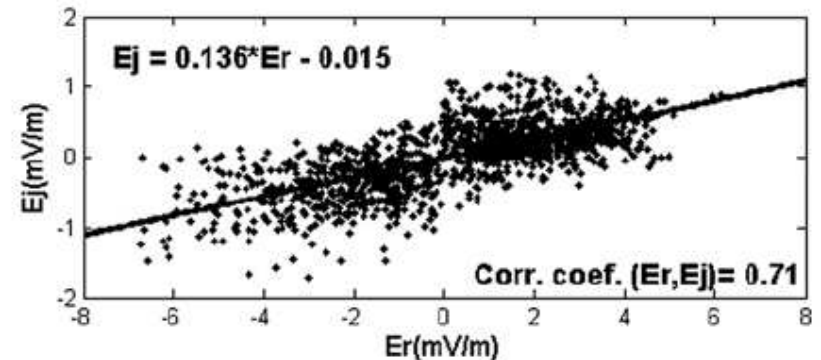


Figure 3. The scatter plot of reconnect electric field and equatorial zonal electric field during November 11–16, 2003. The solid line represents the least-square fit of the data.

(3) Nopper and Carovillano' Polar-Equatorial Coupling The Currents Produced by M-I Coupling

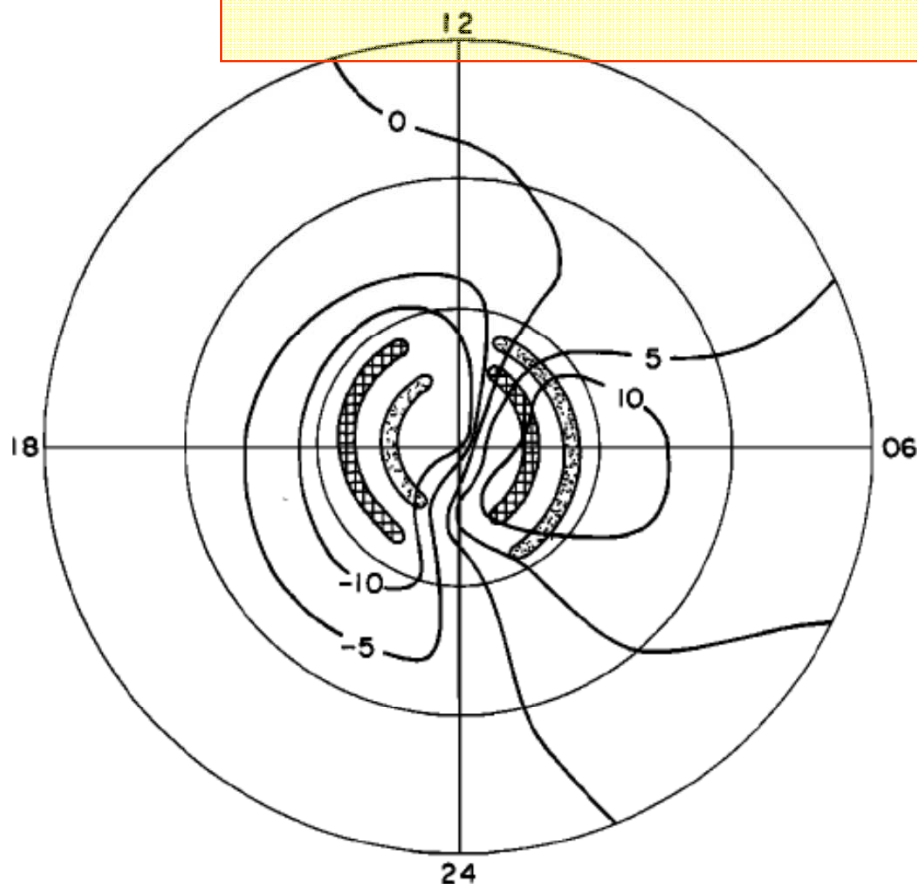


Fig. 2a. Equipotential pattern of region 1 currents of 10^6 A at 72° and region 2 currents of 5×10^5 A at 66° . This scenario approximates the quiet-time TRIAD observations.

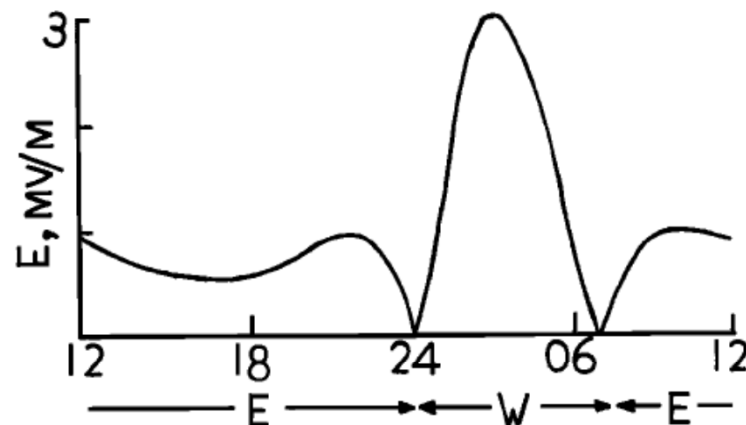


Fig. 1b. Electric field as a function of local time at the equator. The letters E and W at the bottom of the figure give the sense, east or west, of the equatorial field.

Nopper and Carovillano, GRL, 1978

(4) IEF penetration from polar to equator Kikuchi et al, 1979-2008

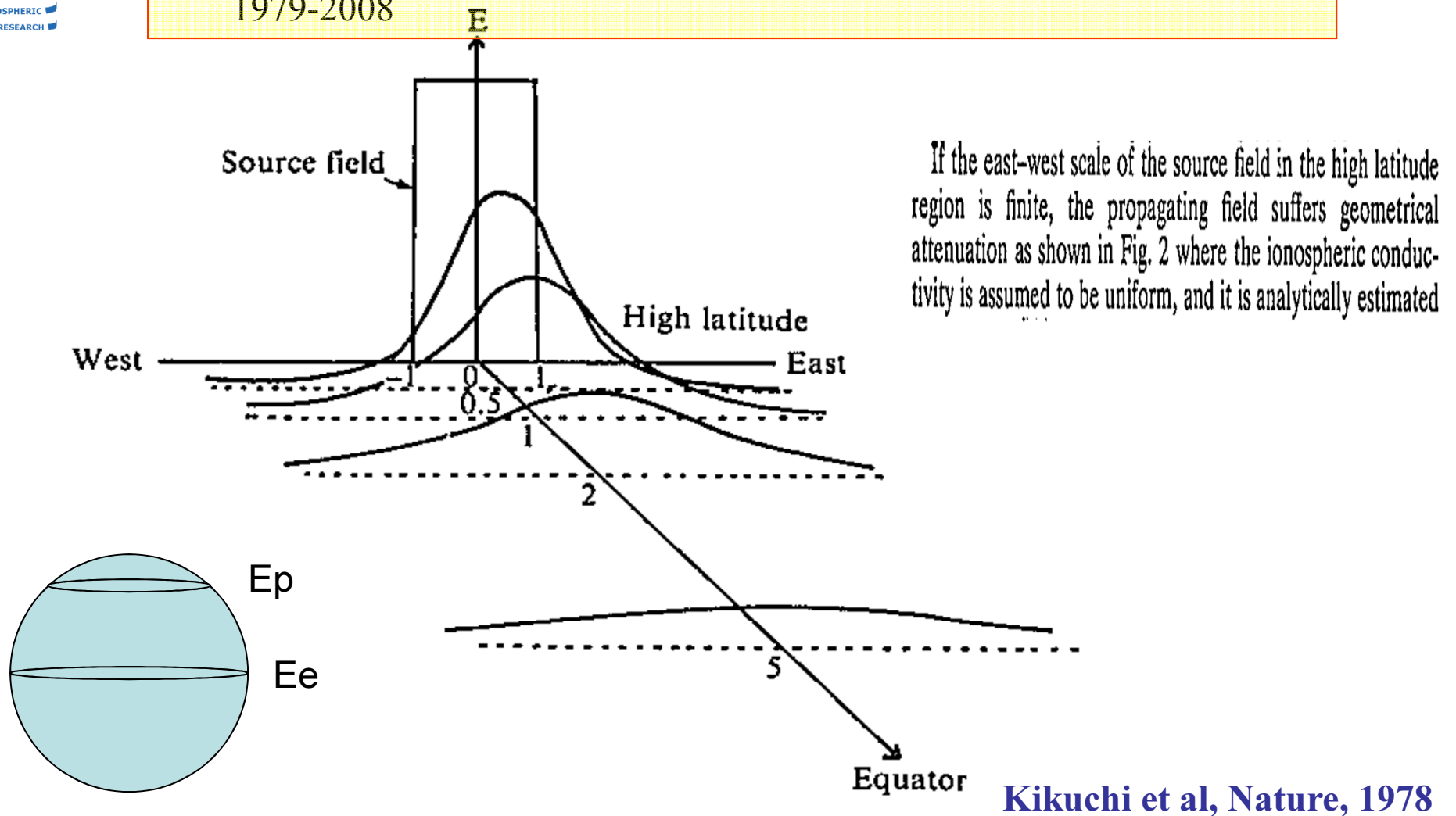


Fig. 2 Attenuation of electric fields due to finite scale of a source field. Distance in the north-south direction is normalised by the east-west scale of the source field.

(4) IEF penetration from polar to equator Kikuchi et al, 1979-2008

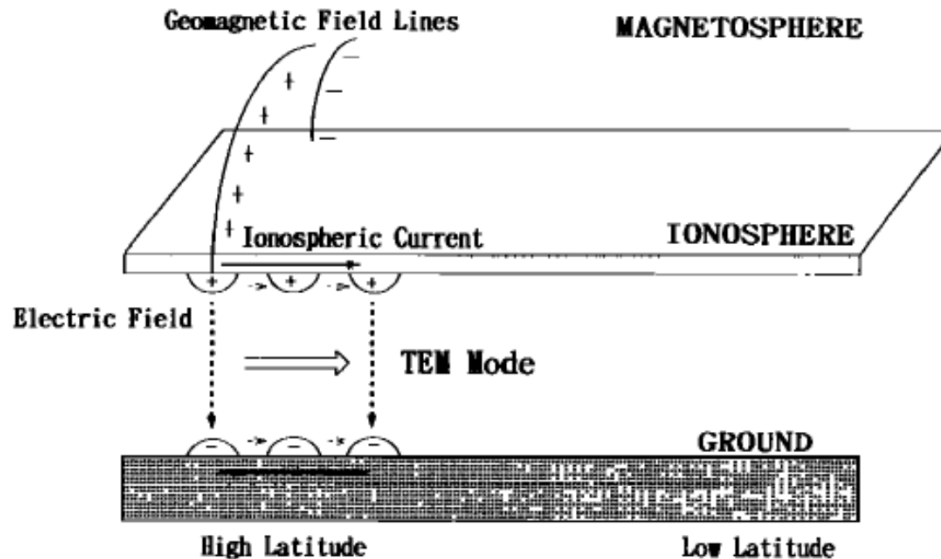


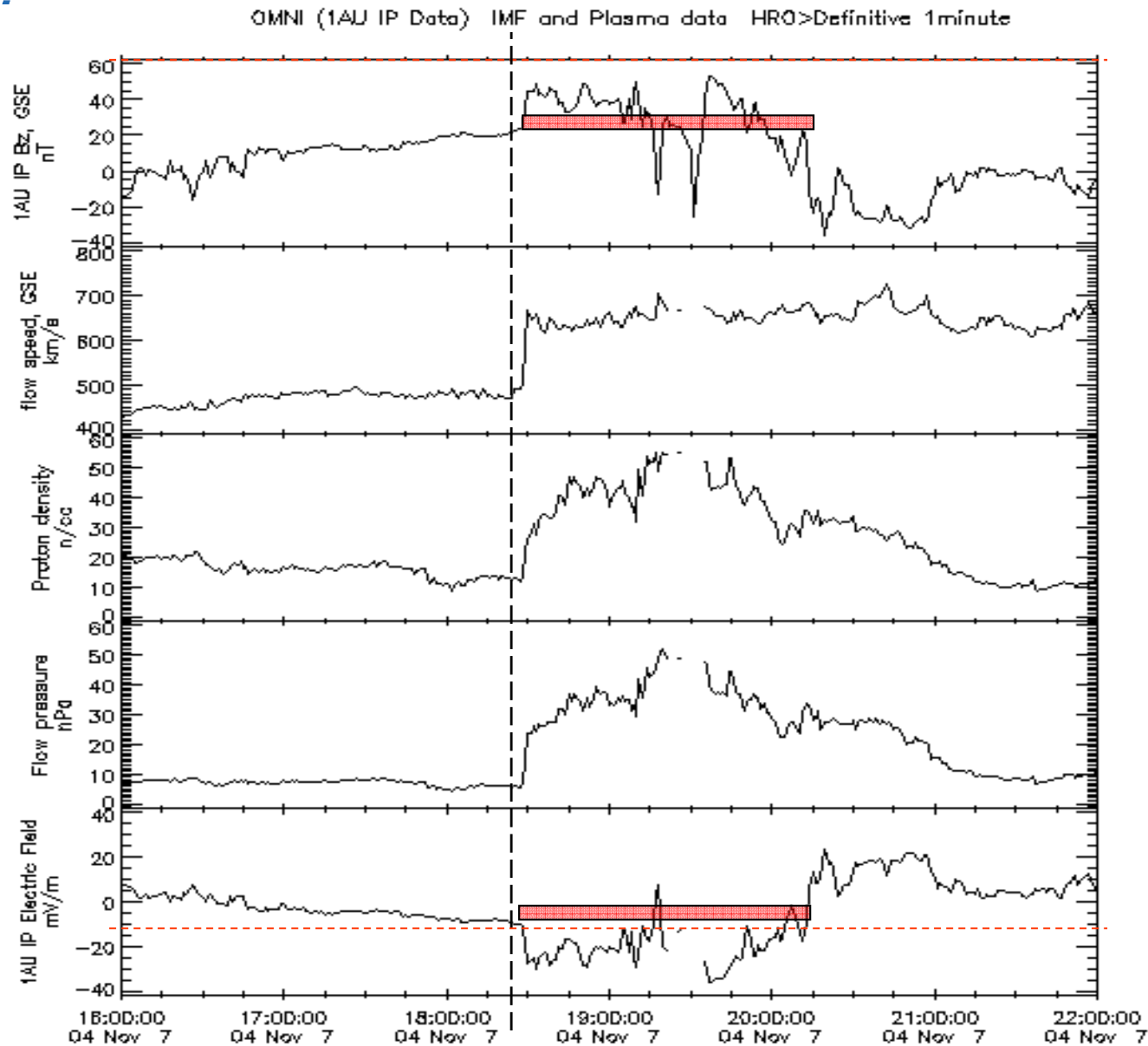
Figure 10. A parallel plane transmission line model composed of the isotropically conductive ionosphere and the Earth, which enables an instantaneous propagation of an auroral electric field to the equatorial ionosphere. An electric charge carried along the magnetic field line from the magnetosphere into the polar ionosphere induces a vertical electric field between the two conductive plates, which in turn propagates horizontally towards the low latitude with a speed of light, accompanying a TEM mode which does not suffer from attenuation.

the zeroth-order TM mode
Propagating along the Earth-
ionosphere cavity
approximately at the speed
Of light

[Kikuchi, 1979, 1996]

Kikuchi et al, JGR 1996

(5) Our Understanding: Timing the shock front propagation



IMF

Solar Wind

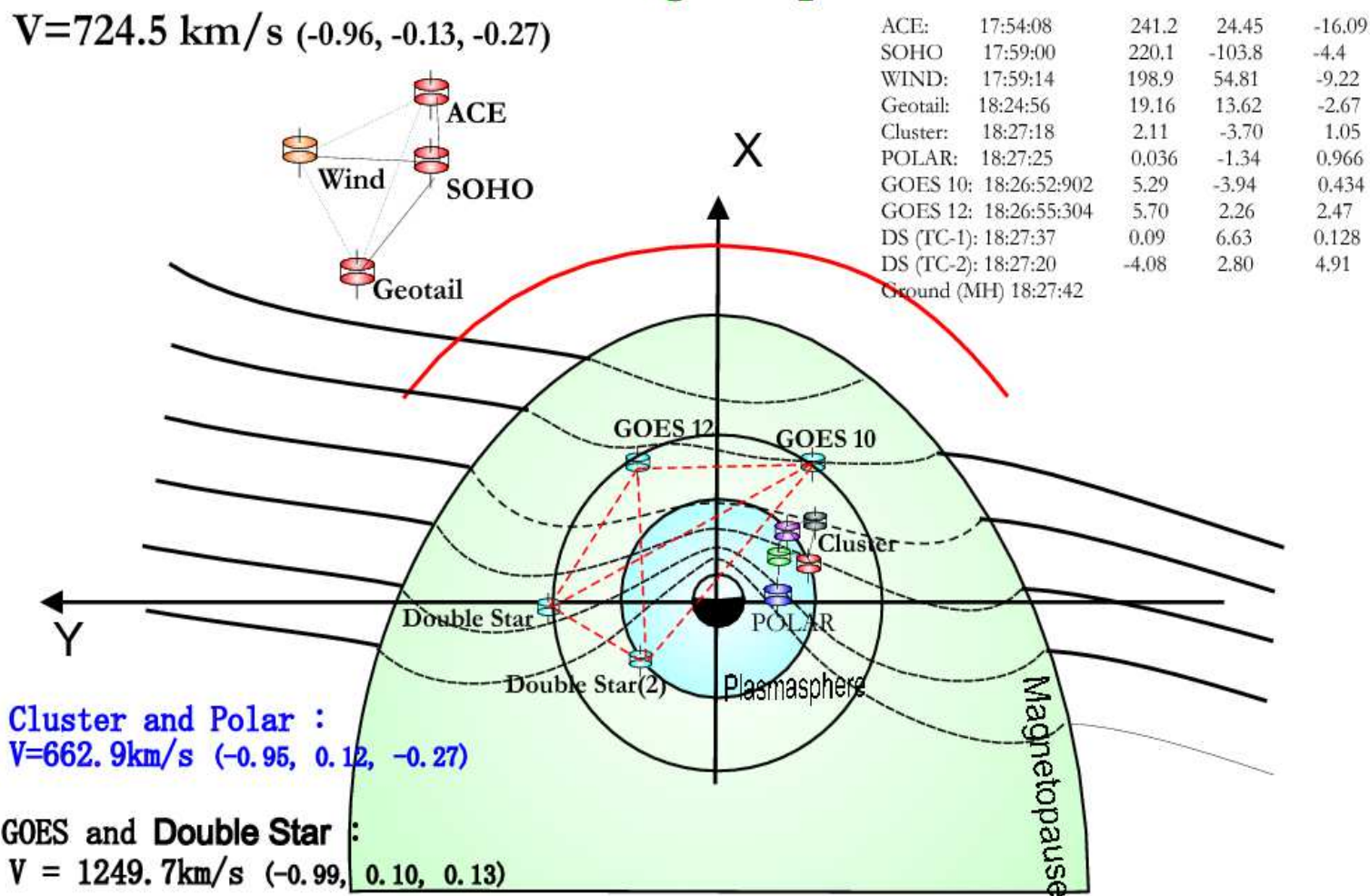
**Nov. 7,
2004**

(5) Our Understanding: Timing the shock front propagation

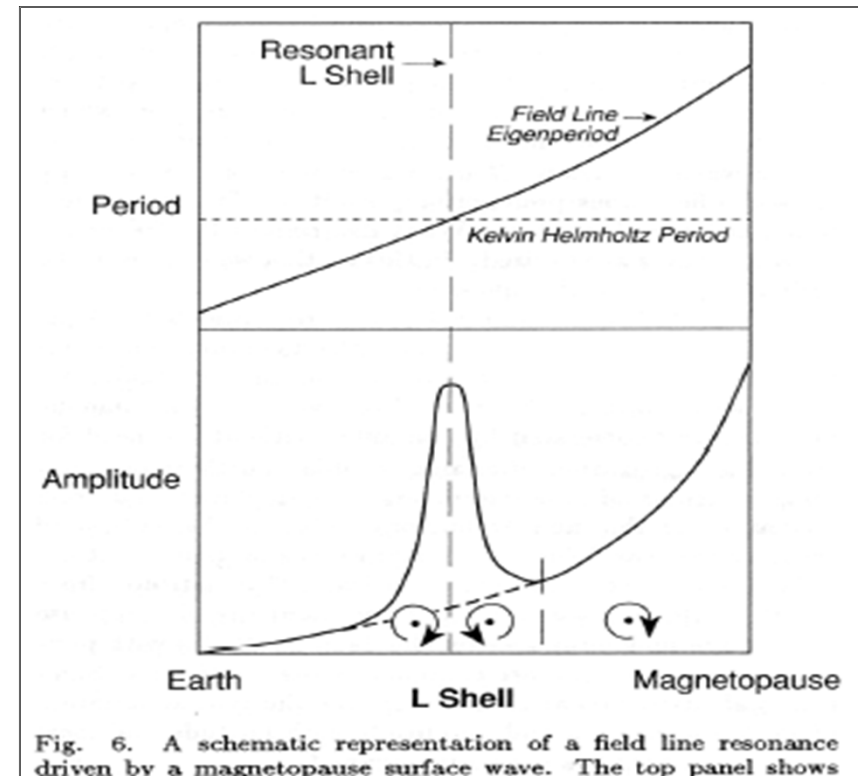
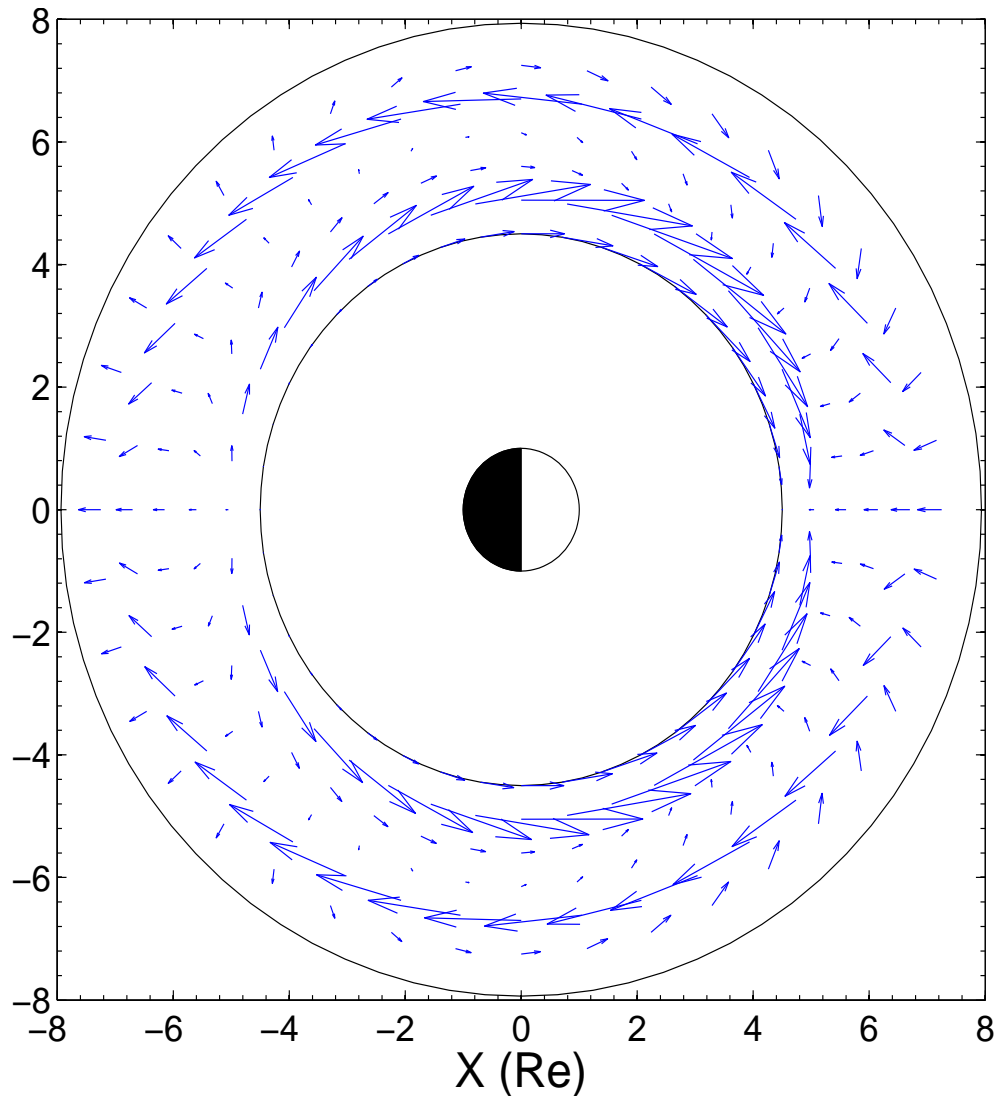
Zong et al, 2008

The Propagation of the Wave Fronts in the magnetosphere

$V=724.5 \text{ km/s } (-0.96, -0.13, -0.27)$



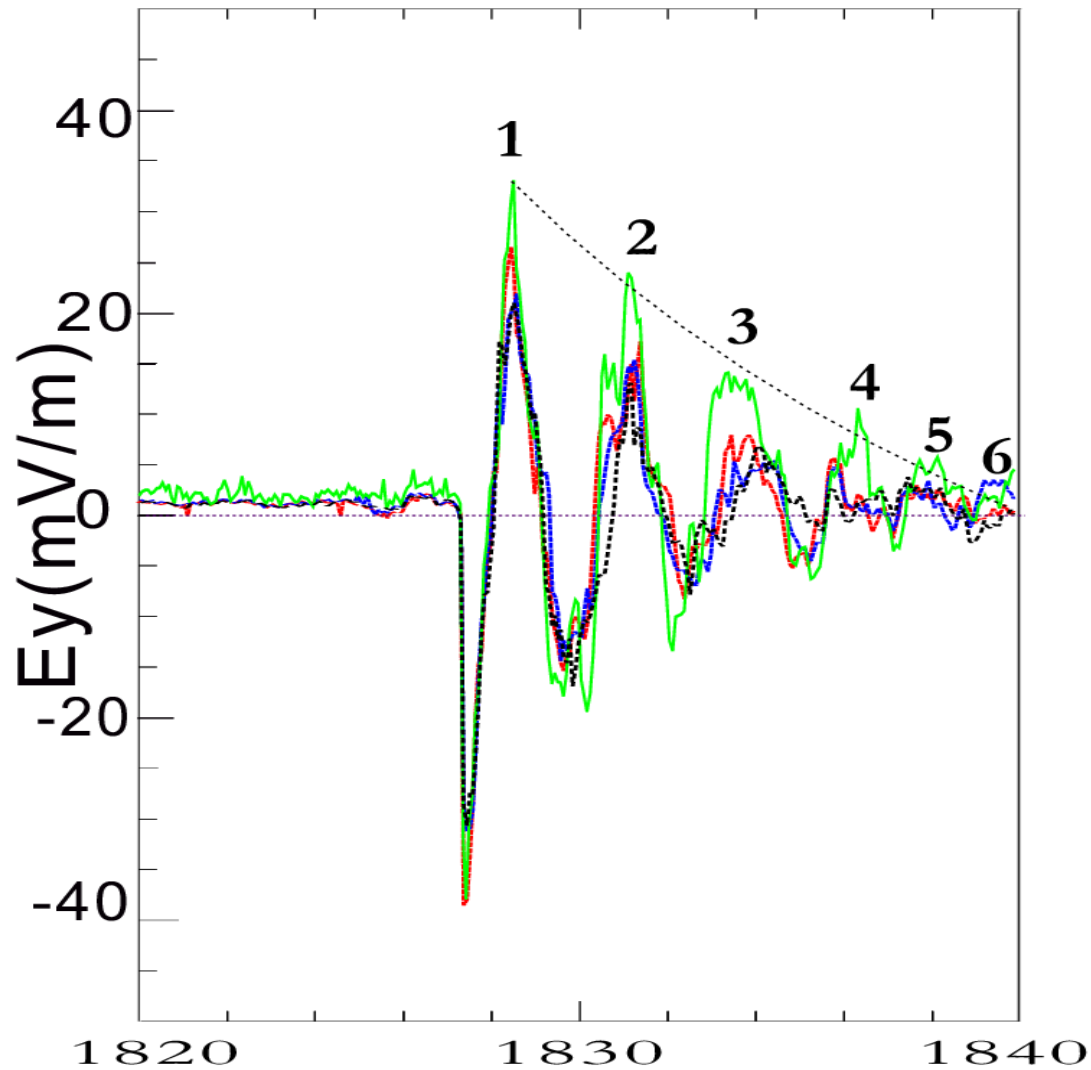
(5) Our Understanding: **Field Line Resonance**



Yang et al, 2008
Zhang et al, 2008

Plasma drift velocity driven by solar wind pressure impulse

(5) Our Understanding:

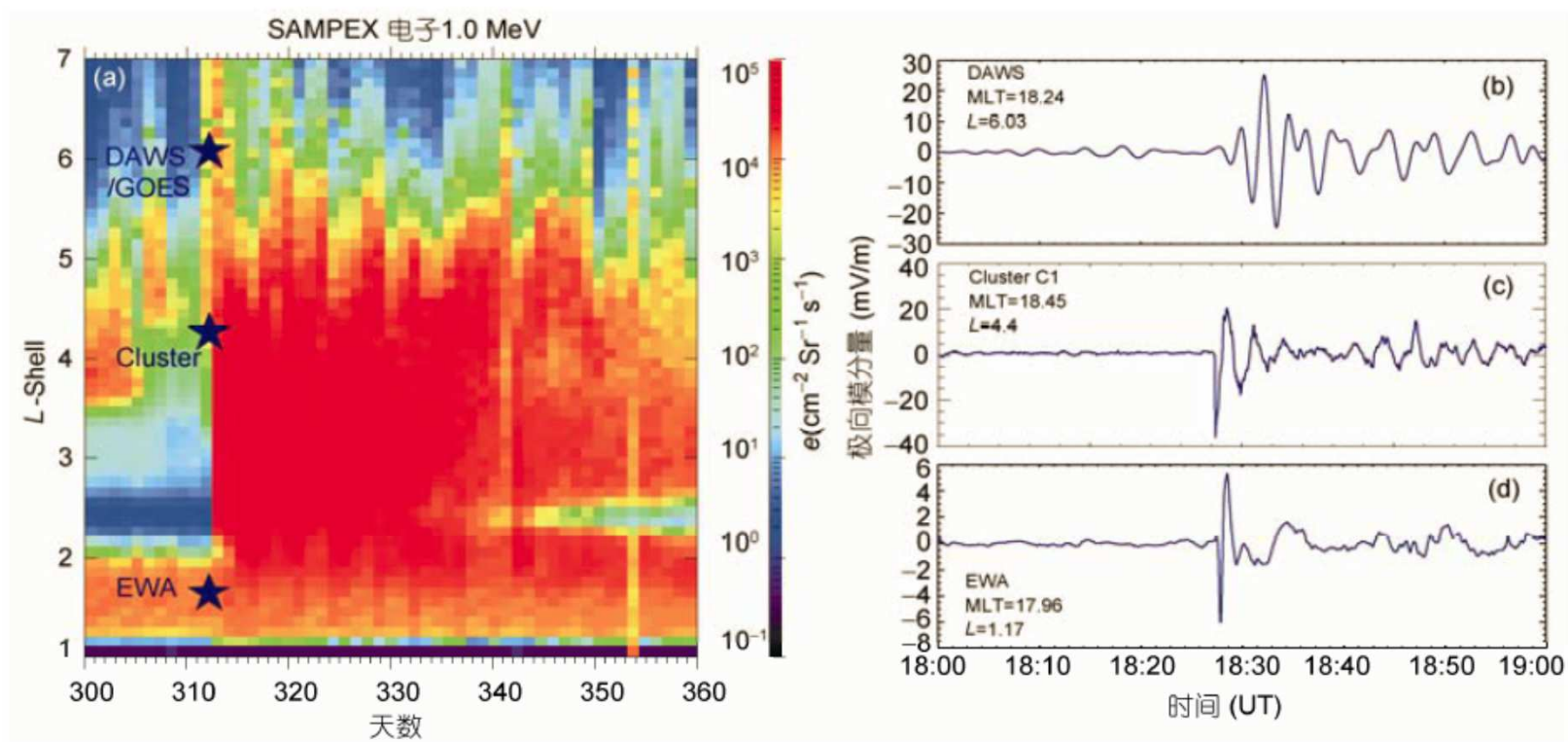


$$E = Ae^{-D_1 t} \sin(\omega t) + Be^{-(D_1 + D_2)t} \sin(\omega t + \phi)$$

$$\Sigma Ey = -\int E(t)$$

Zong et al, 2008

ULF Poloidal Mode Electric Field



2004

(5) Our Understanding:

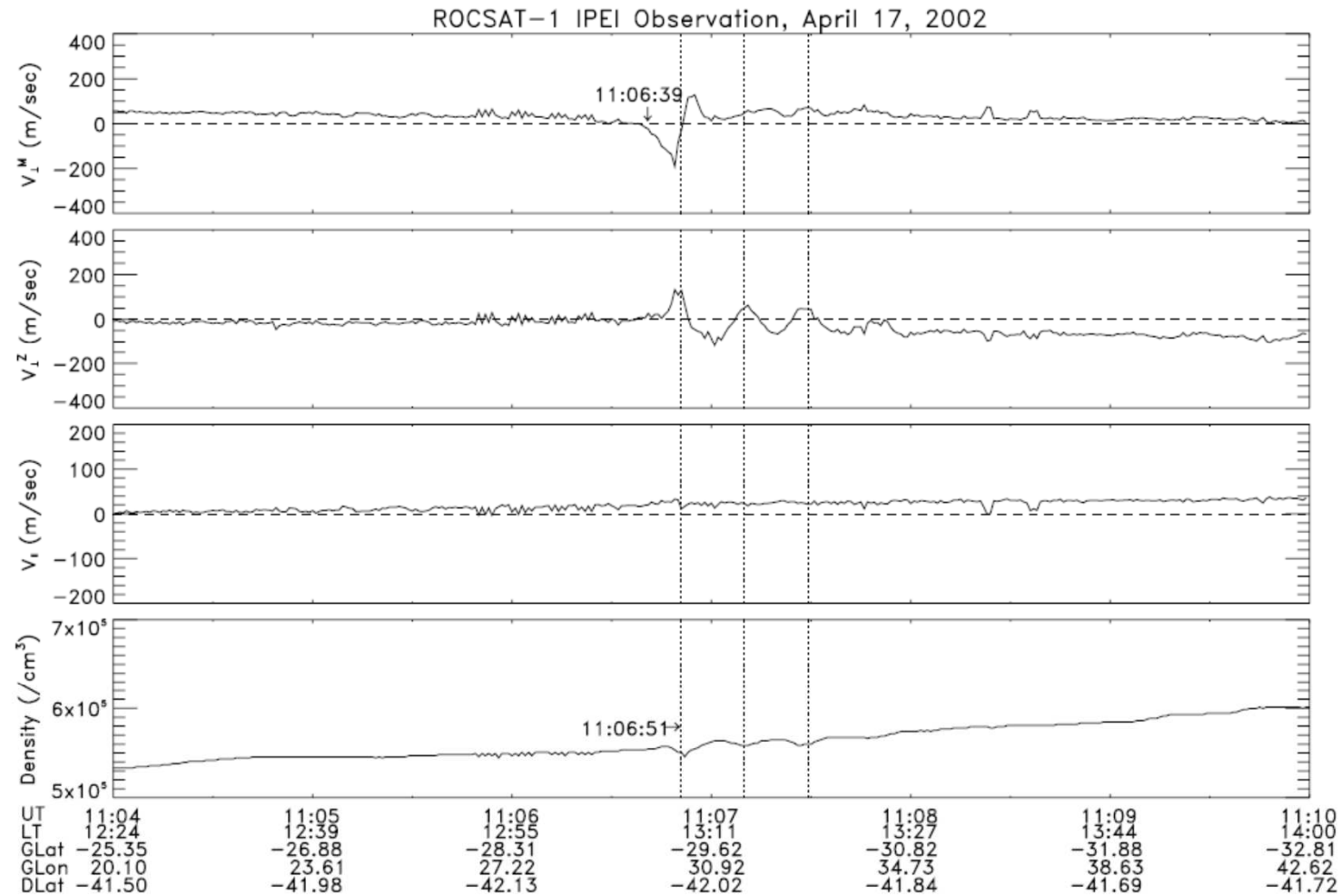


Figure 2. Topside ionospheric flow and density variations that indicate the SI induced Pi-1 pulsations. The arrow is drawn to indicate the arrival of the SI impact. A time reference is set on the first dotted line which is drawn at 1106:52 UT and the following two dotted lines are separated by 19 s.

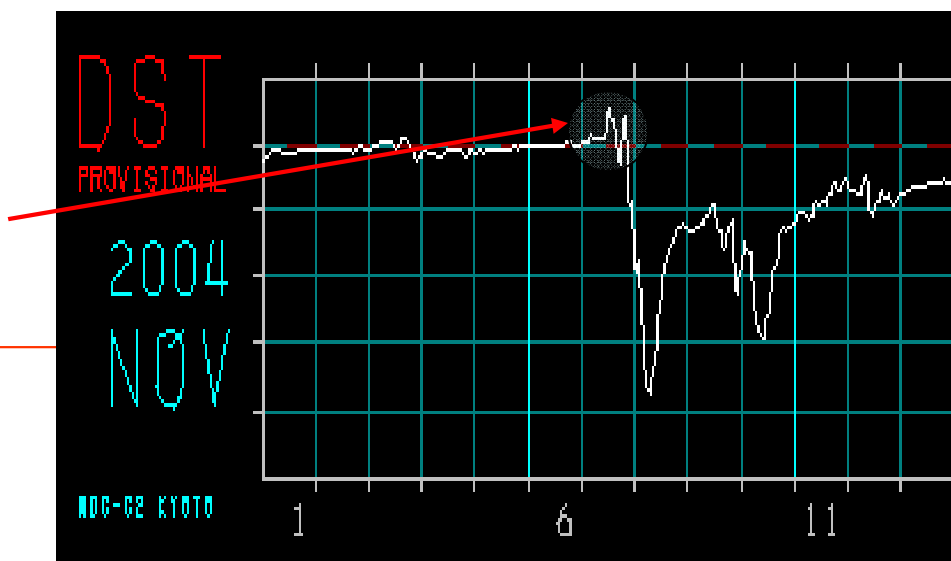
Observations

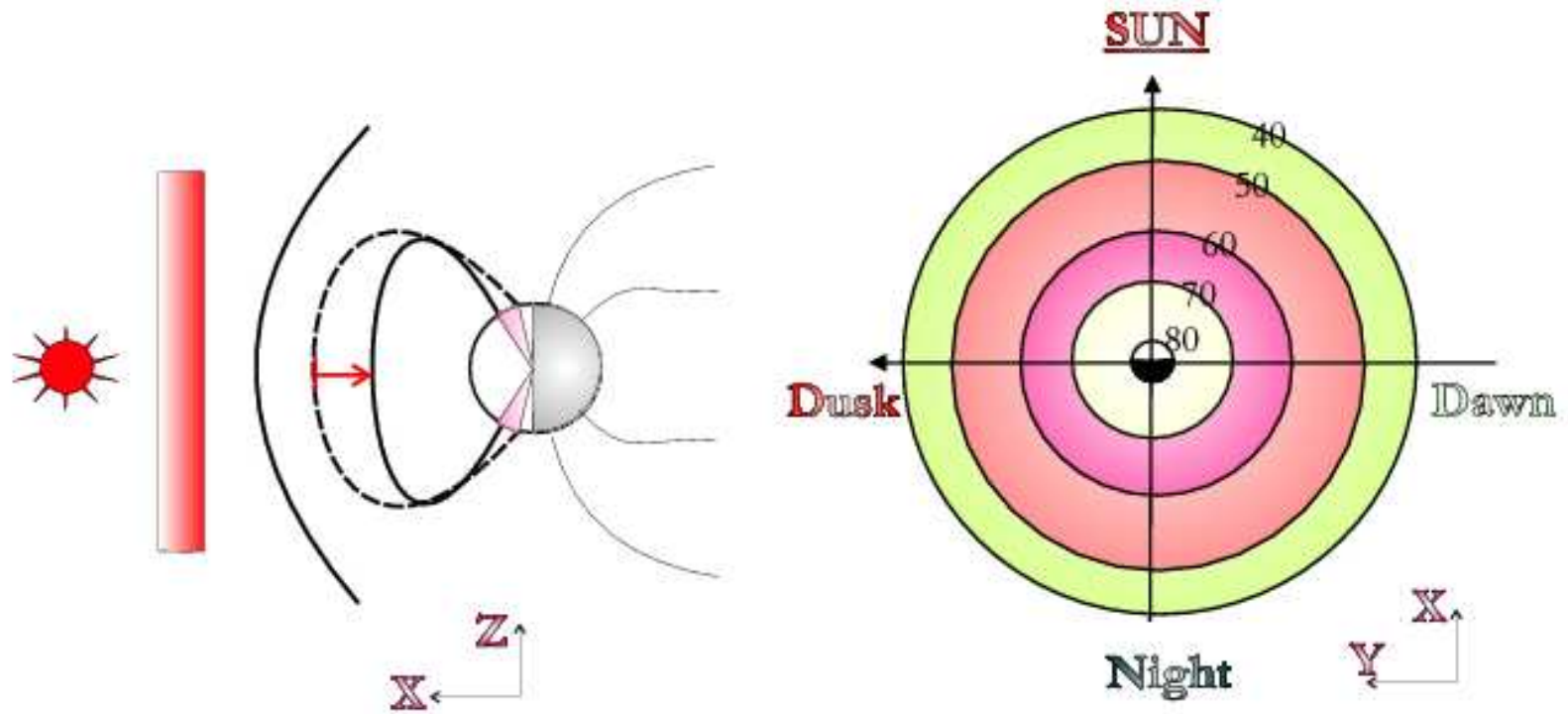
- **Motivation**

- dayside aurora
- shock aurora
- Interplanetary Shock

- Jan 21, 2005 (1710UT),
Dst=- 101 nT

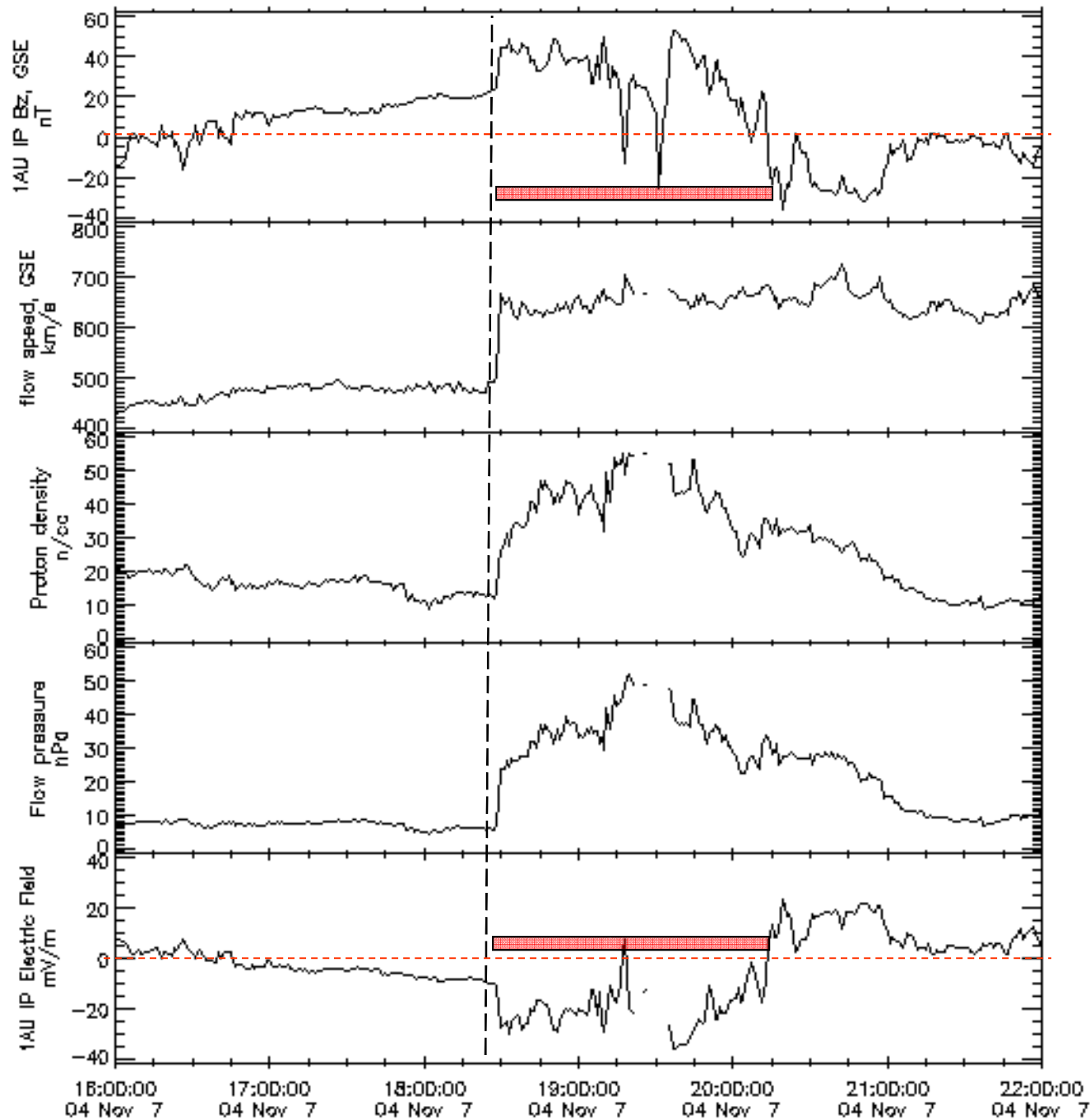
- Nov. 7, 2004 (1828UT)
Dst=-373 nT





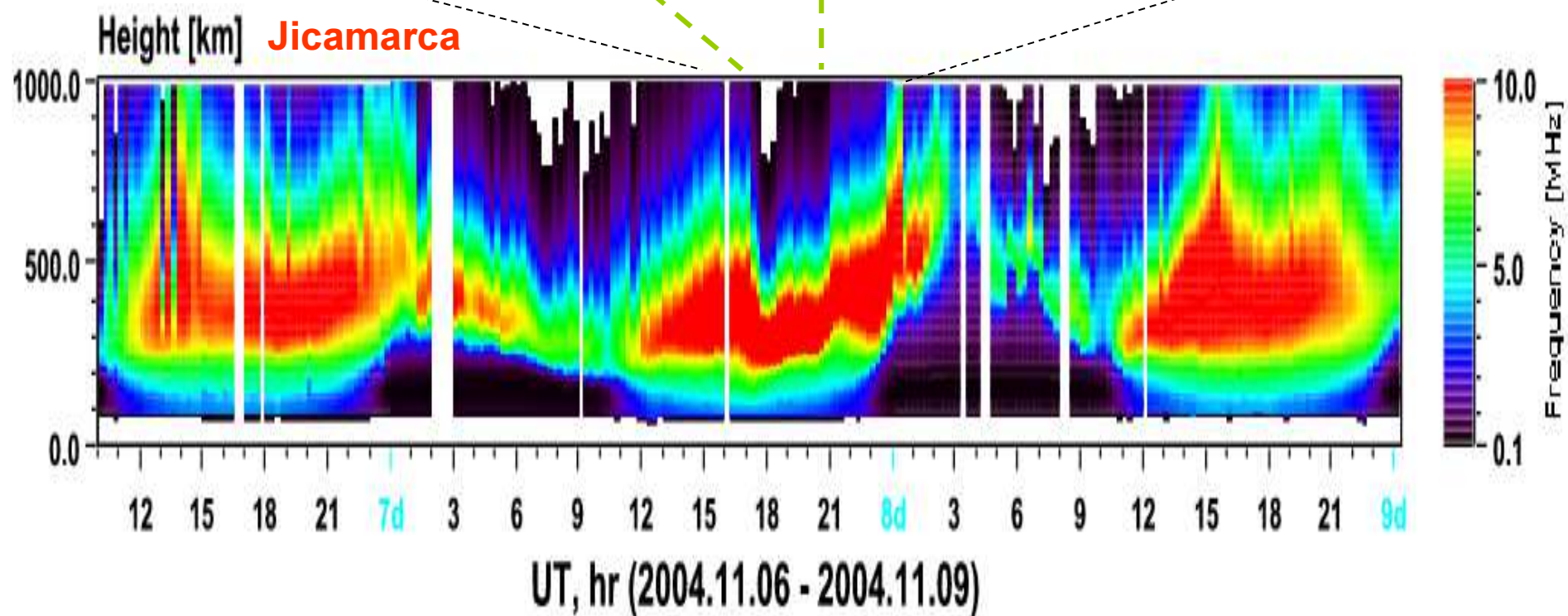
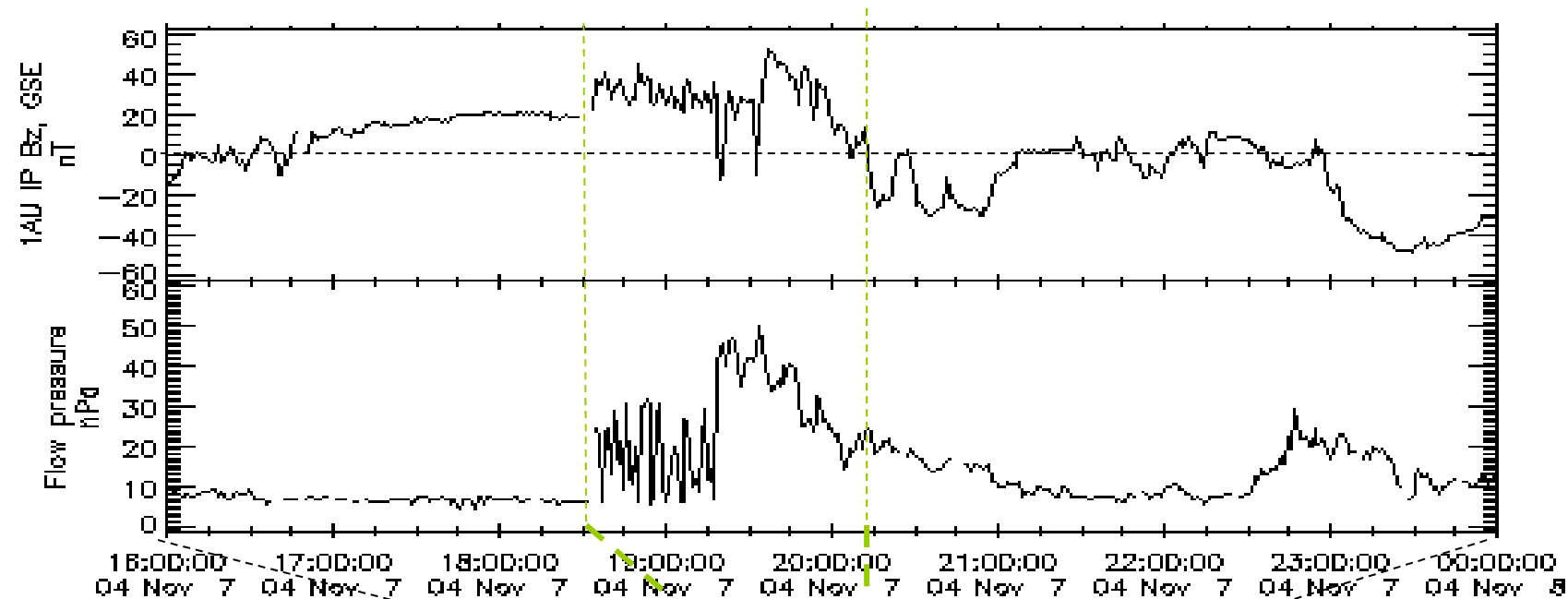
2. Global Ionosphere Response

OMNI (1AU IP Data) IMF and Plasma data HRO>Definitive 1minute

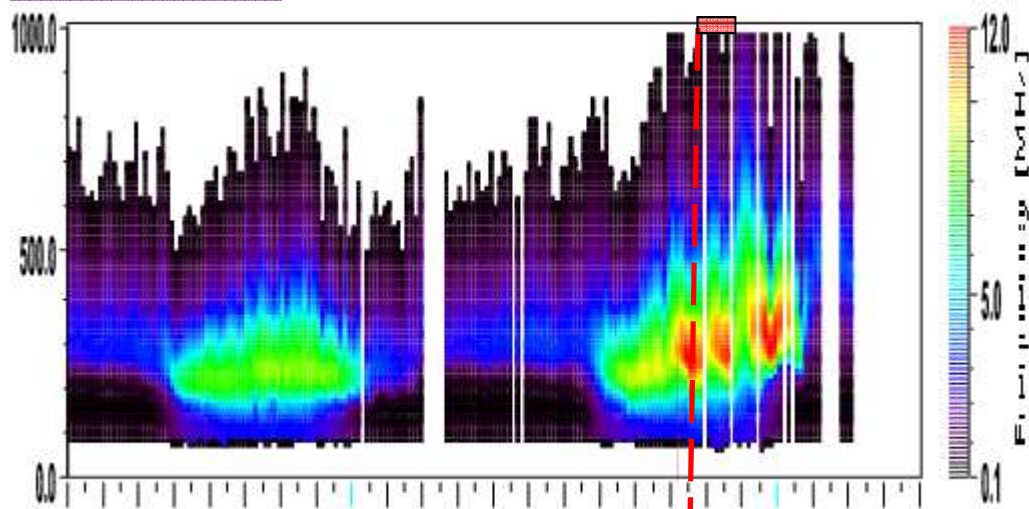


IMF

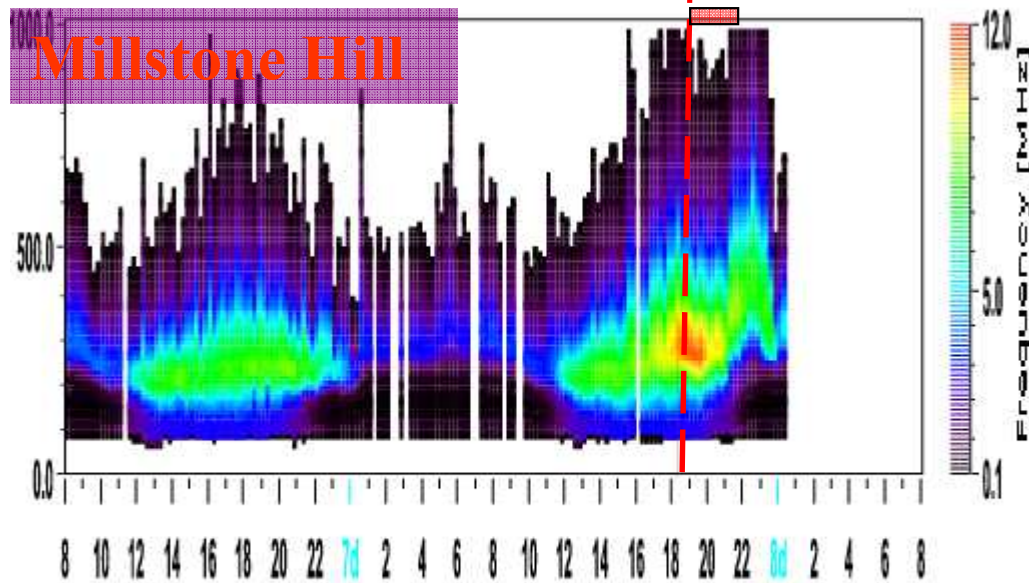
Solar Wind



Boulder

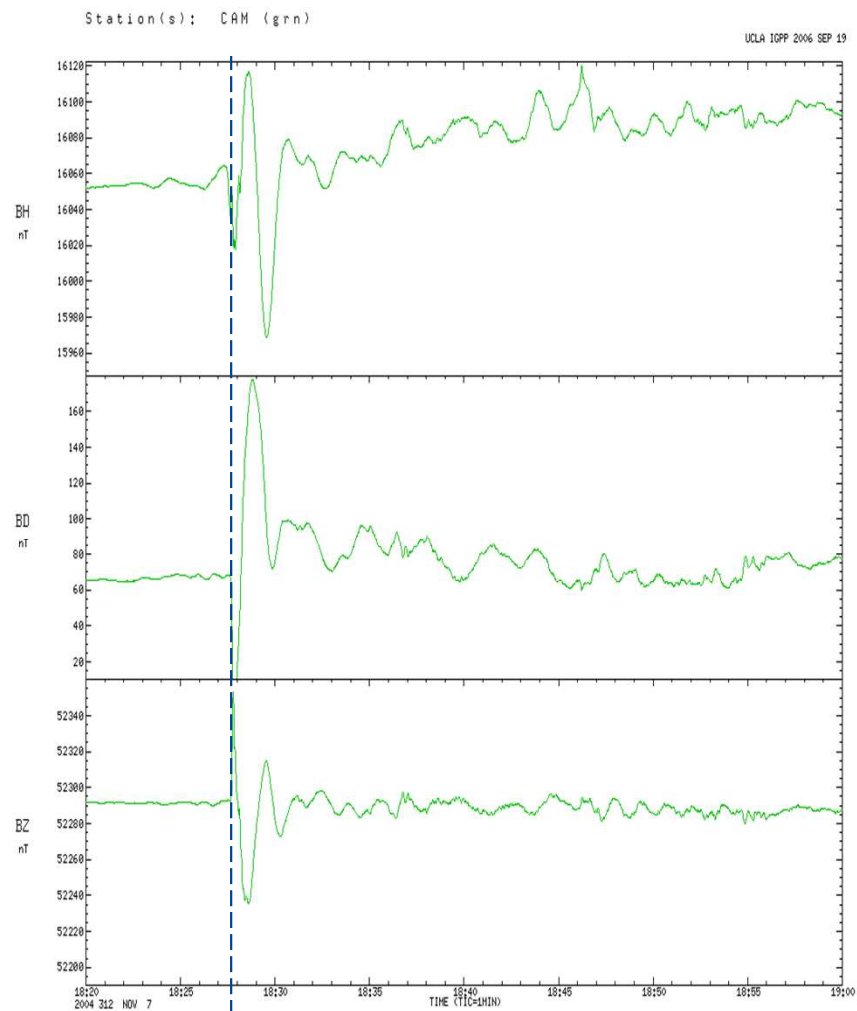


Millstone Hill



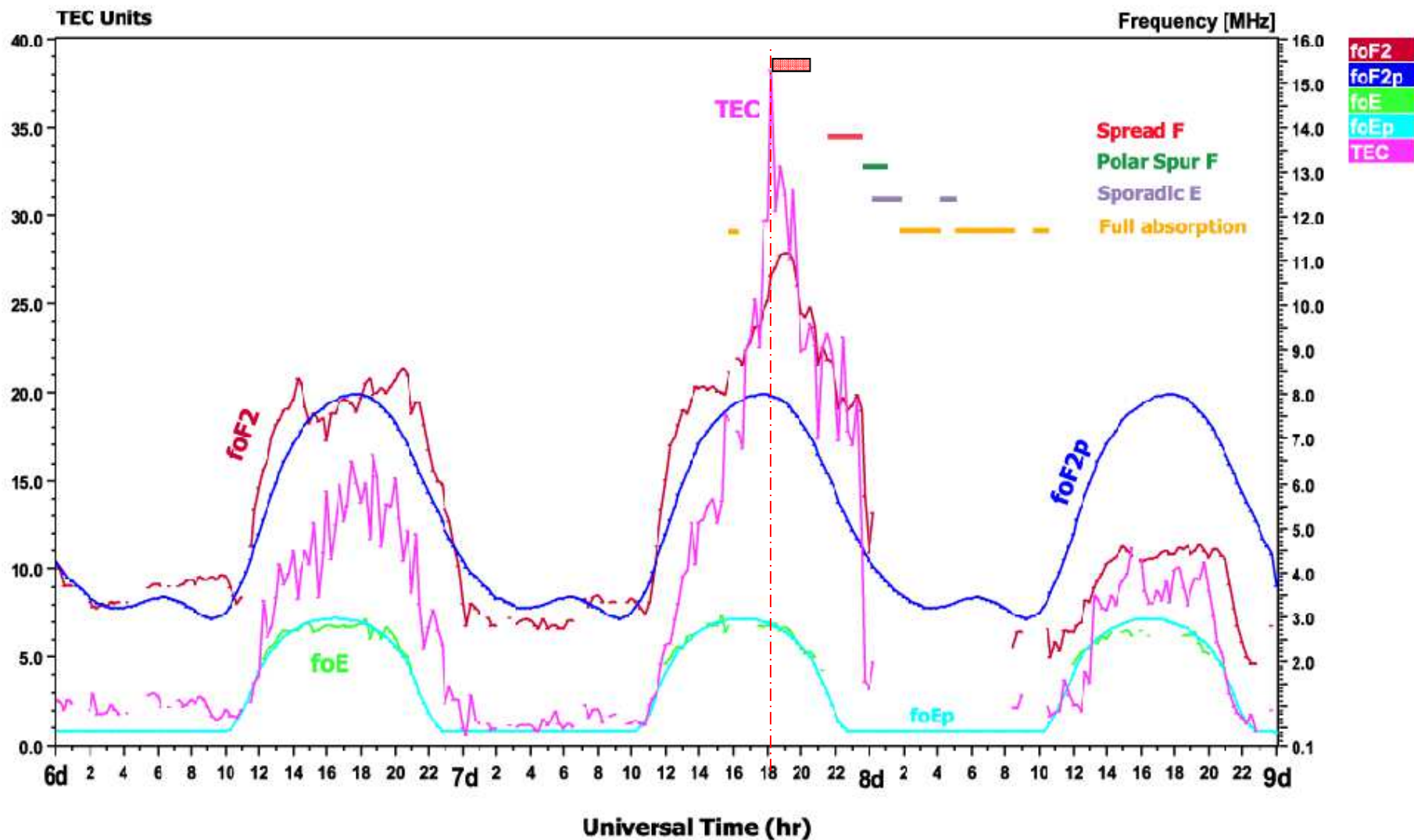
UT, hr (2004.11.06 - 2004.11.08)

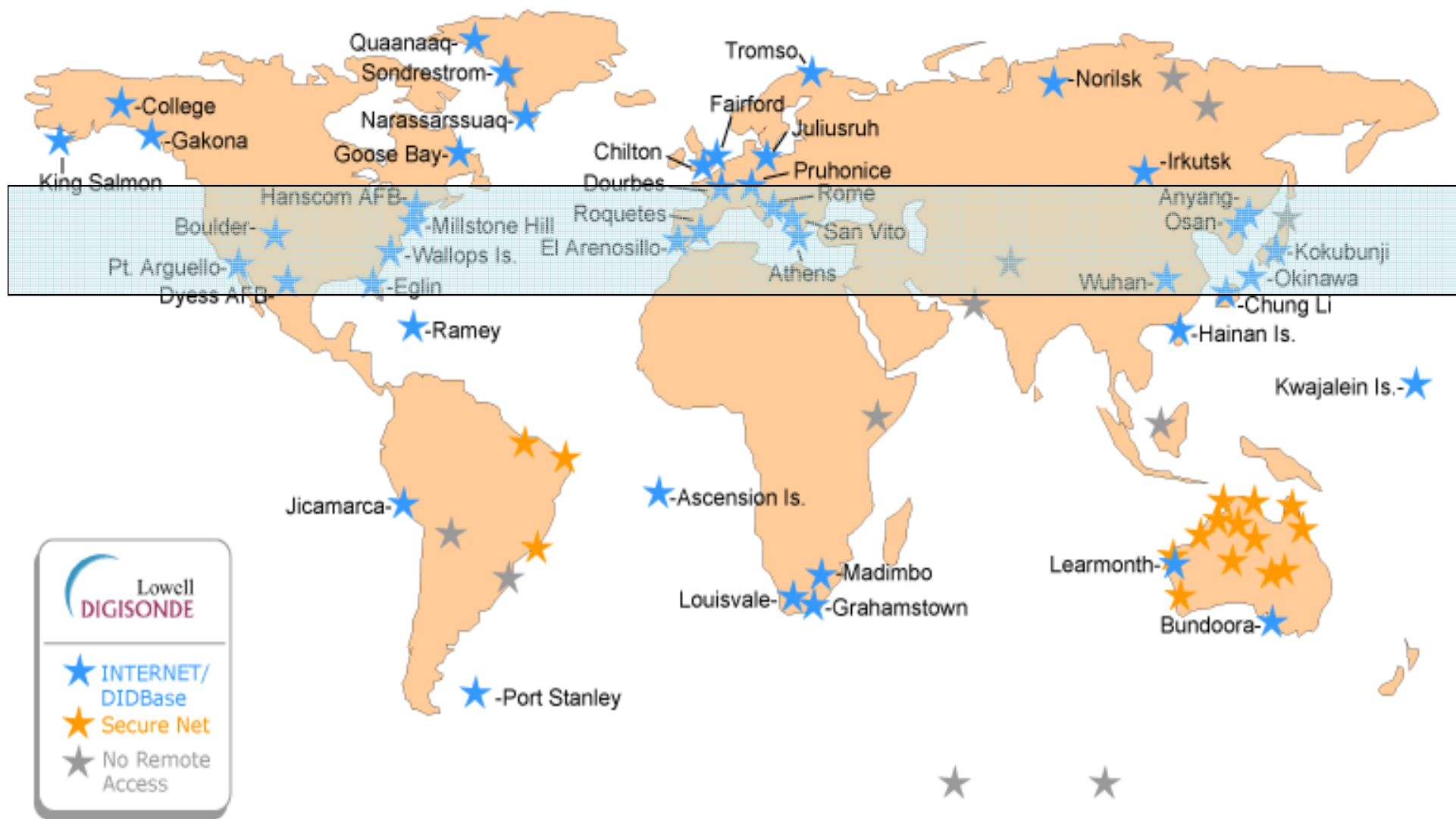
Dayside



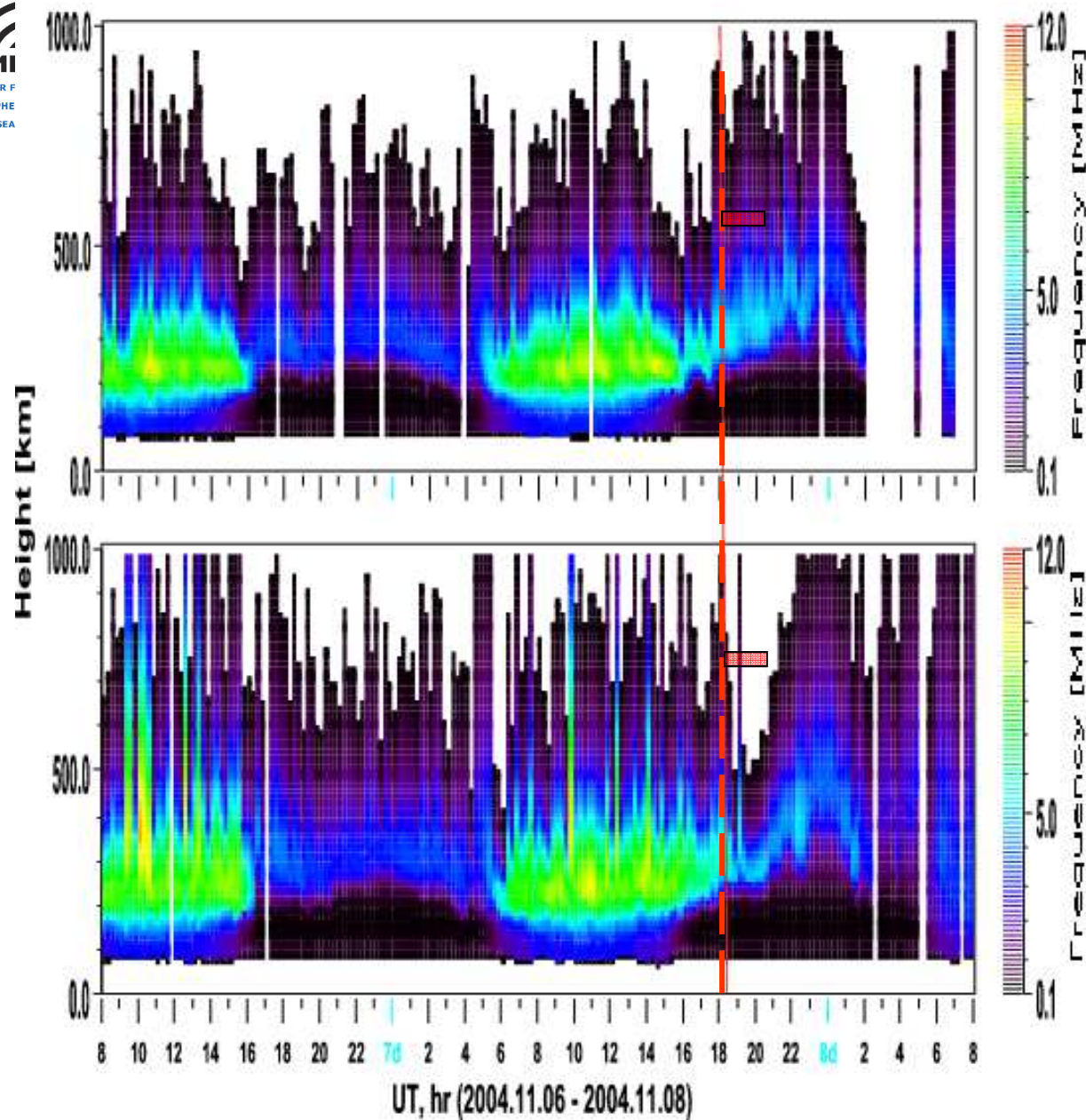
Millstone Hill

Millstone Hill Digisonde, November 6-8, 2004



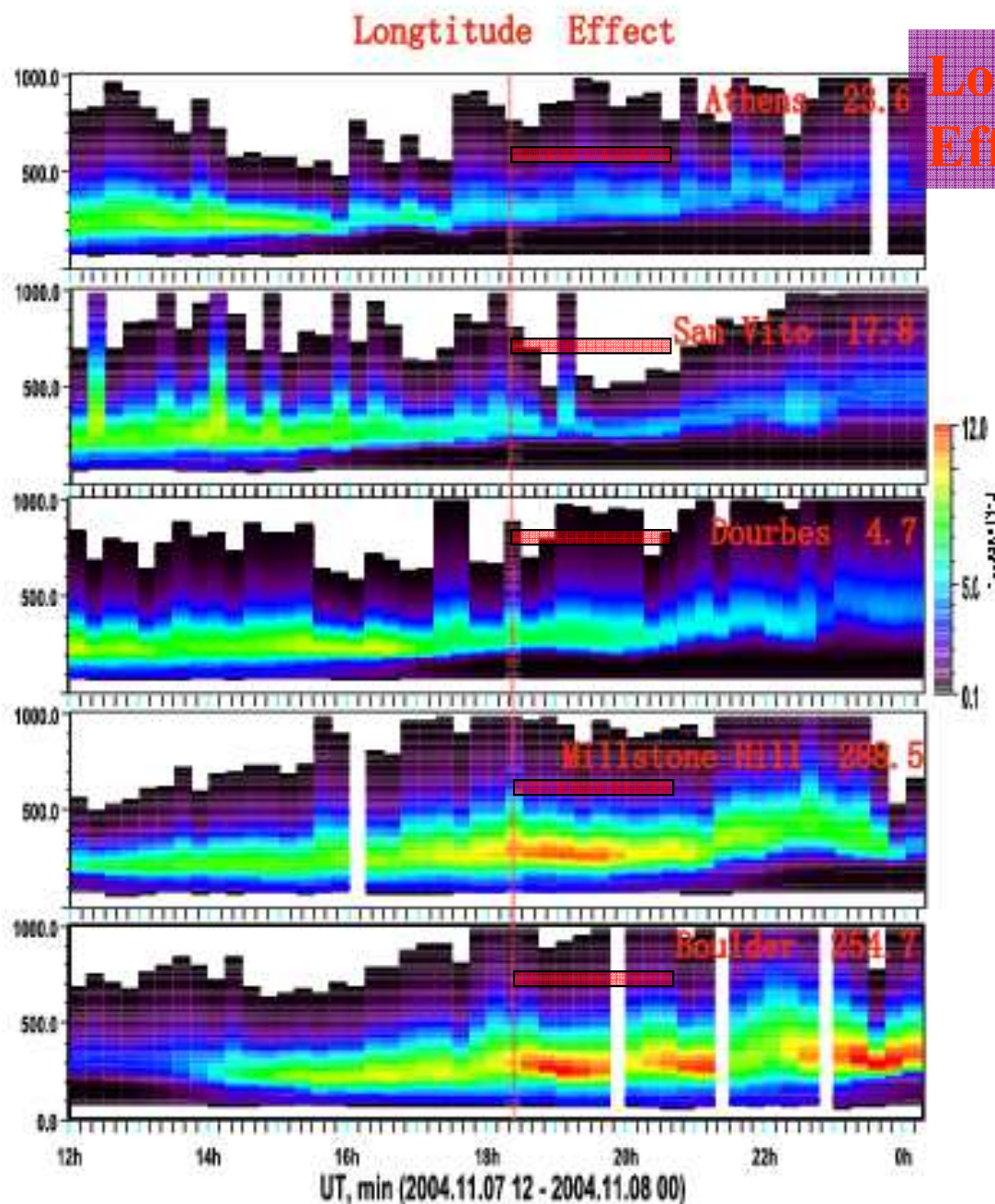


Night Side

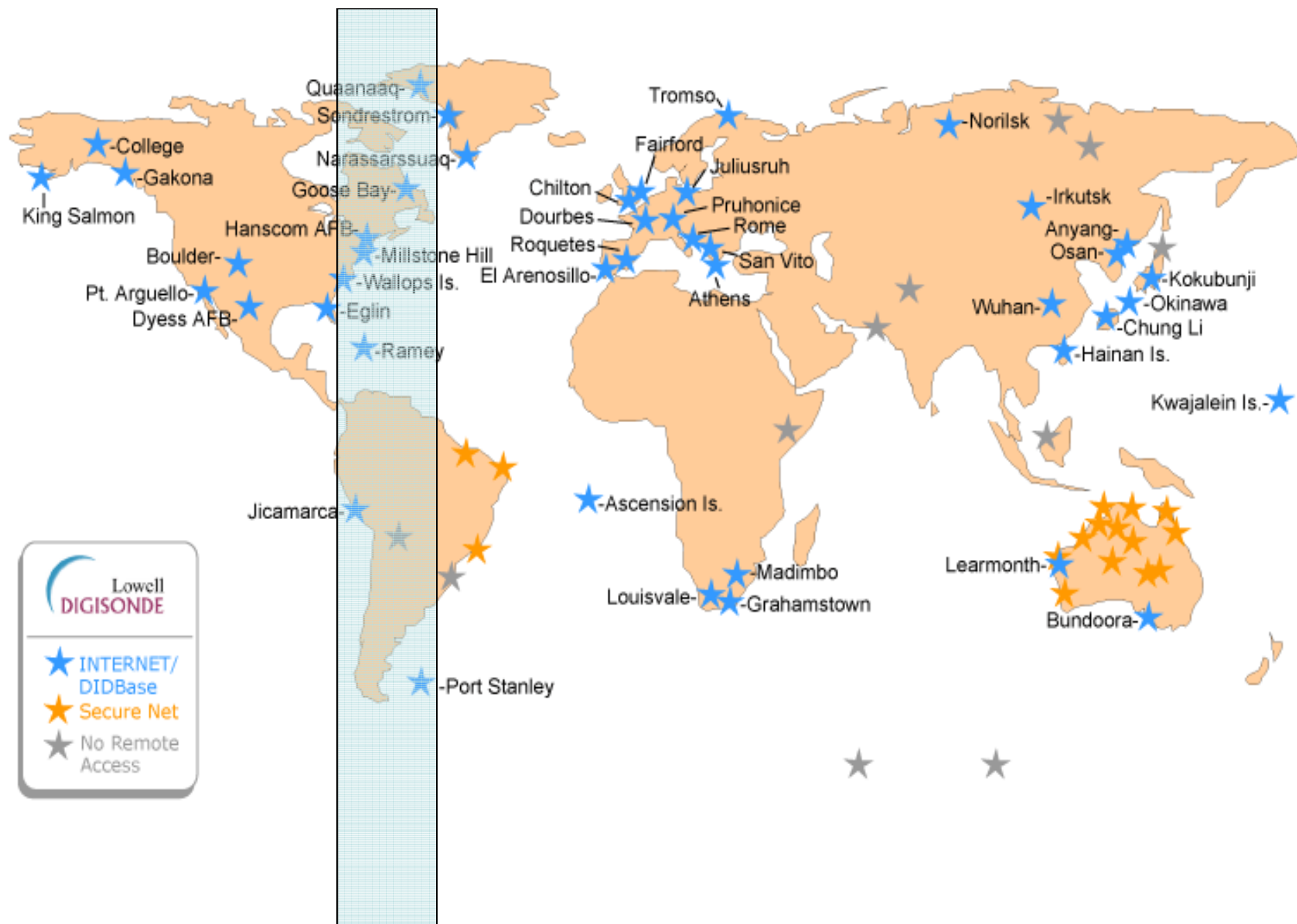


Athens

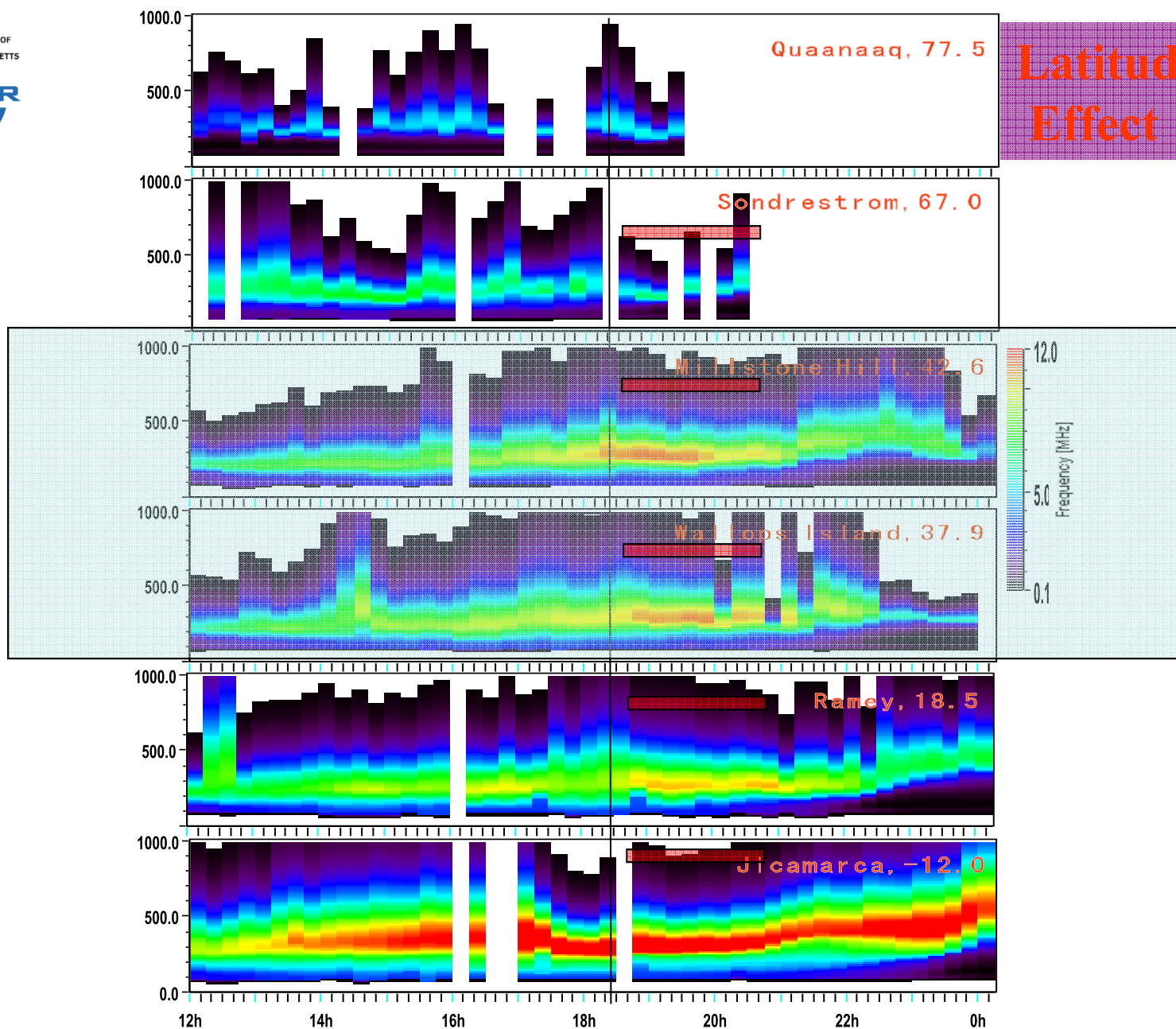
San Vito



Longitude
Effect

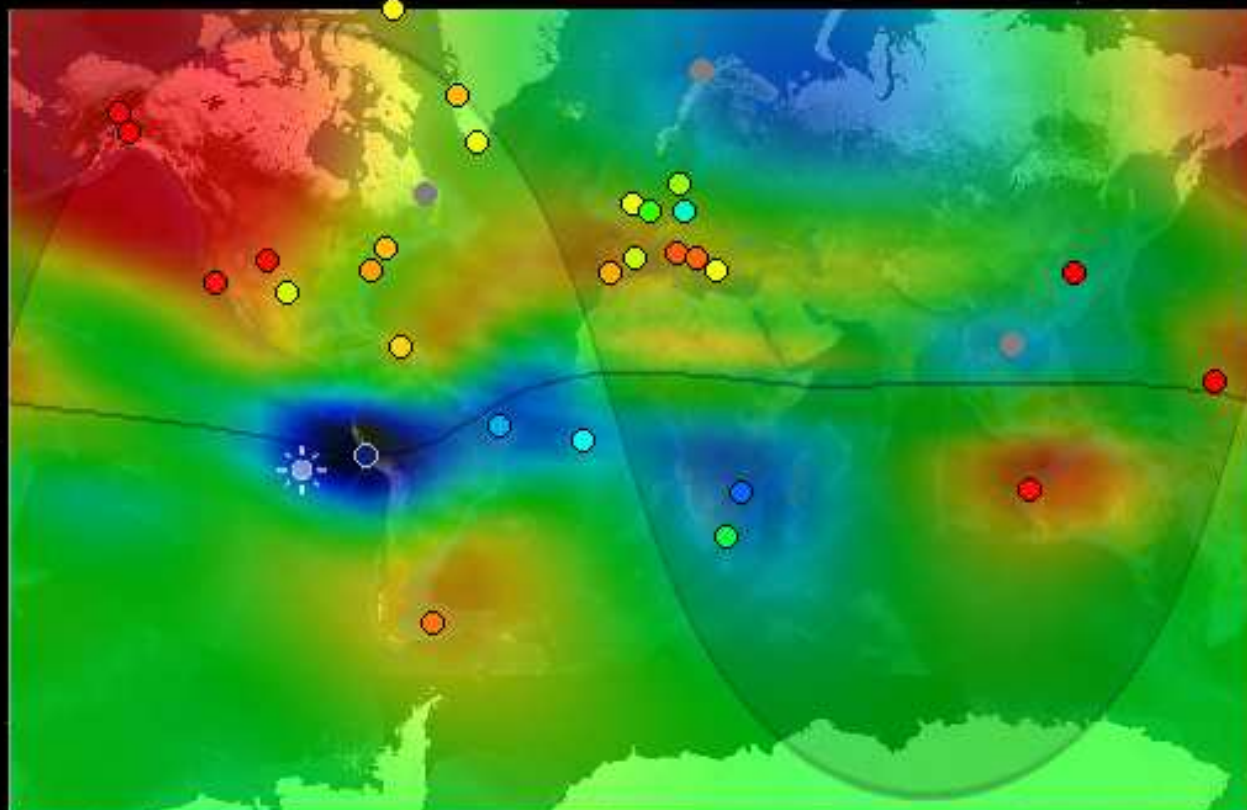


Latitude Effect



IRTAM v0.1B

Time UT - 2004.11.07 18:07:00



Map: hmF2 (IRTAM-Brunini) km



-60 -30 0 30 60

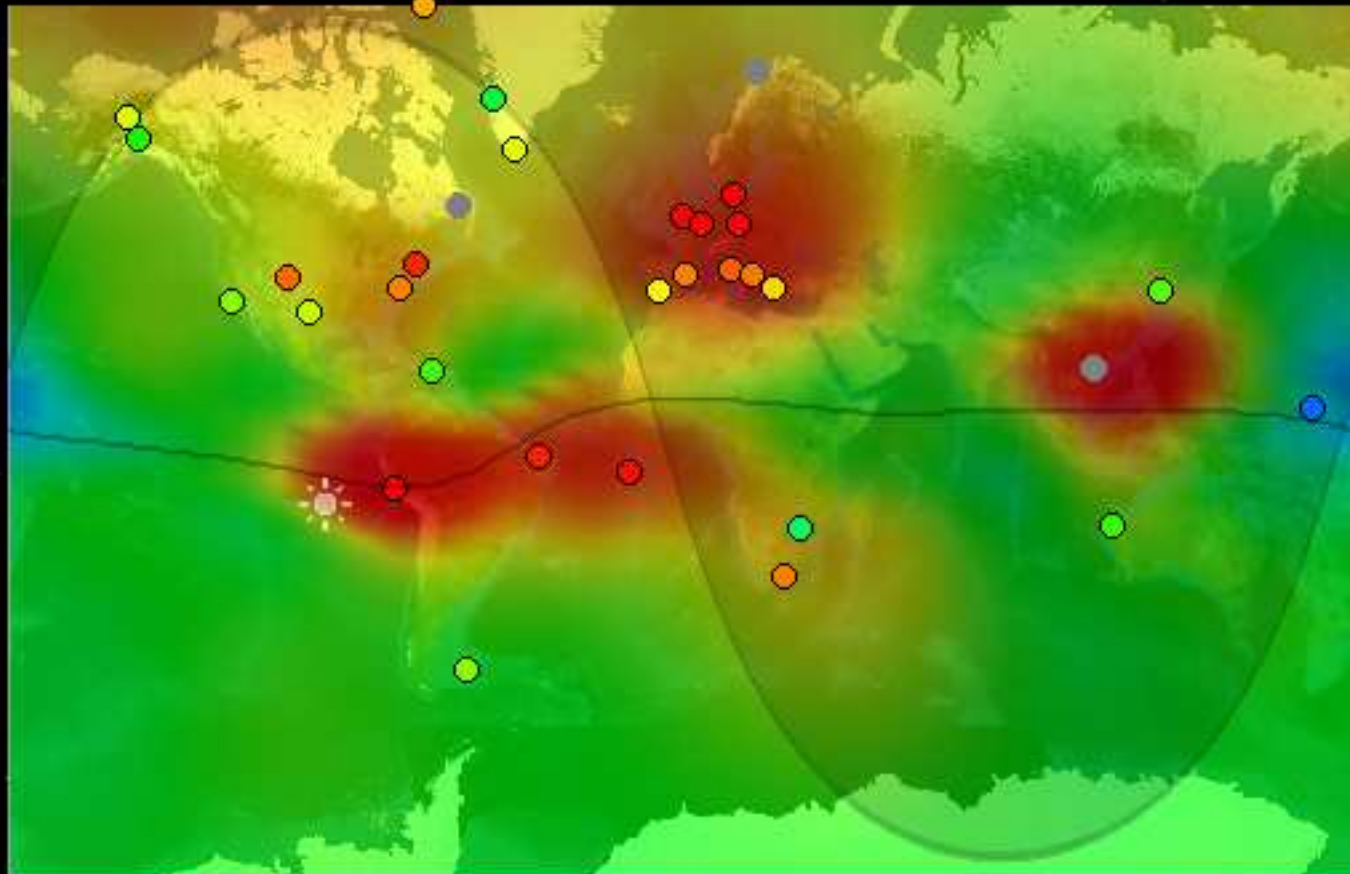
Circles(sites): hmF2 (GIRO-Brunini) km



-70 -35 0 35 70

IRTAM v0.1B

Time UT - 2004.11.07 18:07:00



Map: foF2 (IRTAM-IRI) MHz



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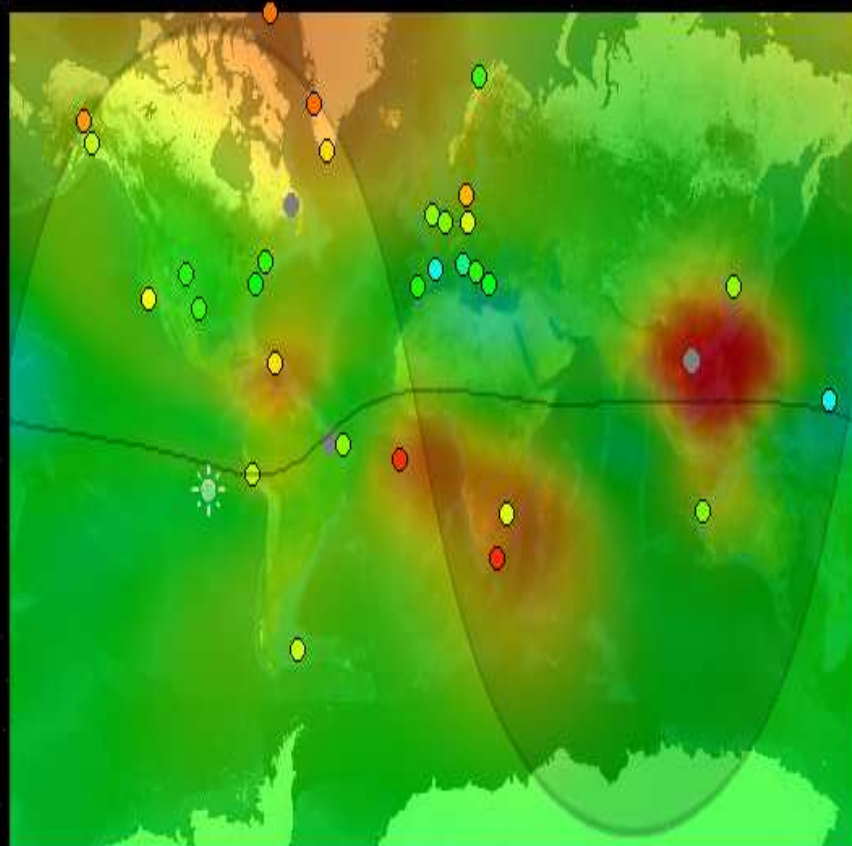
Circles(sites): foF2 (GIRO-IRI) MHz



-3 -1.5 0 1.5 3

IRTAM v0.1B

Time UT - 2004.11.06 18:07:00



Map: foF2 (IRTAM-IRI) MHz



-3 -1.5 0 1.5 3

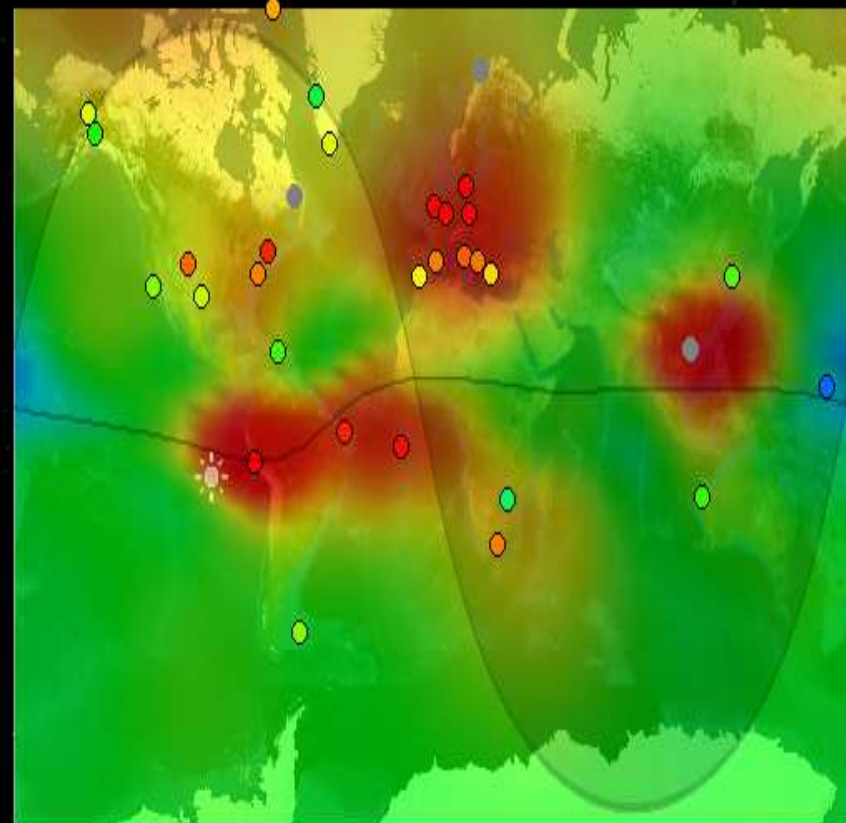
Circles(sites): foF2 (GIRO-IRI) MHz



-3 -1.5 0 1.5 3

IRTAM v0.1B

Time UT - 2004.11.07 18:07:00



Map: foF2 (IRTAM-IRI) MHz

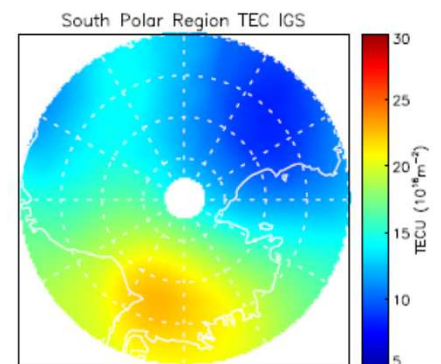
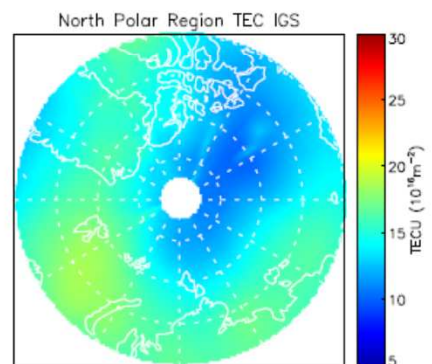
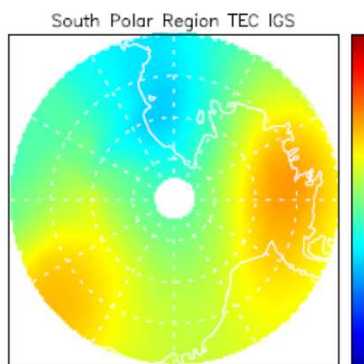
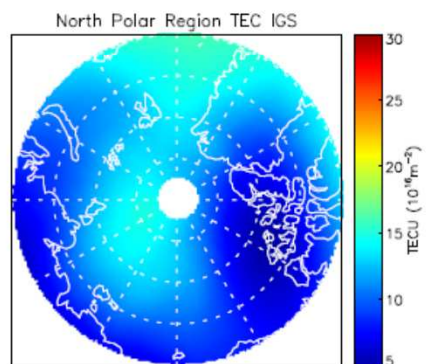
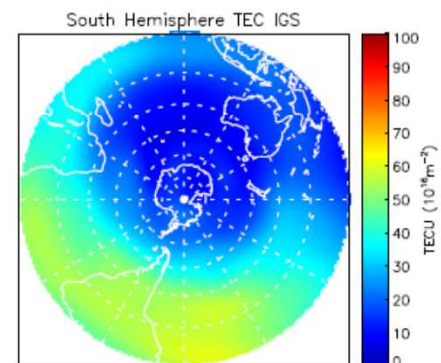
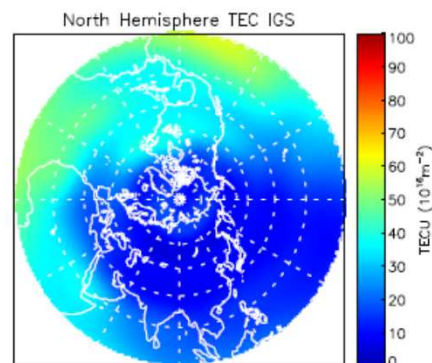
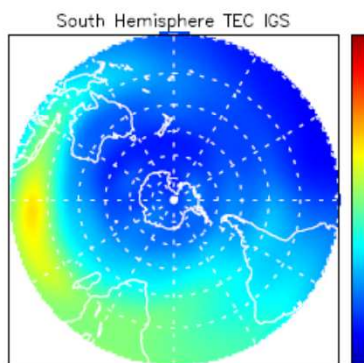
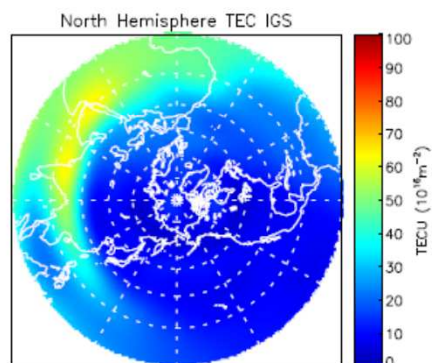
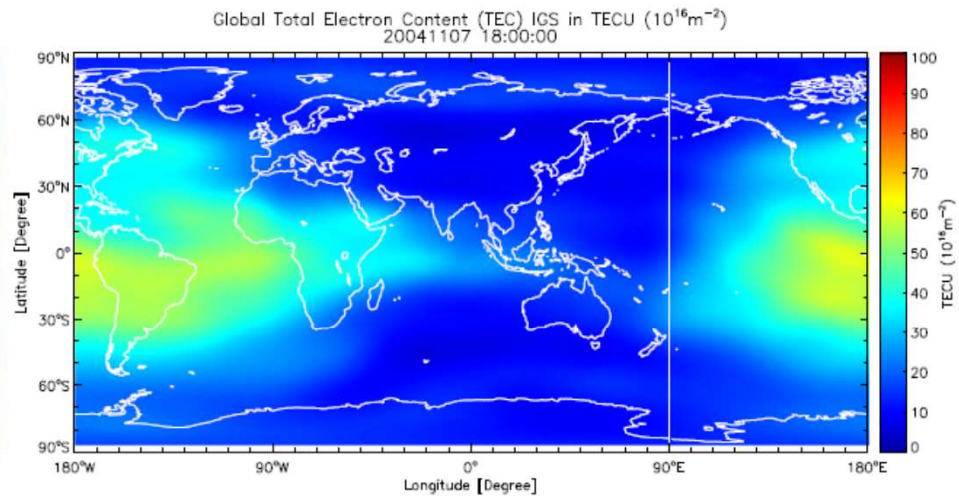
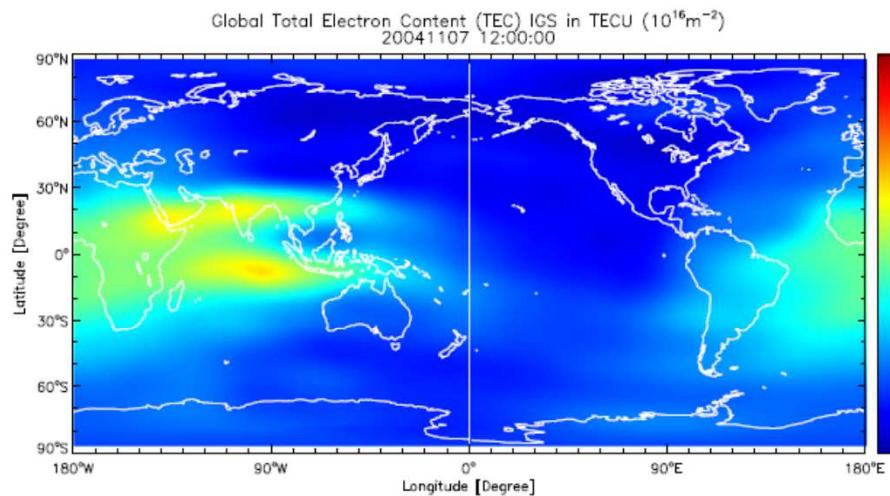


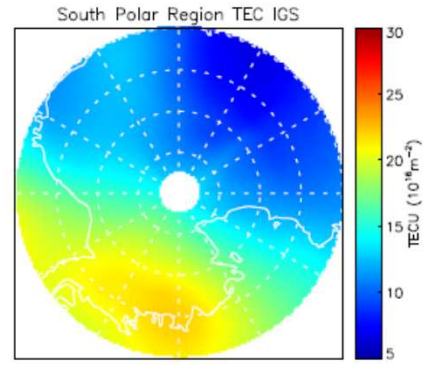
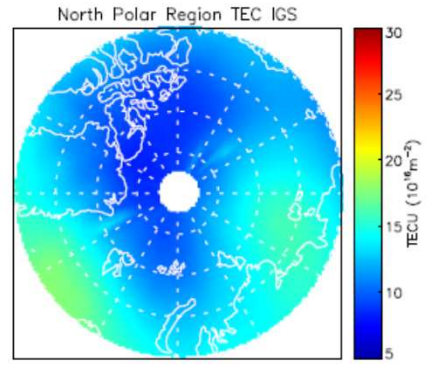
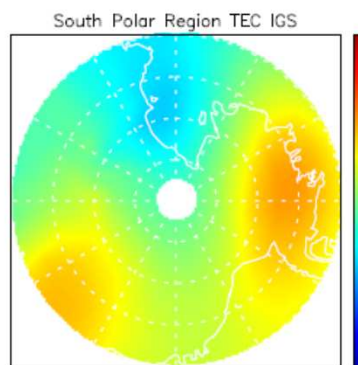
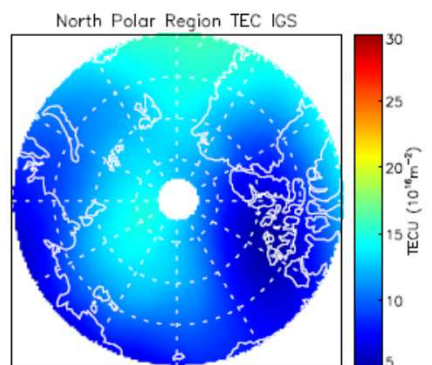
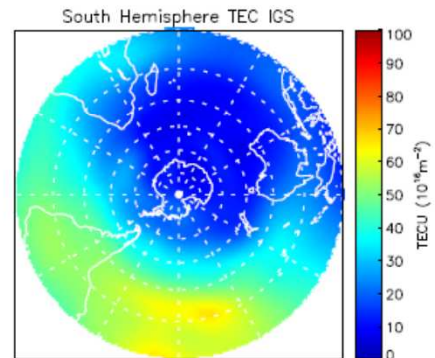
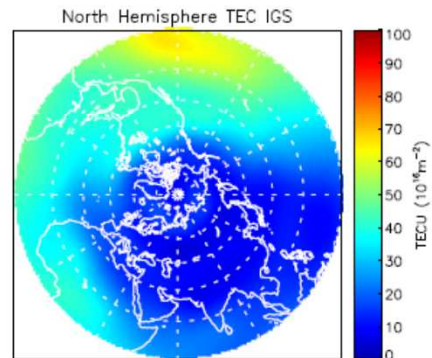
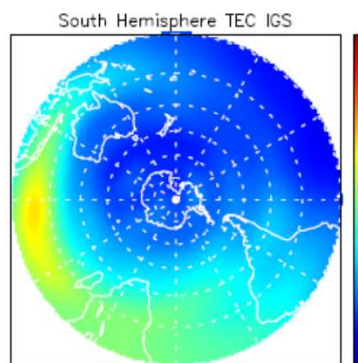
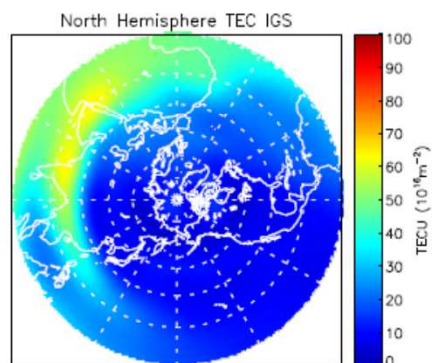
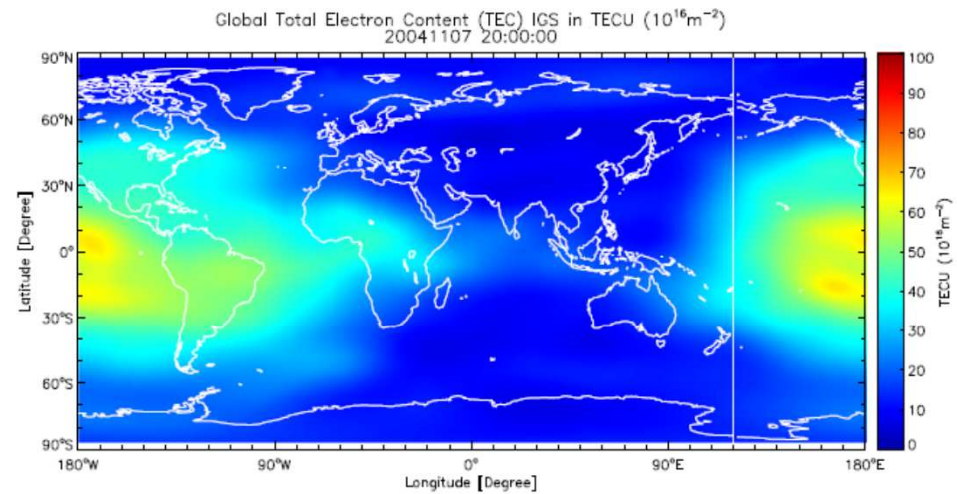
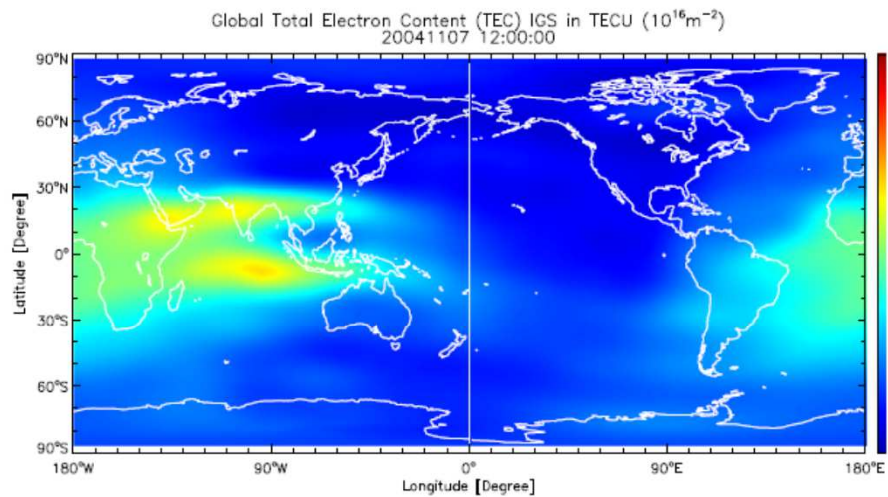
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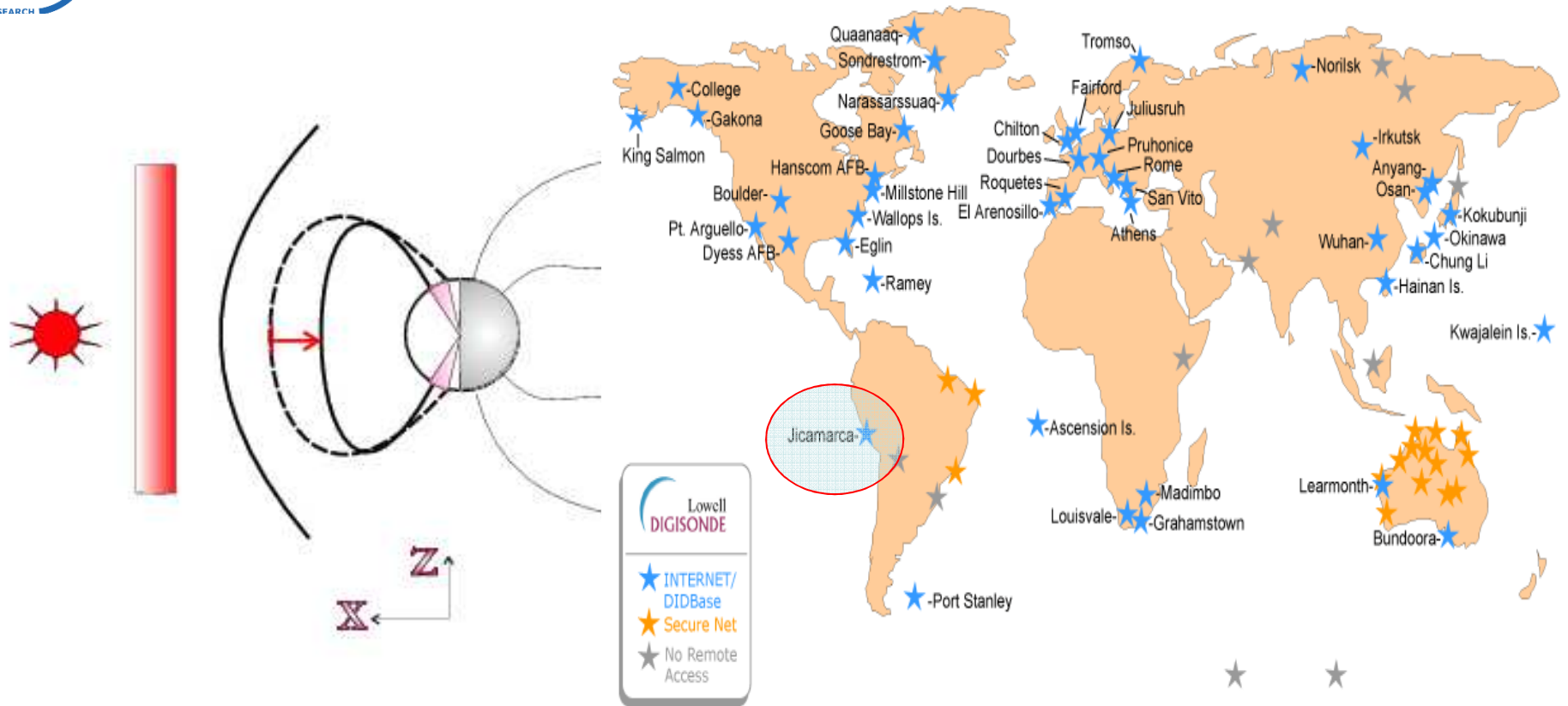
Circles(sites): foF2 (GIRO-IRI) MHz



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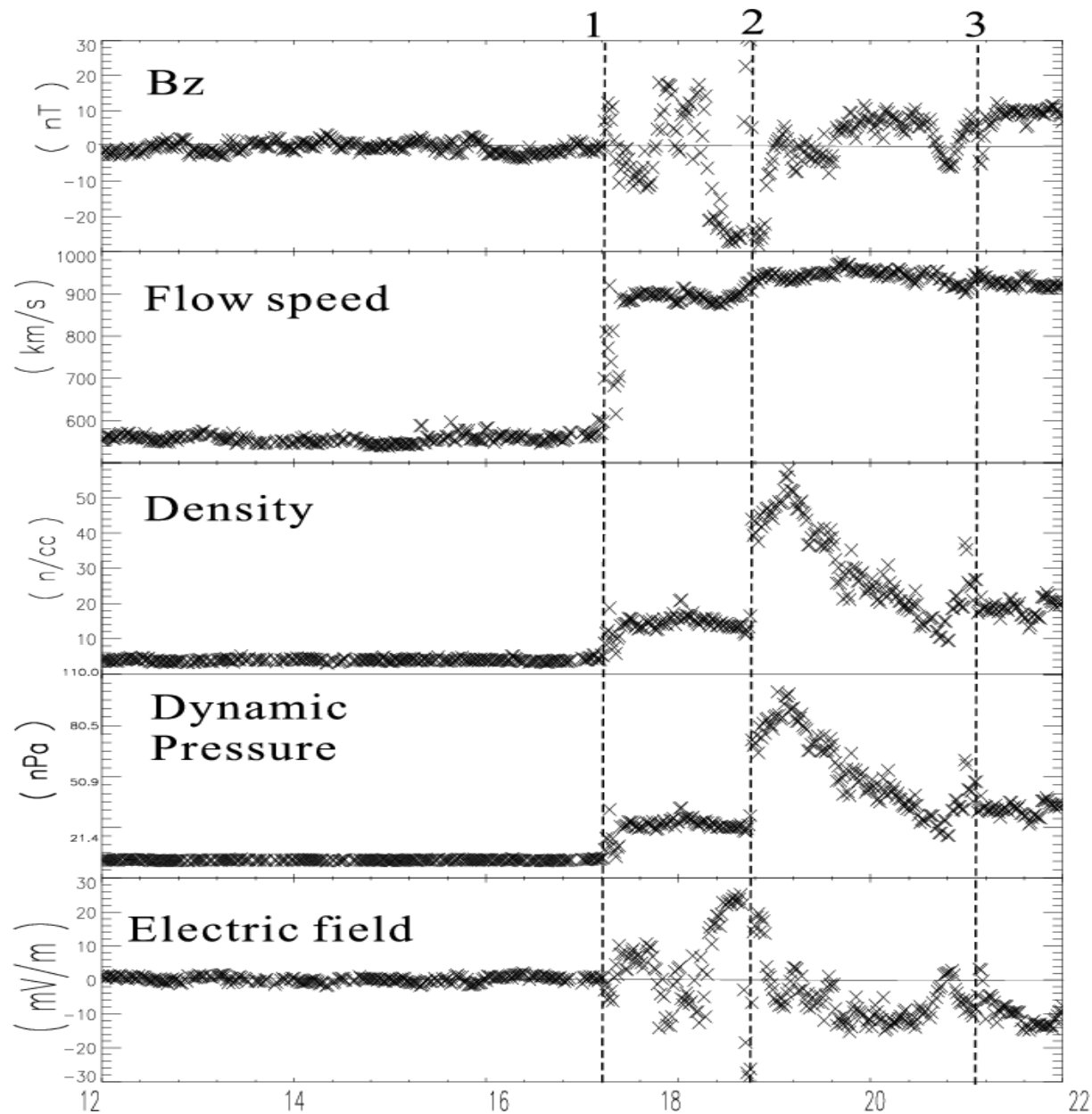


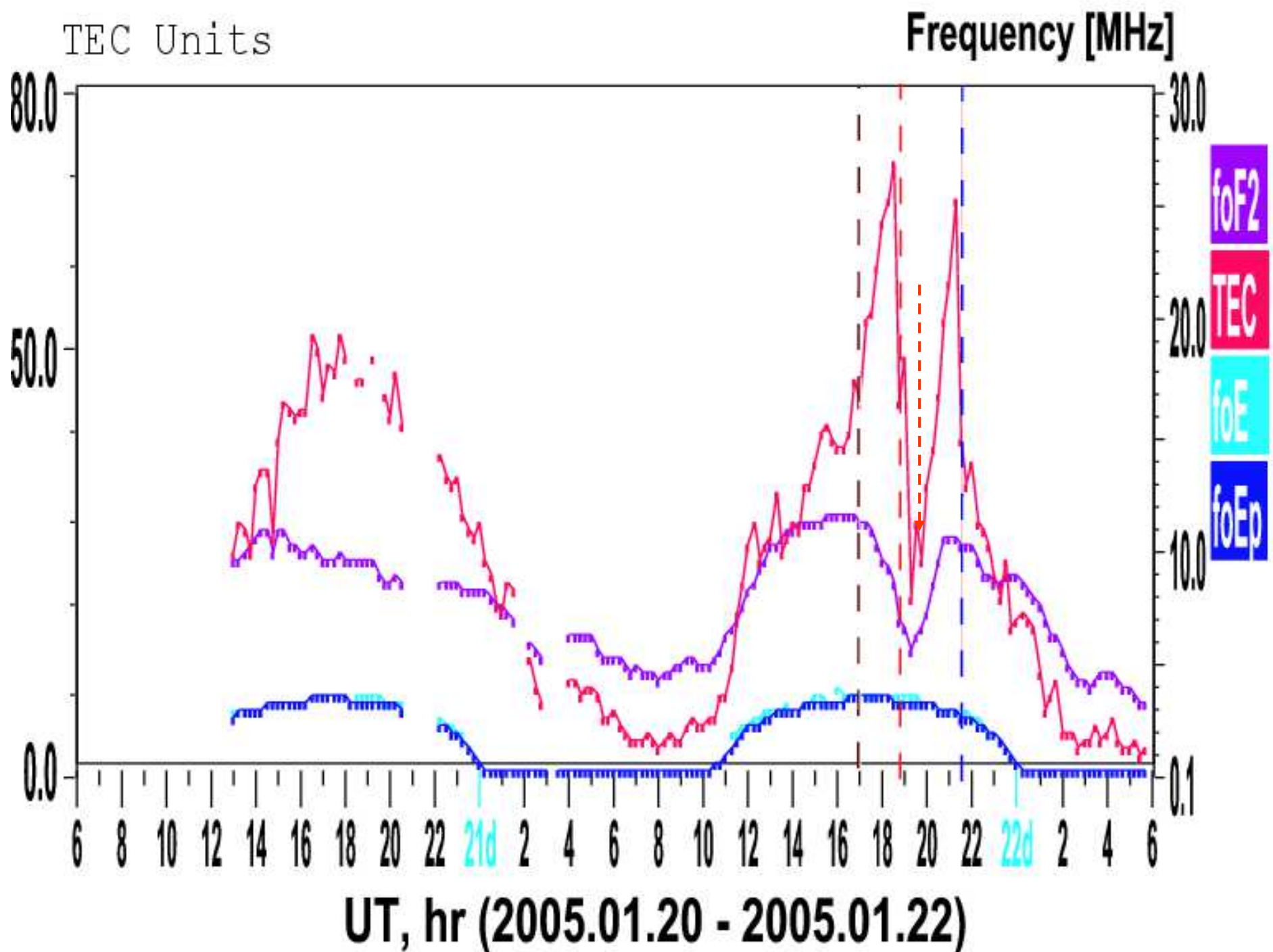


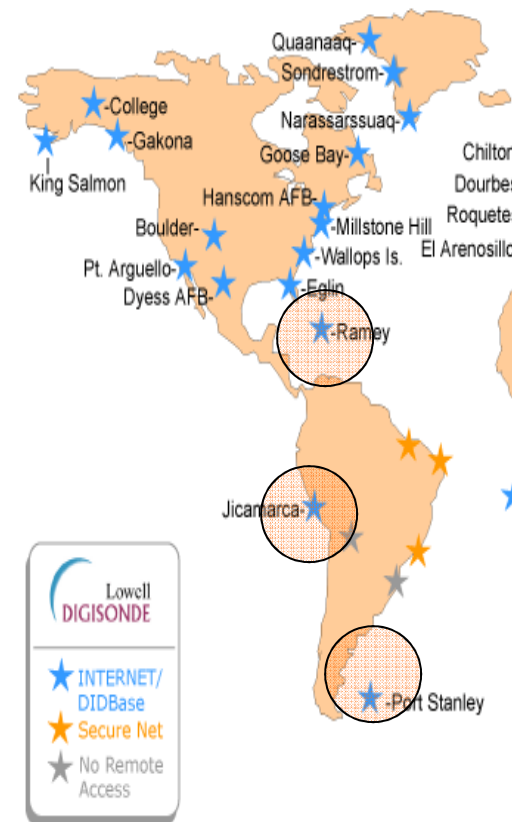
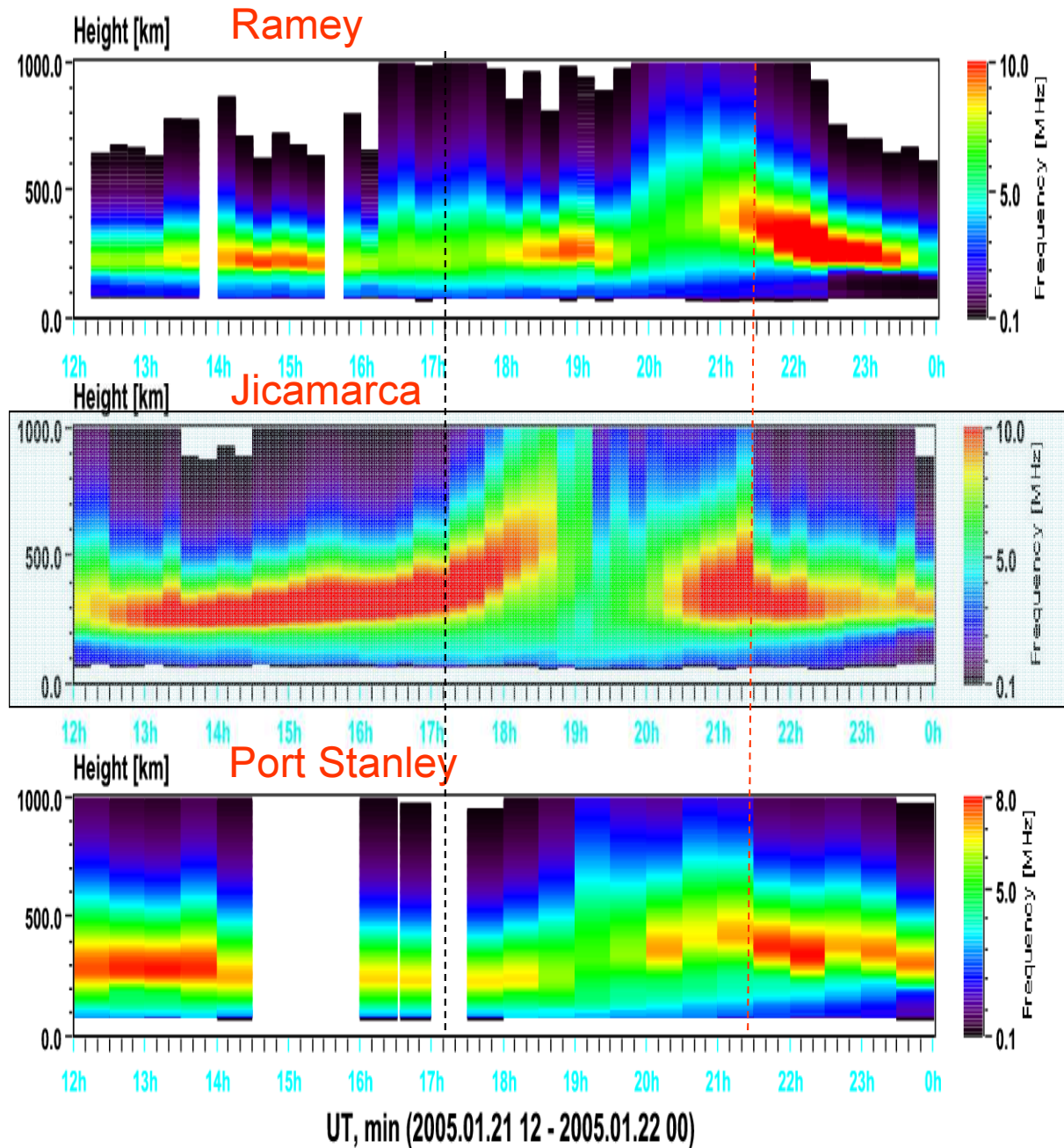


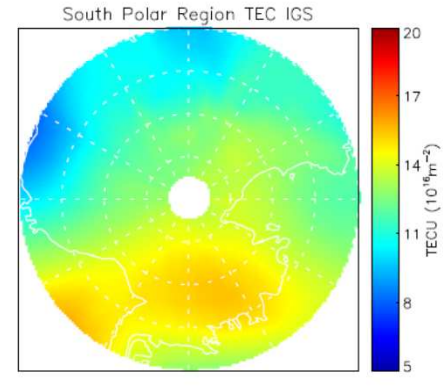
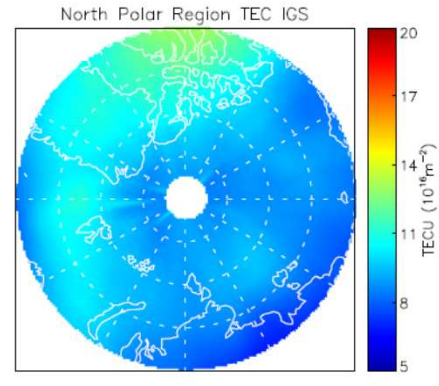
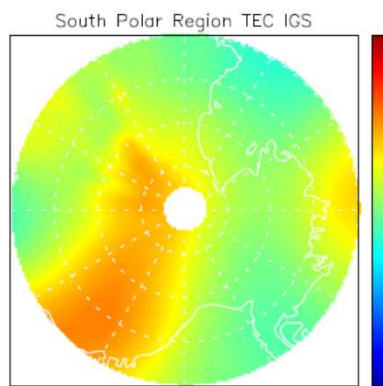
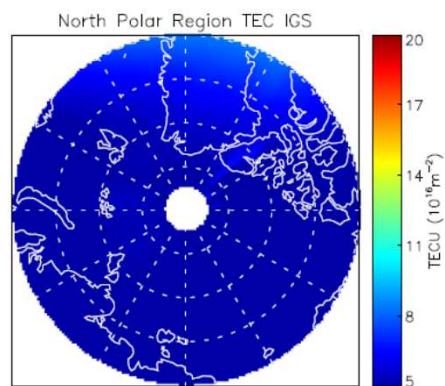
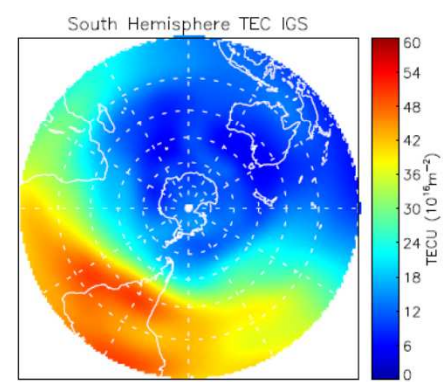
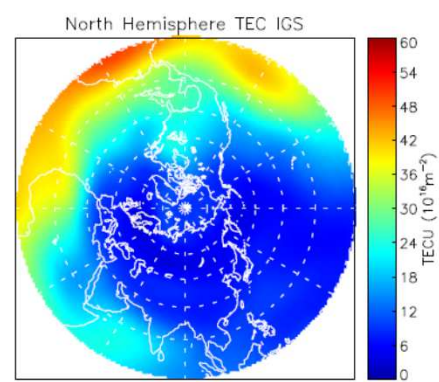
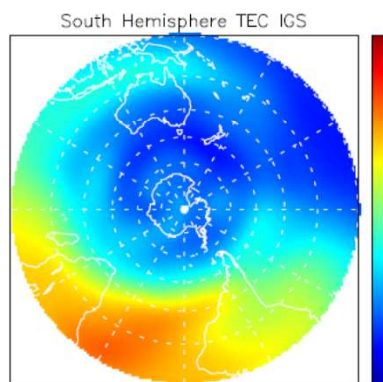
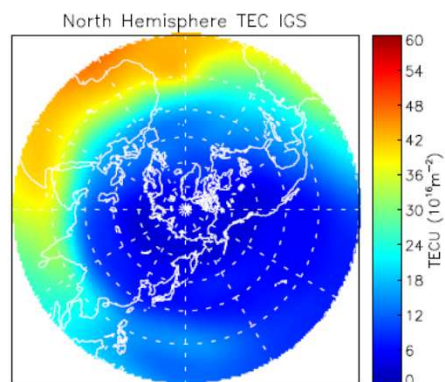
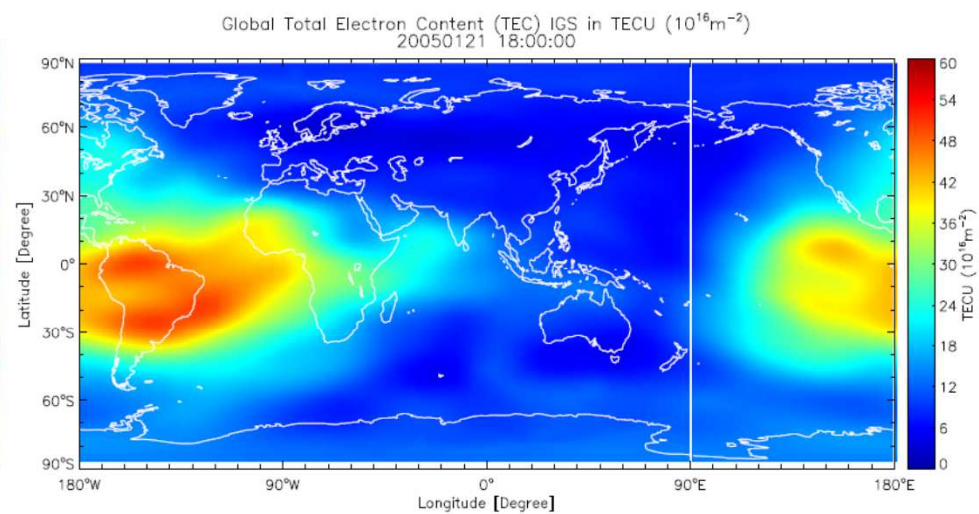
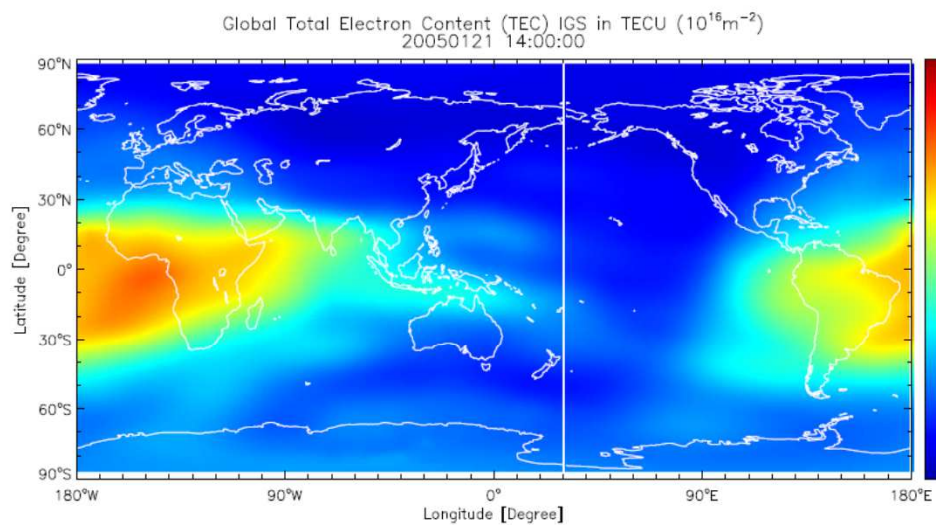
1. Equatorial Ionosphere Response

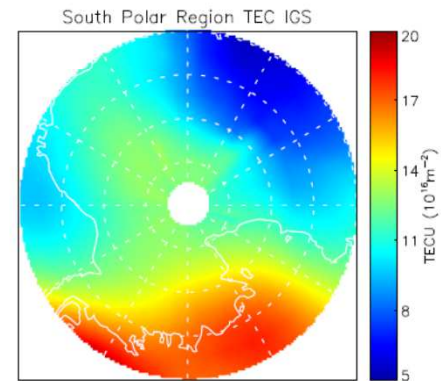
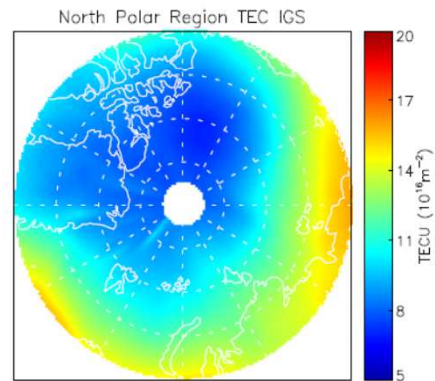
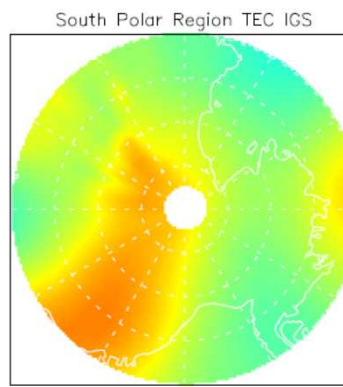
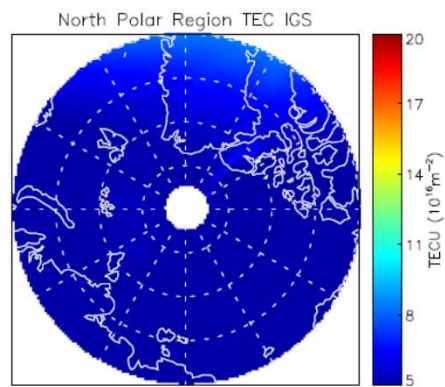
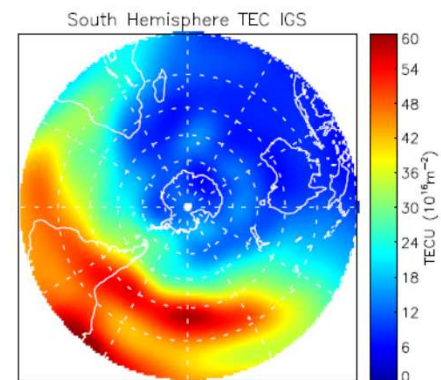
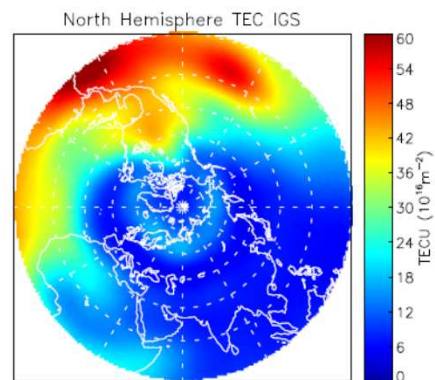
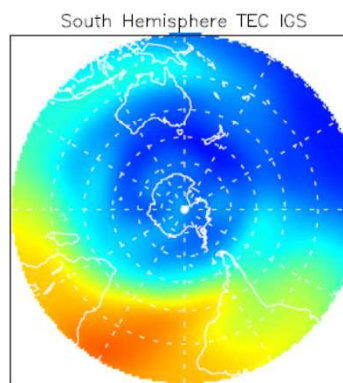
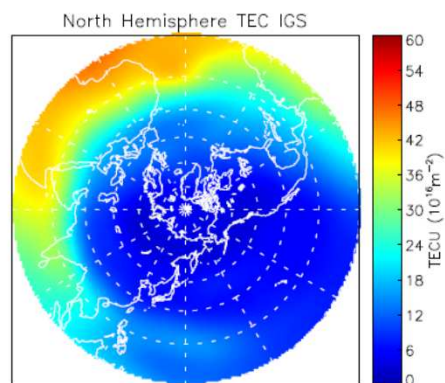
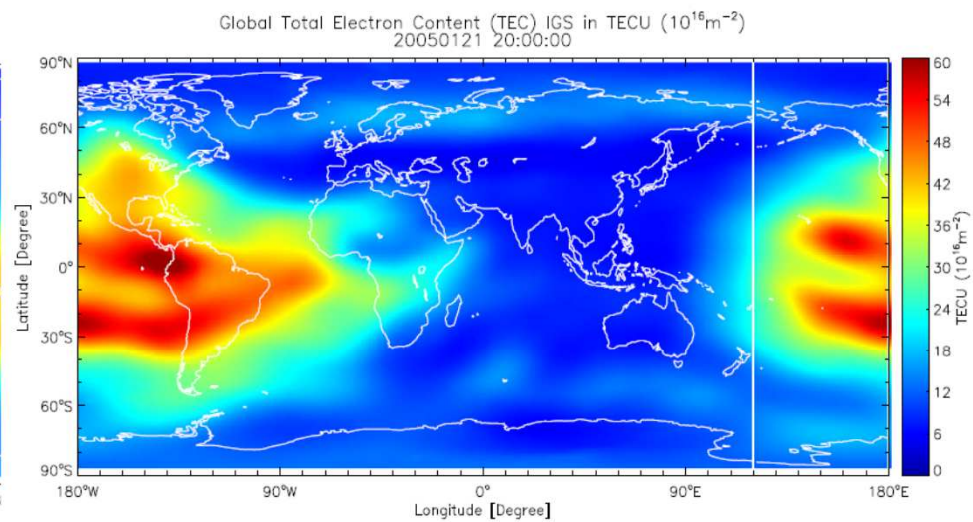
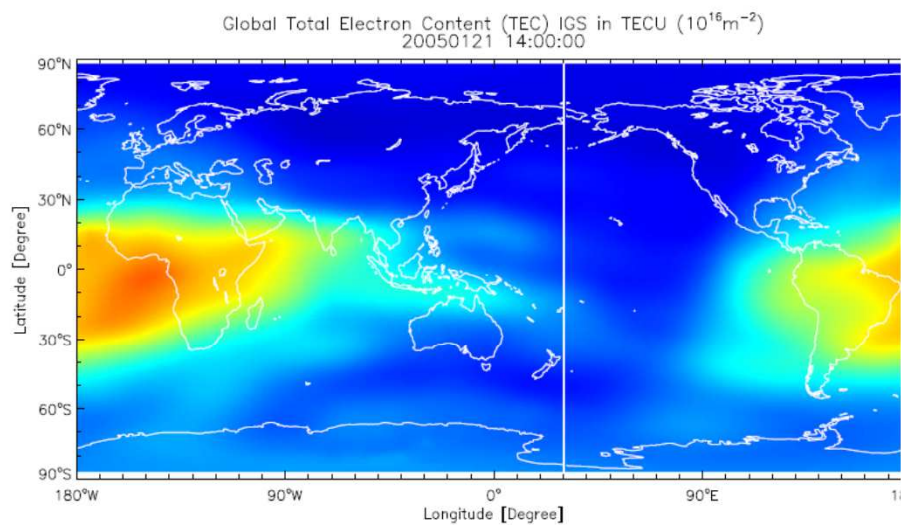
IMF/Solar Wind Jan 21, 2005



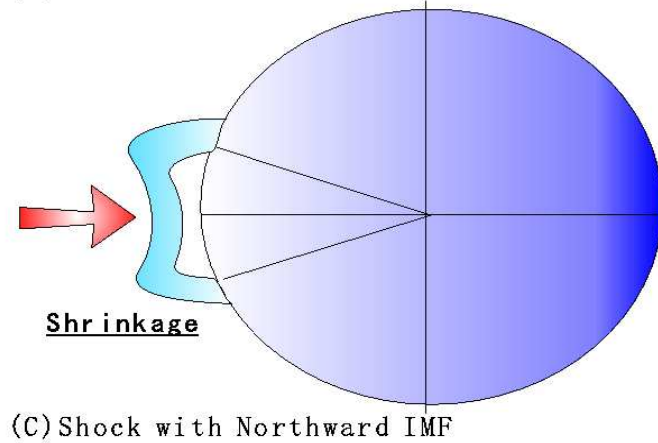
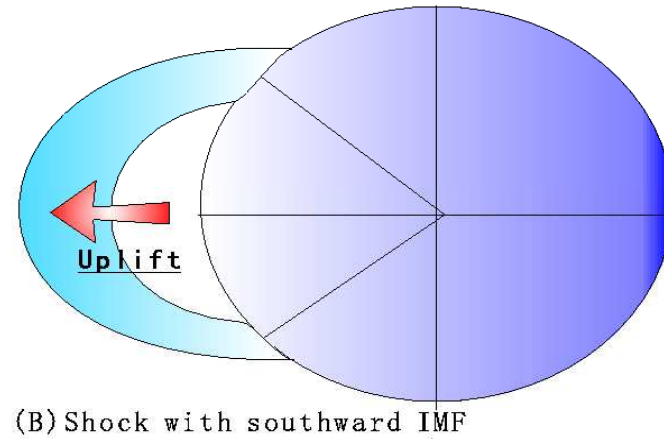
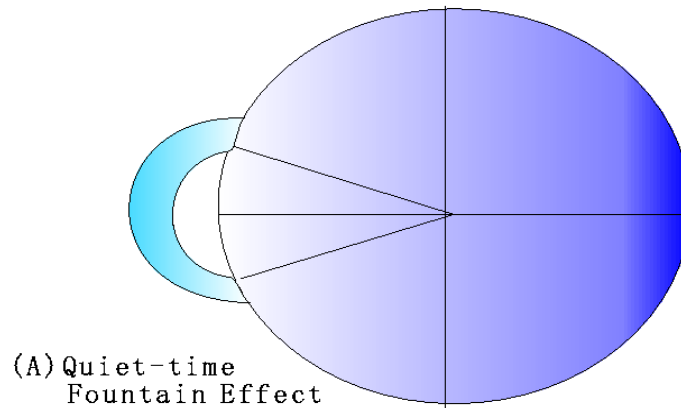








Super-Fountain Effect (After Tsurutani et al, 2006)

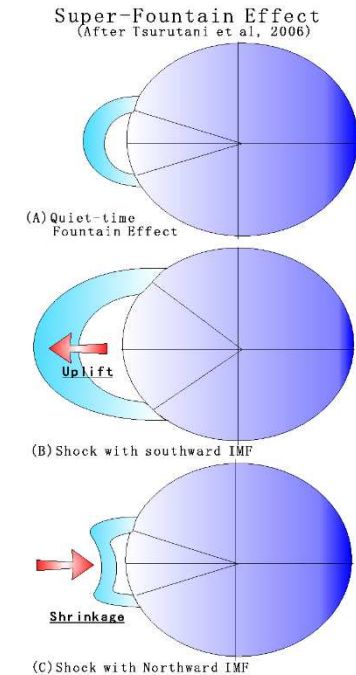
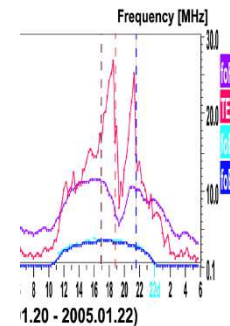


Summary

- **Equatorial ionospheric response**

- 1. quick response
- 2. rapid uplift (~ 66.7 m/s)
- 3. shrinkage (~ 42 m/s)
- 4. TEC sudden dropout

(The TEC is dropped from 72 TEC unit to 20 TEC unit, then recover to 68 TEC unit in about 2 hours)



- **Midlatitude ionospheric response**

- 1. Longitude effect
- 2. Latitude effect

