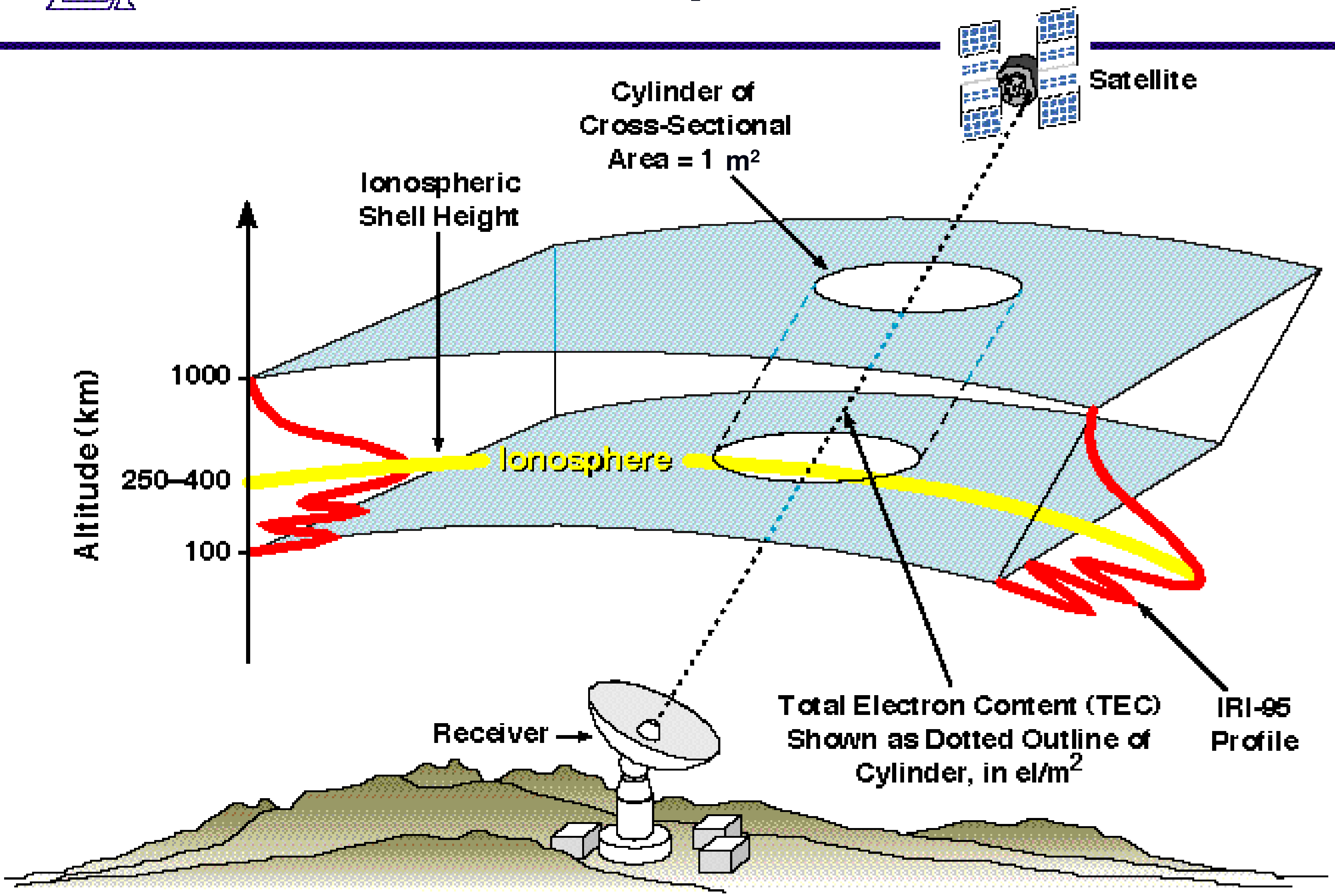
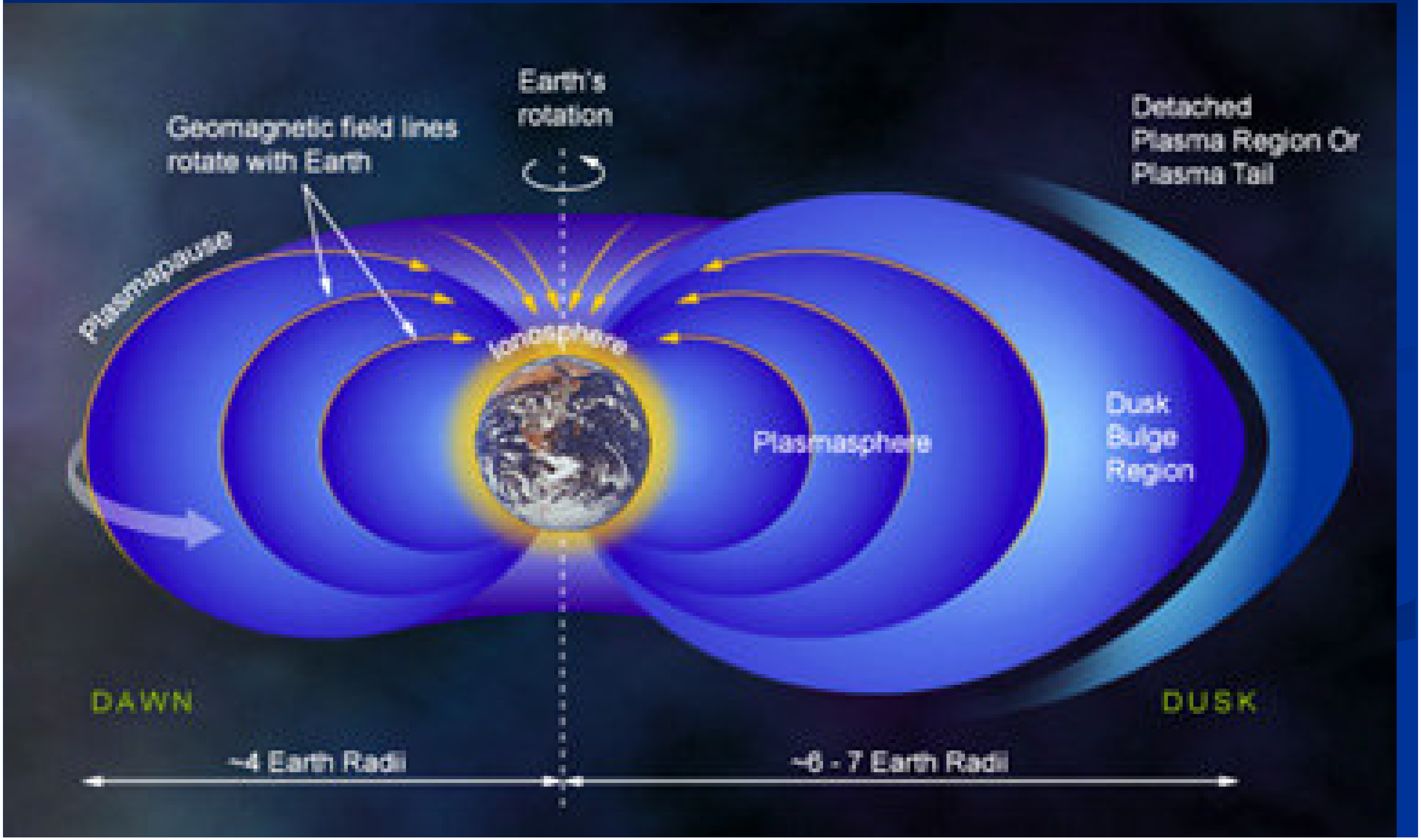
1. Ionosphere – What is it? Where is it? Why do we care?

Ionosphere


Satellite
Cylinder of Cross-Sectional Area = 1 m²
Ionospheric Shell Height
Altitude (km)
1000
250–400
100
Ionosphere
Receiver
Total Electron Content (TEC) Shown as Dotted Outline of Cylinder, in el/m²
IRI-95 Profile

Ionosphere and Plasmasphere



Sun – Earth System Overview

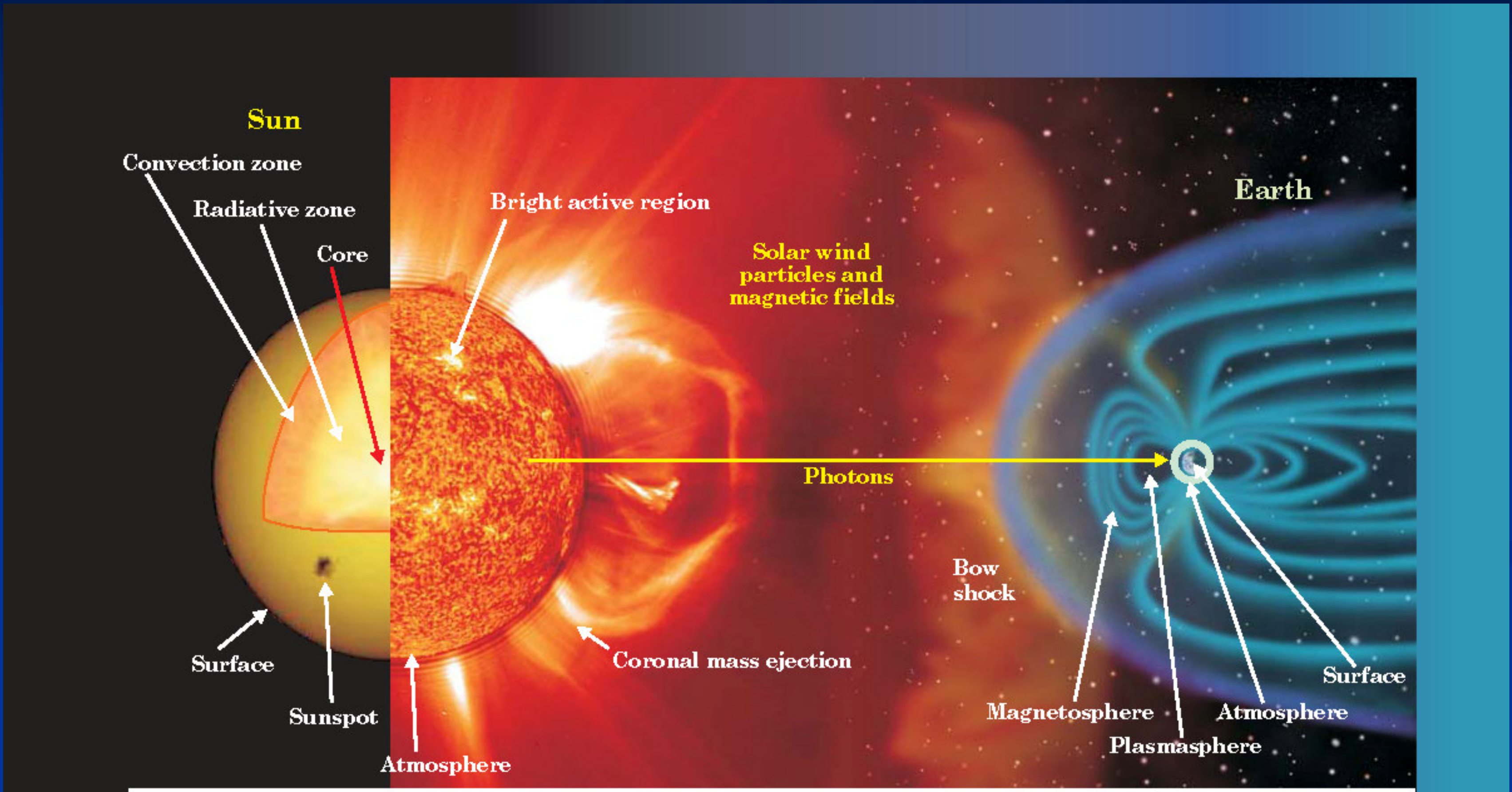


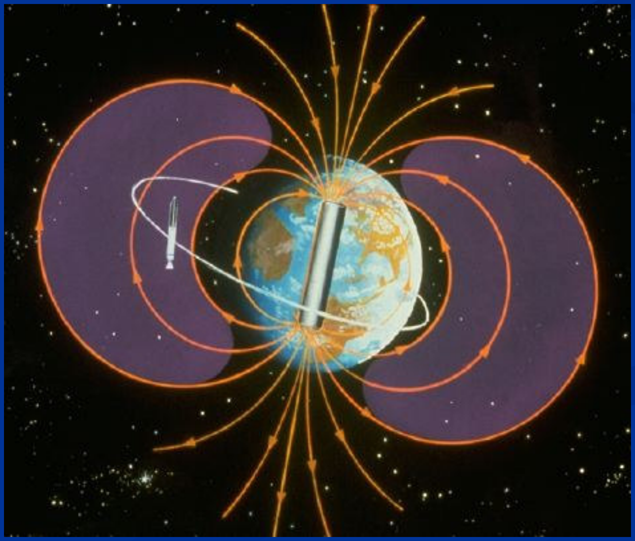
Figure 1. The Sun–Earth system. Energy in various forms is constantly flowing from the Sun to Earth. Dynamo action in the convection zone drives variations in this energy flow by producing sunspots and bright active regions. Photons from the Sun's surface and atmosphere reach Earth's surface and atmosphere, but particles and fields that together form the solar wind are intercepted by the magnetosphere (blue). Eruptive events such as coronal mass ejections, shown emerging from the Sun's atmosphere into the solar wind, perturb the magnetosphere and allow energetic particles to penetrate Earth's atmosphere in the polar regions, where the magnetic field lines are anchored. (Figure not to scale.)

Earth's Upper Atmosphere (and most of the Solar System): A Natural Plasma

- Plasma is the fourth state of matter

- The universe is filled with plasma

- Extreme ultraviolet output from the Sun creates a plasma in Earth's upper atmosphere through ionization



2. What is it made of? Scale Heights. Different regions (D/E/F - importance of different processes in different regions).
How does it form? Production/Loss Mechanisms

Distinct Regions in the Ionosphere Form because:

The Solar spectrum deposits its energy at various heights depending on the absorption characteristics of the atmosphere.

The physics of recombination depends on the atmospheric density which changes with height.

The composition of the atmosphere changes with height

Scale Height

A **scale height** is a term often used in scientific contexts for a distance over which a quantity decreases by a factor of e. It is usually denoted by the capital letter *H*.

For planetary atmospheres, it is the vertical distance upwards, over which the pressure of the atmosphere decreases by a factor of *e.* The scale height remains constant for a particular temperature. It can be calculated by

- H = kT/Mg

where:

k = gas constant = 8.314 J·(mol K)–1

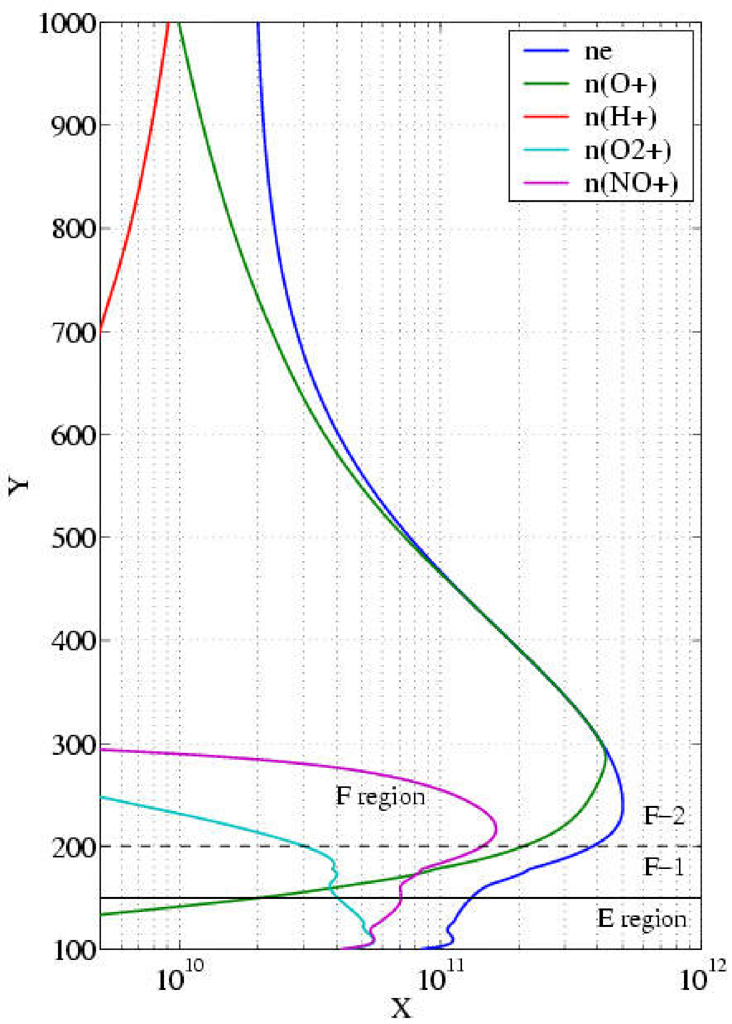
T = mean molecular temperature in kelvins

M = mean molecular mass of dry air (units kg·mol–1)

g = acceleration due to gravity on planetary surface (m/s²)

http://www.answers.com/topic/scale-height?cat=technology

Composition



At heights over 100 km, molecular diffusion means that each molecular atomic species has its own scale height.

Dominant Constituent

0-200 Km	Nitrogen
200-1000 Km	Oxygen
1000-2500 Km	Helium
2500 – 8-14 Earth Radii	Hydrogen

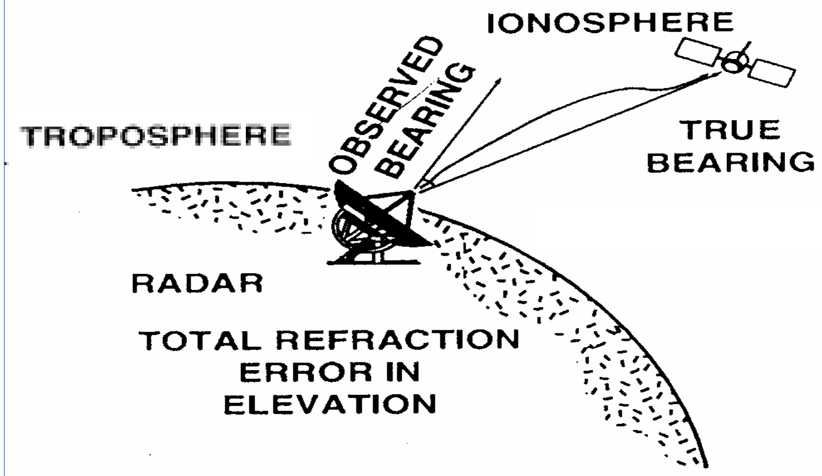
Introduction to the IONOSPHERE

3. Index of refraction; definition of plasma frequency and gyrofrequency (introduction of magnetic field).

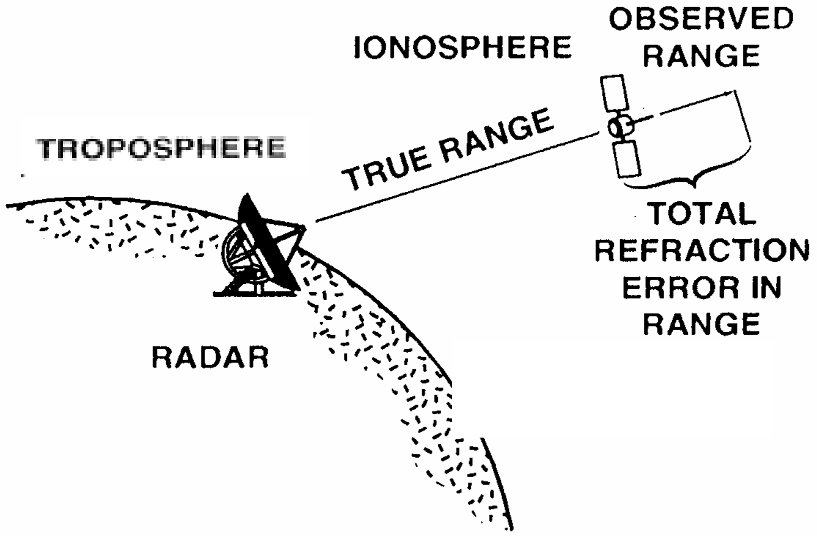
Radio Waves Refract just like light

Illustration of Atmospheric Effects

Elevation Refraction



Range Delay



INDEX OF REFRACTION

$$n^2 = \underline{1} - \frac{\underline{X(1-X)}}{(1-X) - \frac{1}{2}Y_T^2 \underline{\pm} \left(\frac{1}{4}Y_T^4 + (1-X)^2 Y_L^2\right)^{1/2}}$$

$$X = \frac{\omega_N^2}{\underline{\omega^2}} \qquad Y = \frac{\omega_H}{\underline{\omega}} \qquad \omega_N = \left(\frac{\underline{Ne^2}}{\varepsilon_0 m_e}\right)^{1/2} \qquad \omega_H = \frac{\underline{e|B|}}{m_e}$$

ω = the angular frequency of the radar wave,

$Y_L = Y\cos\theta$, $Y_T = Y\sin\theta$,

θ = angle between the wave vector $\bar{k}$ and $\bar{B}$,

$\bar{k}$ = wave vector of propagating radiation,

$\bar{B}$ = geomagnetic field, N = electron density

e = electronic charge, m_e = electron mass,

and ε_0 = permittivity constant.

4. Debye length/Debye sphere why important

5. Debye length/Debye sphere

The Debye length is a measure of the plasma’s ability to shield out electric potentials that are applied to it.

The Debye length marks the division between different regimes of plasma’s behavior; i.e. collective plasma motion versus that of individual particle motion.

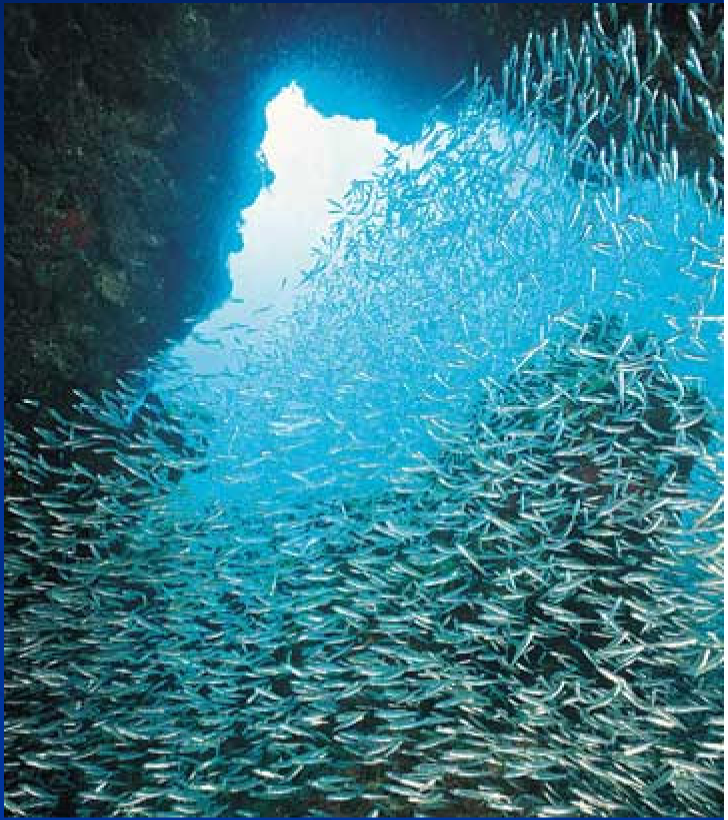
Plasma phenomenon that take place over distances greater than the Debye length must be described in terms of collective behavior of the plasma.

Debye Length

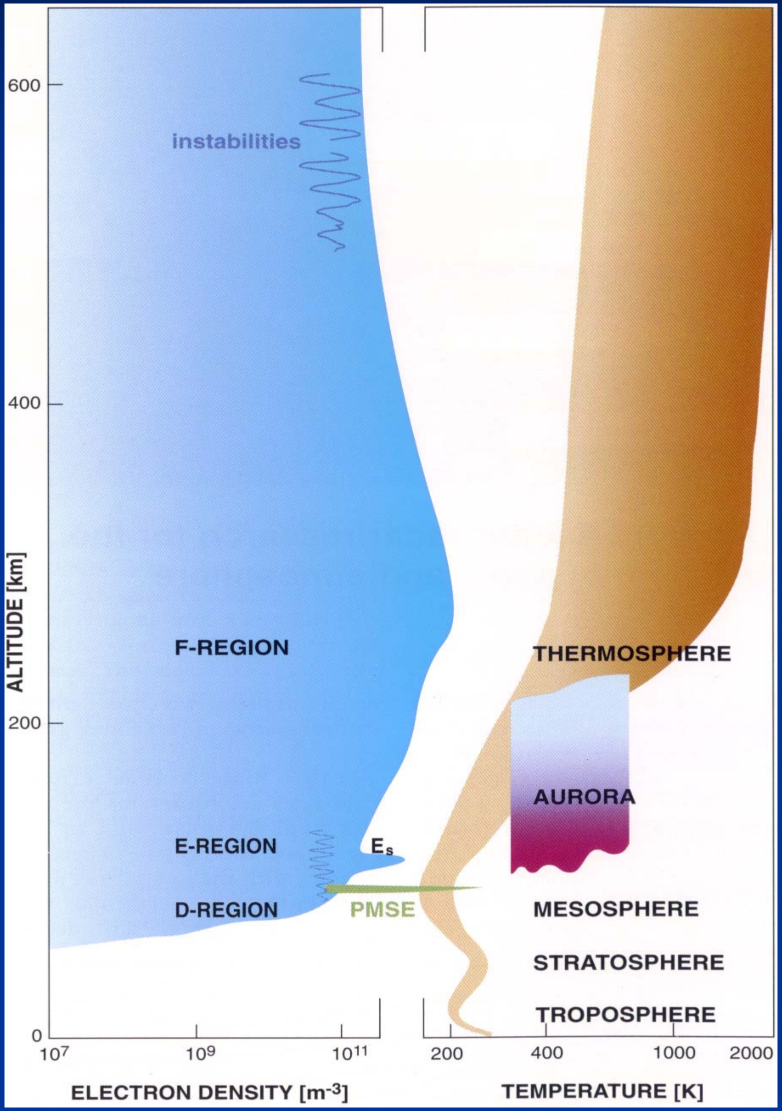
1. Plasma will not support large potential variations (i.e. will seek to maintain charge neutrality) over distances larger than the Debye length.

2. Potential gradients that do exist have a characteristic length parameter equal to a Debye length

3. These potential gradients are characterized by a natural oscillation frequency known as the plasma frequency.



Debye length dependence

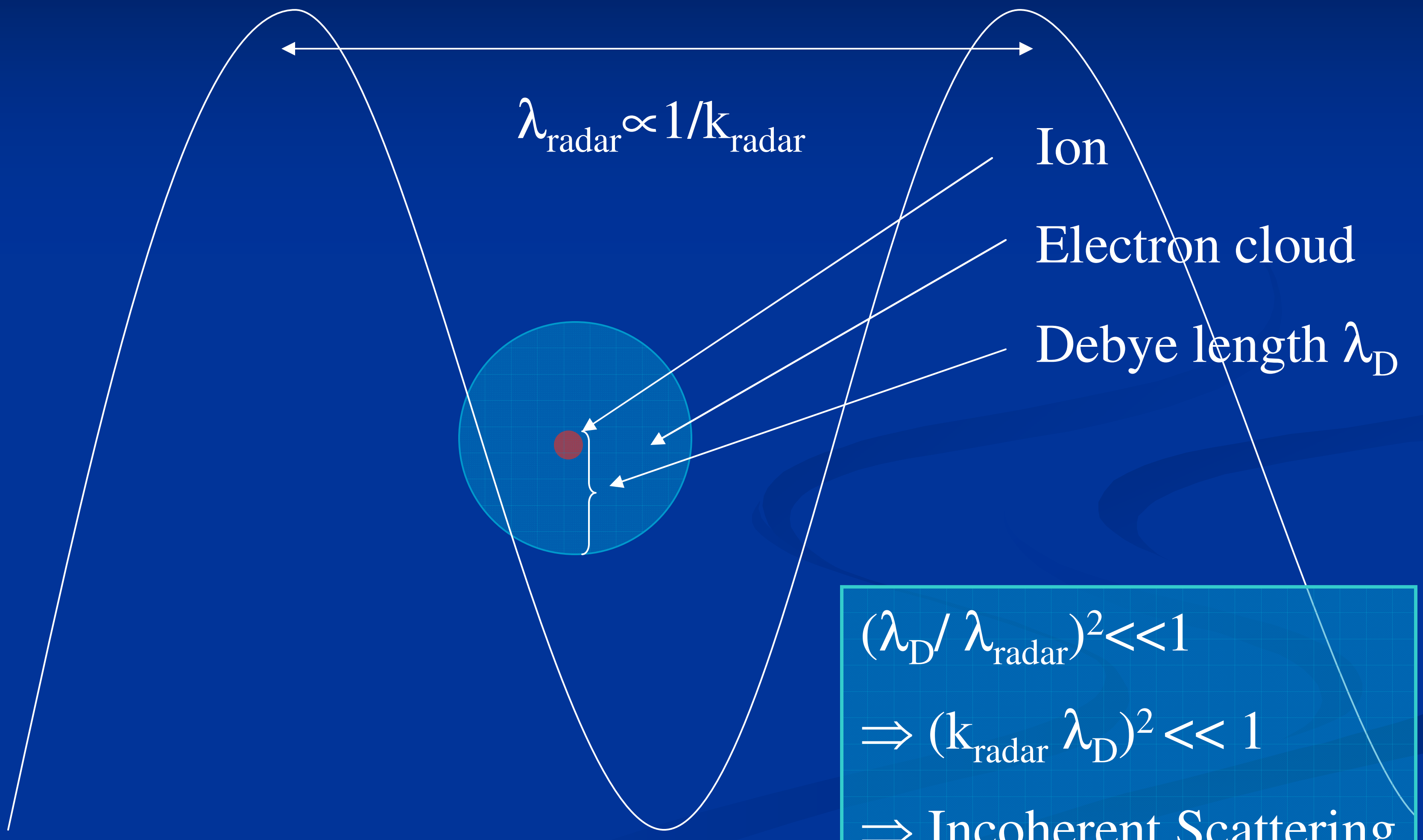


$$\lambda_D \simeq 69\sqrt{\mathrm{T}_e/\mathrm{n}_e}$$

The Debye length is increasing with altitude - from a few millimeter in the D-region up to meters in the magnetosphere

Debye length in E and F region is 0.1 to 1 cm.

Debye cutoff



$\lambda_{radar} \propto 1/k_{radar}$

Ion

Electron cloud

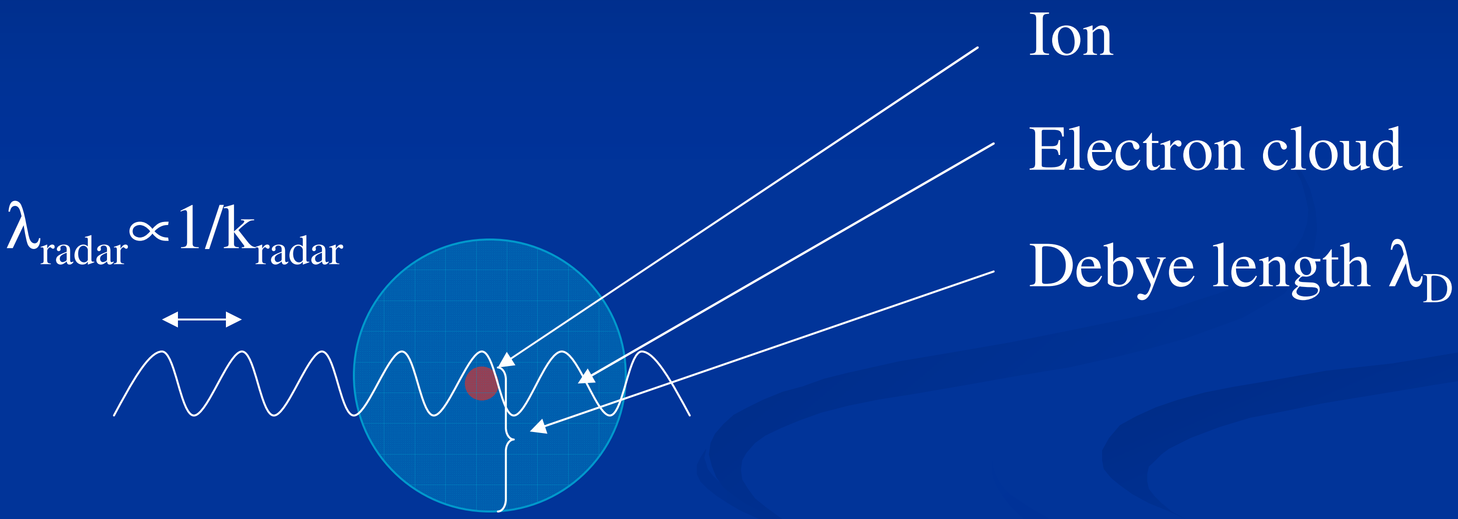
Debye length λ_D

$(\lambda_D / \lambda_{radar})^2 << 1$

$\Rightarrow (k_{radar}\ \lambda_D)^2 << 1$

$\Rightarrow$ Incoherent Scattering

Debye cutoff



$\lambda_{radar} \propto 1/k_{radar}$

Ion

Electron cloud

Debye length λ_D

$(\lambda_D / \lambda_{radar})^2 > 1$

$\Rightarrow (k_{radar} \lambda_D)^2 > 1$

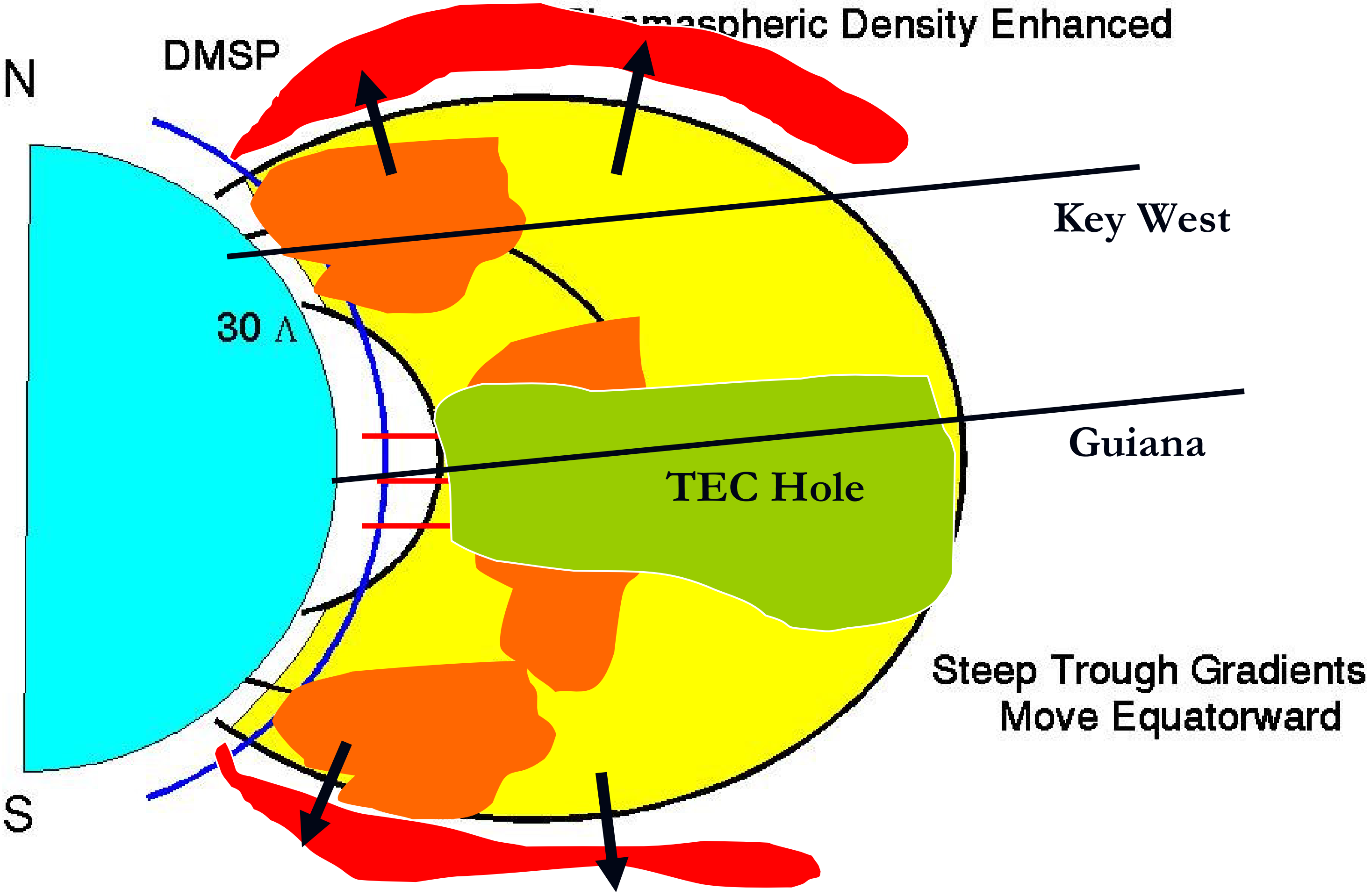
$\Rightarrow$ Not Incoherent Scattering

5. Different regions of ionosphere

1) Low latitudes
2) Mid-latitudes
3) High-latitudes

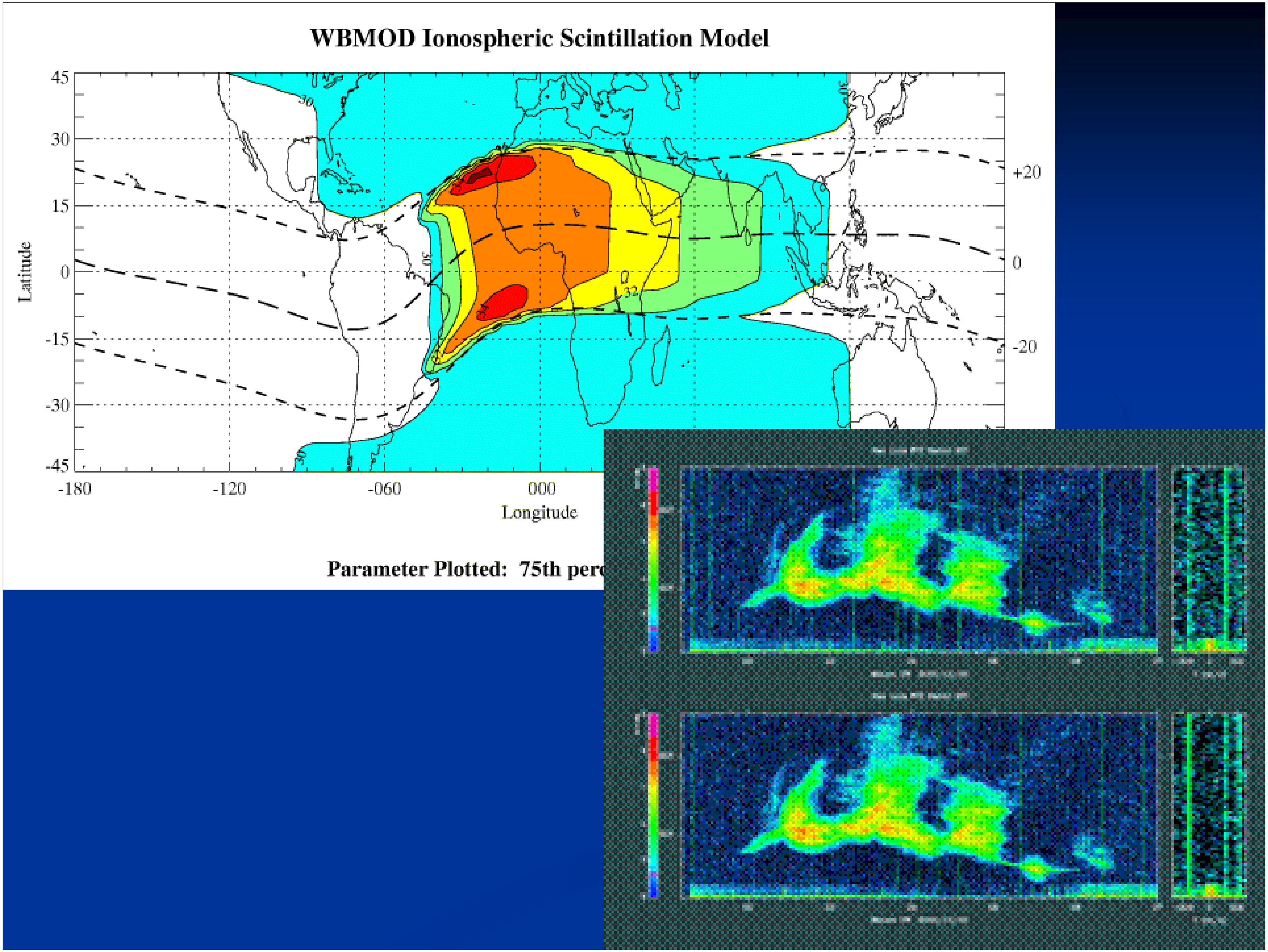
Jicamarca ISR - Low Latitudes

Effects of Penetration Electric Fields



GPS Samples
Ionosphere/Plasmasphere TEC

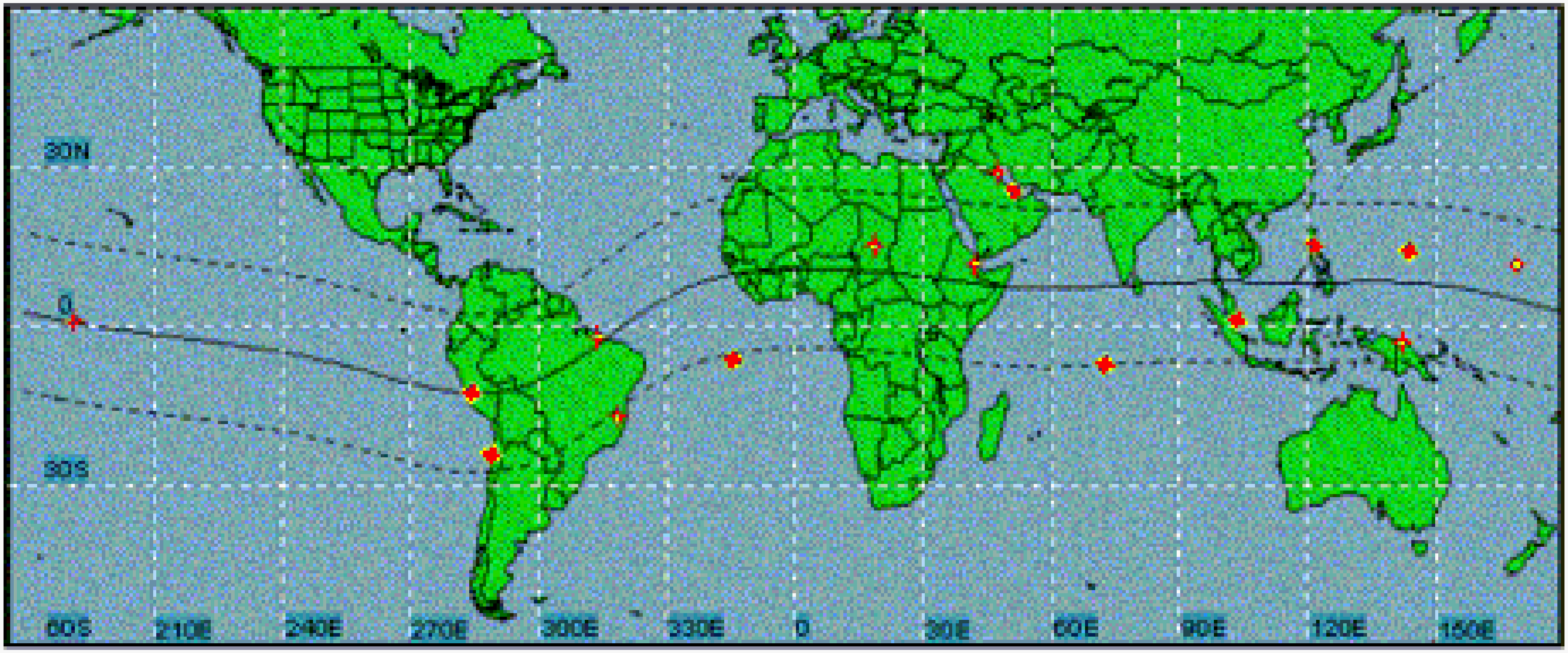
WBMOD Ionospheric Scintillation Model



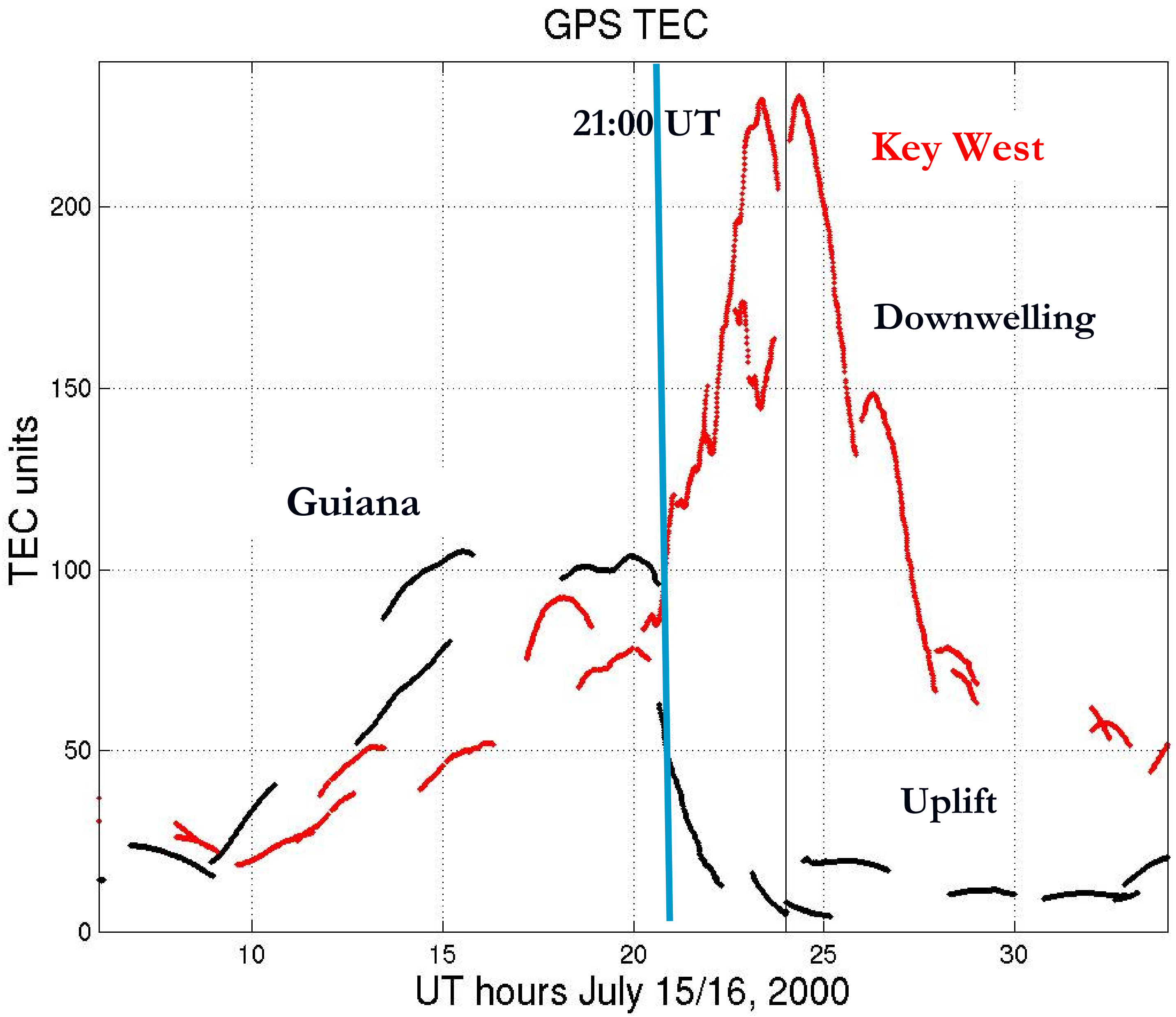
Parameter Plotted: 75th perc

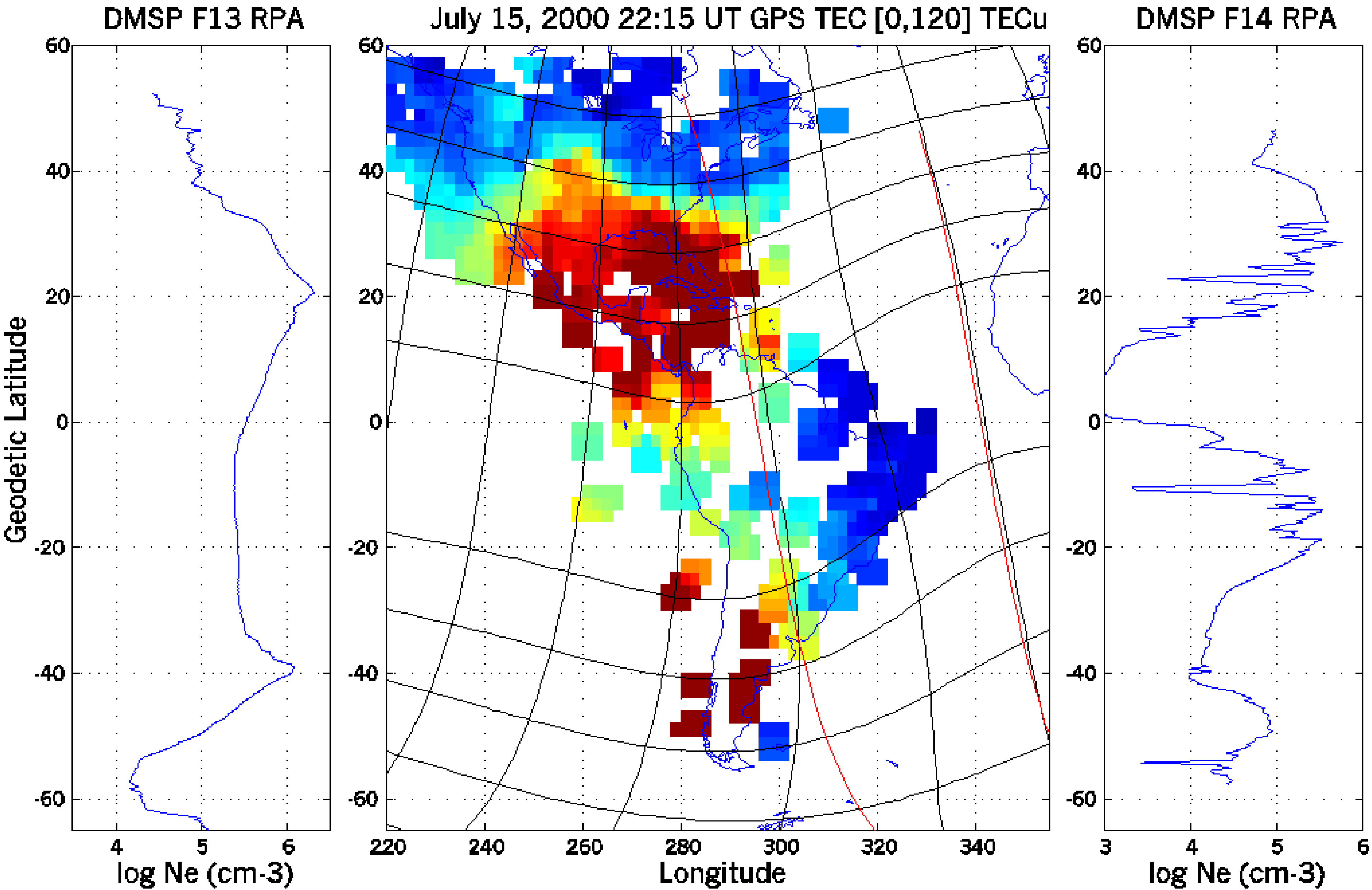
SCINDA

Equatorial SCINDA Sites



◆ Existing Site ✦ Proposed Site


GPS TEC
21:00 UT
Key West
Downwelling
Guiana
Uplift
TEC units
0
50
100
150
200
10
15
20
25
30
UT hours July 15/16, 2000

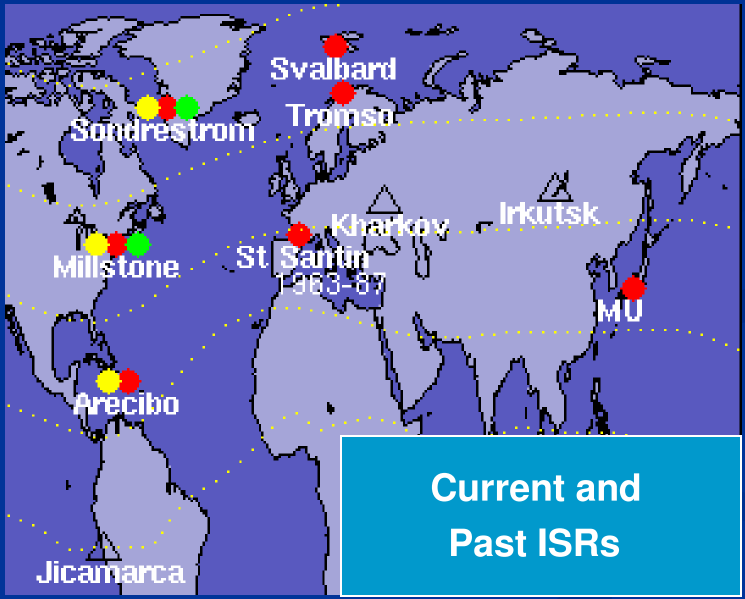

DMSP F13 RPA
July 15, 2000 22:15 UT GPS TEC [0,120] TECu
DMSP F14 RPA
Geodetic Latitude
60
40
20
0
-20
-40
-60
4
5
6
log Ne (cm-3)
220
240
260
280
300
320
340
Longitude
3
4
5
6
log Ne (cm-3)

IS Coordinated Science at Mid-Latitudes

Storm Studies

Instabilities

SED

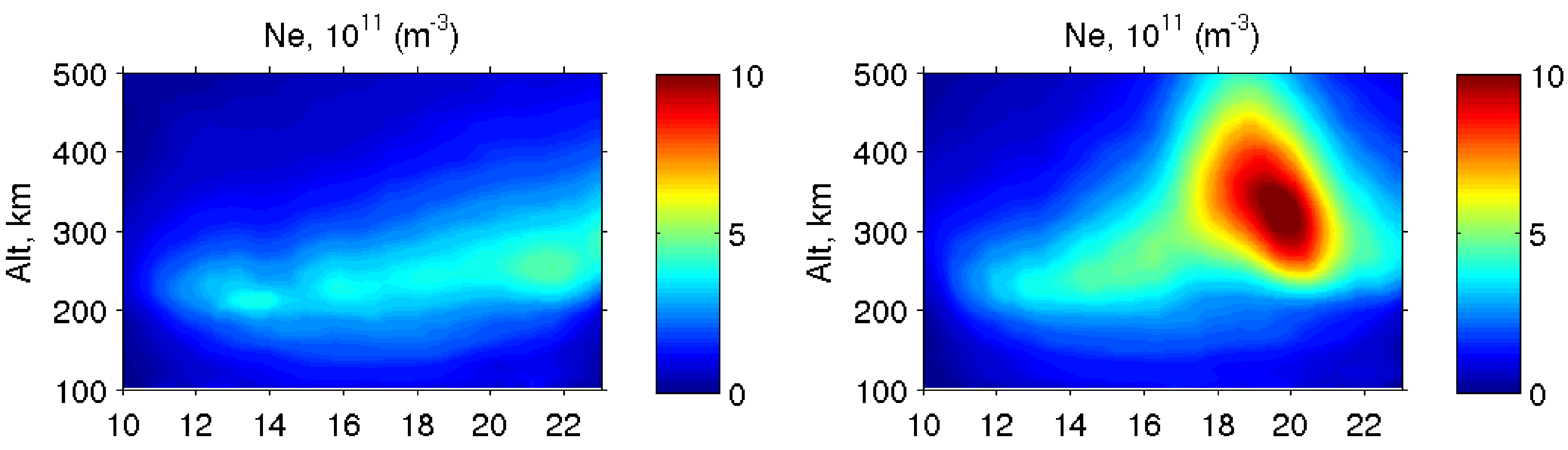


Current and Past ISRs

Positive Phase Storm Studies

Millstone Hill ISR, Ne

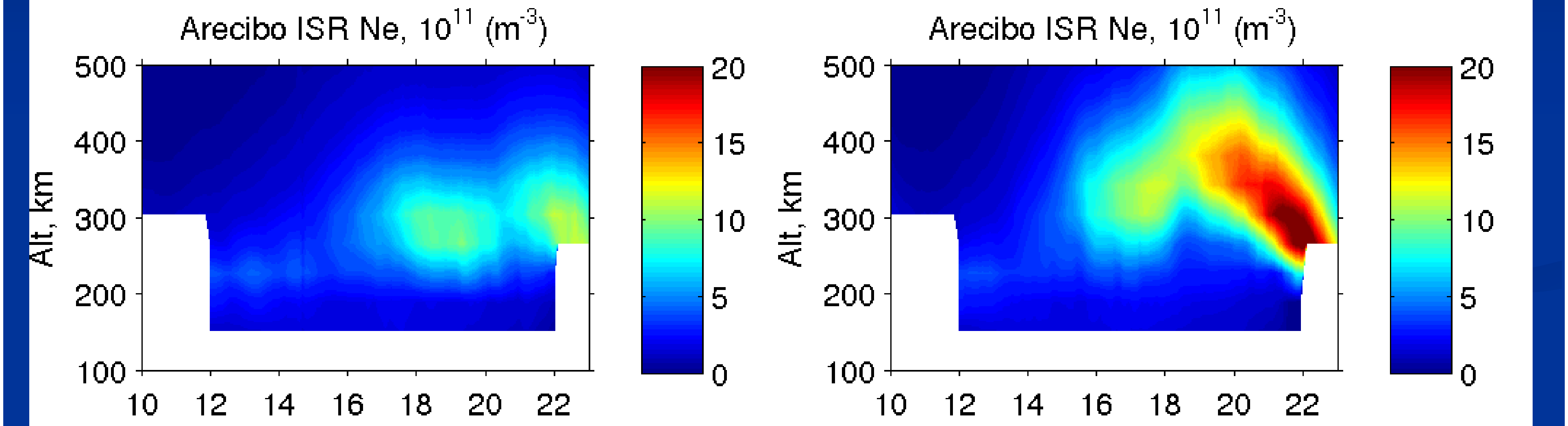
Sep 8, 2005 Sep 10, 2005



- Daytime positive phase lasting for ~13 hours
- Background increase after the sunrise; main increase after 17 UT
- Maximum Ne at 19-20 UT
- Increase in h_mF2 by ~100 km
- Decrease in Te by up to ~1000K, enhancement in Ti by 50-200K

Arecibo Ne

Sep 8, 2005 Sep 10, 2005



Positive storm phase after ~15 UT

Maximum Ne at 21-22 UT, i.e. 1.5-2 hours later than at Millstone Hill

Uplift of the F-layer

Positive phase mechanisms

- Increase in oxygen density (*Burns et al, 1991, 1995*)
- Equatorward meridional wind (*Jones and Rishbeth, 1971*)
- Electric field (*Lanzerotti et al., 1975, Huang et al., 2005, Swisdak et al., 2006*)
- Downward protonospheric plasma fluxes

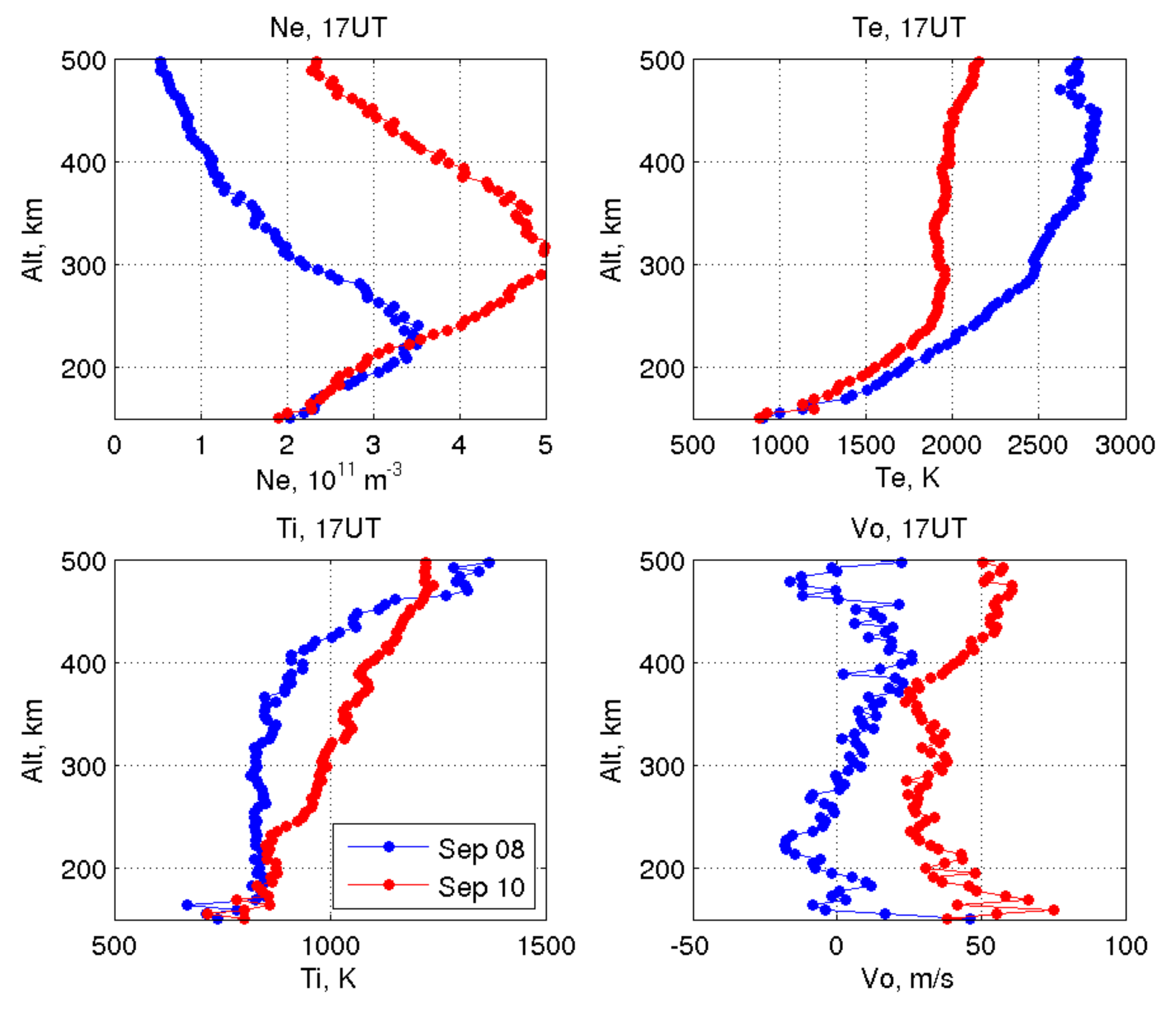
Millstone Hill ISR: Ne, Te, Ti, Vi at 17 UT

Ne

Te

Ti

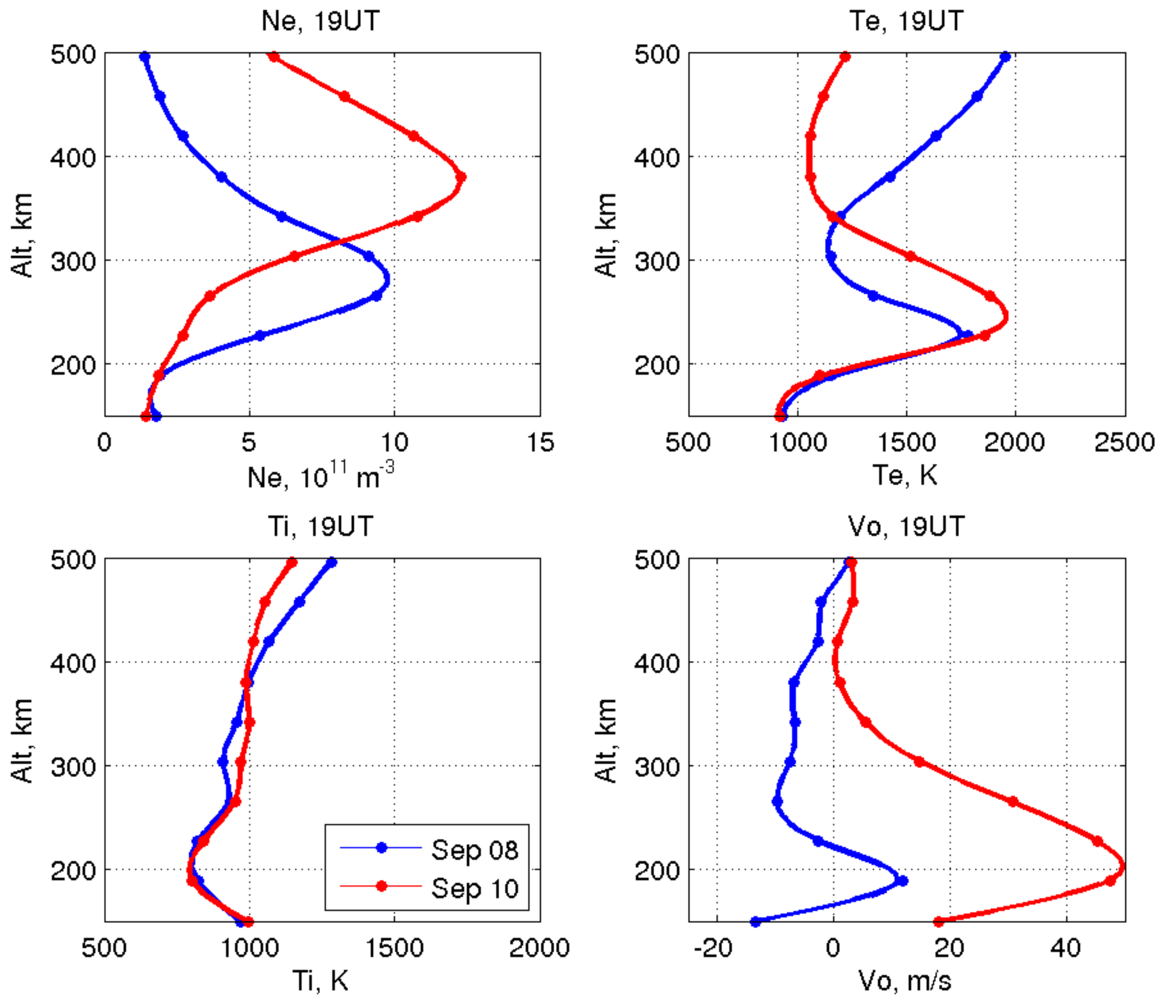
Vi



Arecibo ISR Ne, Te, Ti, Vi at 19 UT

Ne

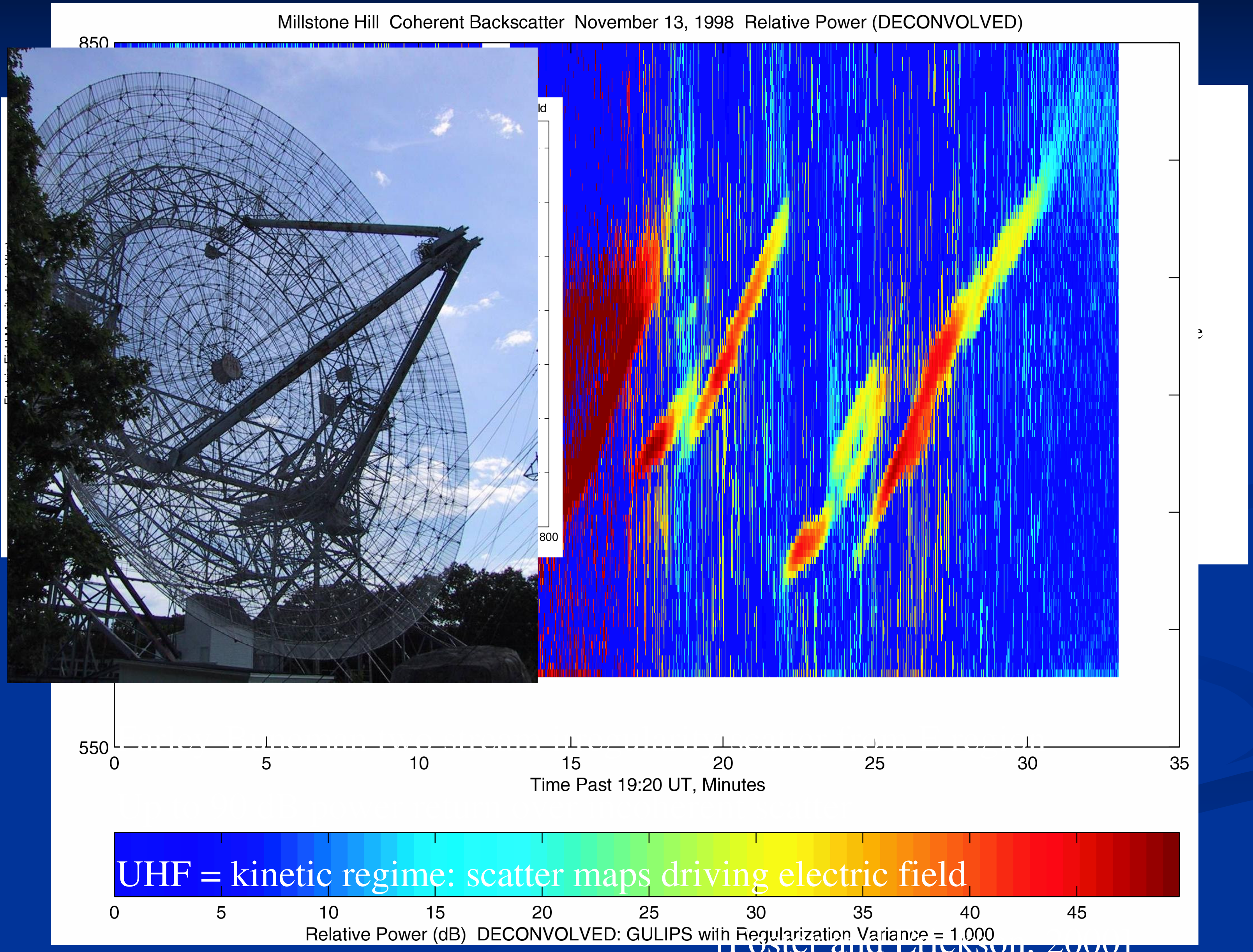
Te



Ti

Vi

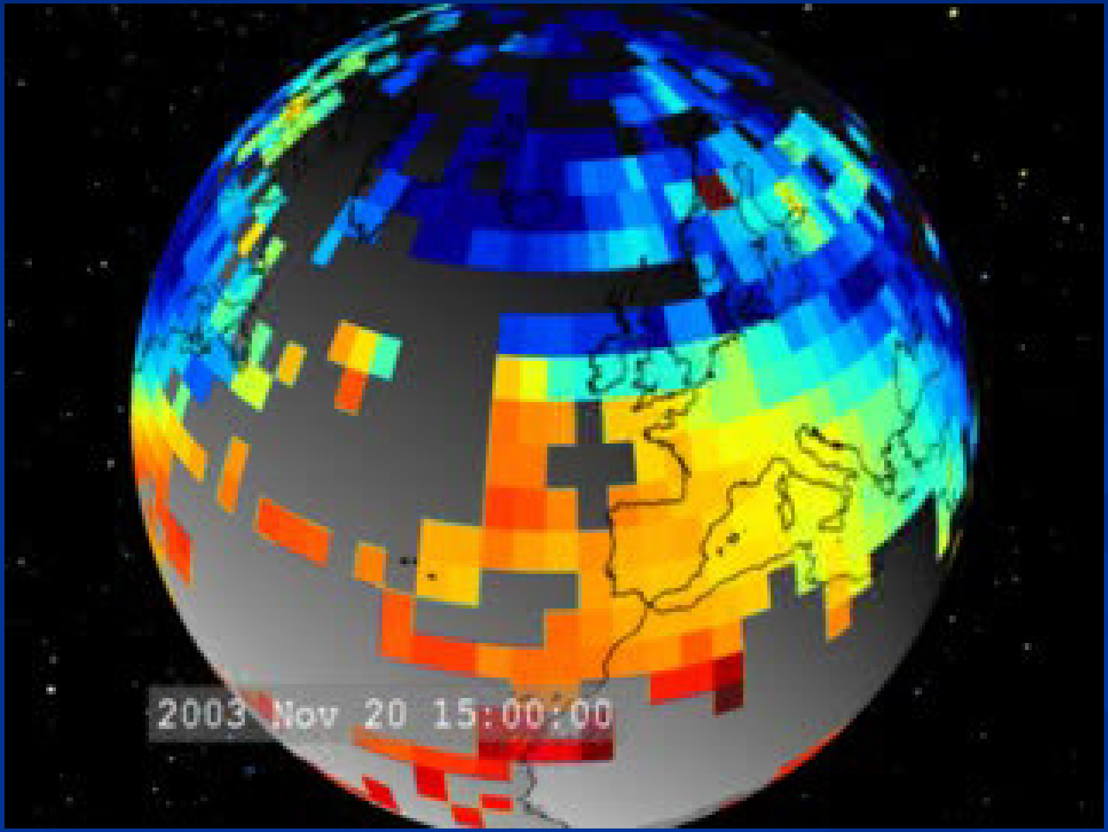
UHF Coherent Backscatter: Microscale SAPS/SAID Physics



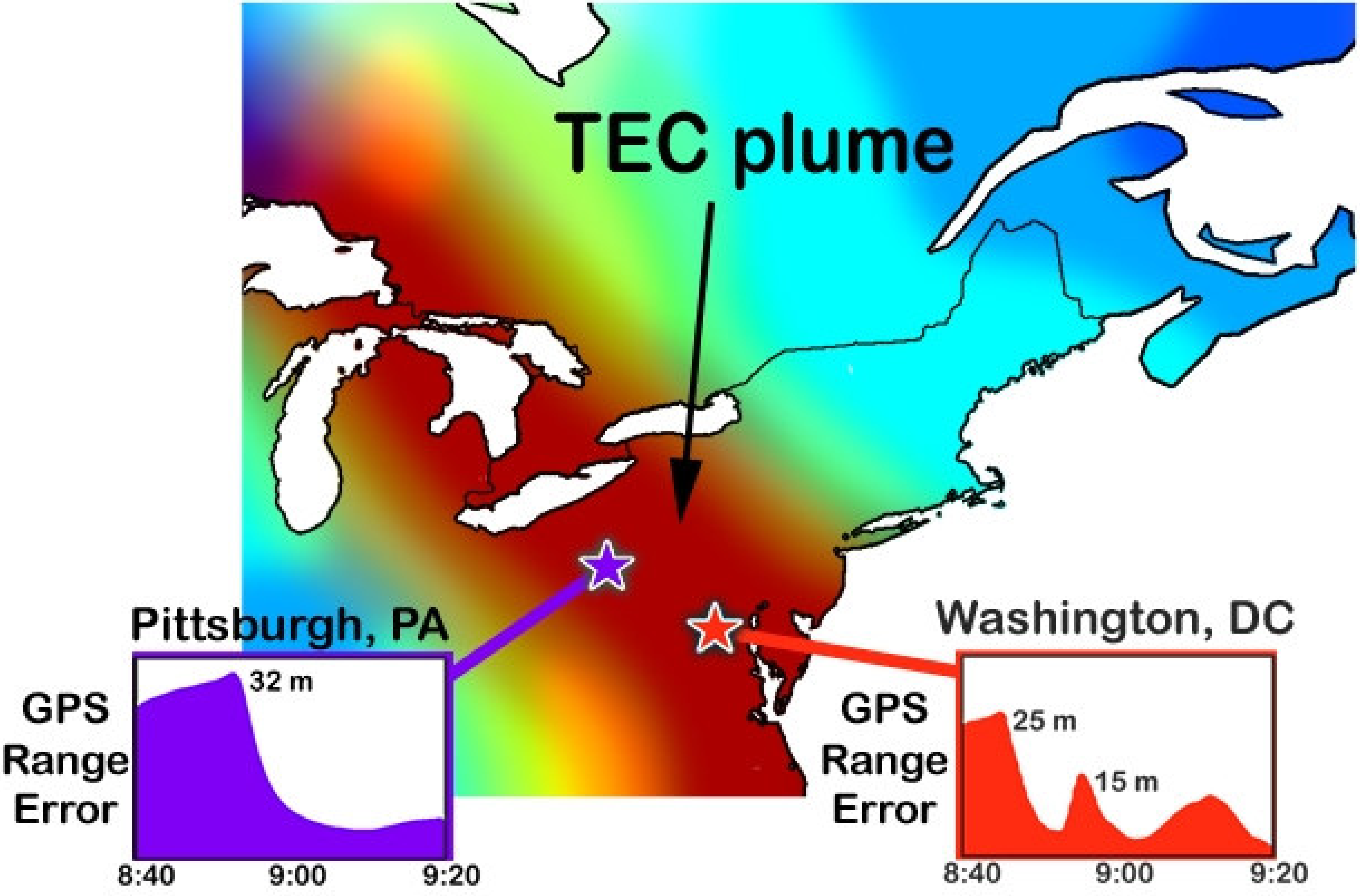
UHF = kinetic regime: scatter maps driving electric field

[Foster and Erickson, 2000]

2003 Nov 20

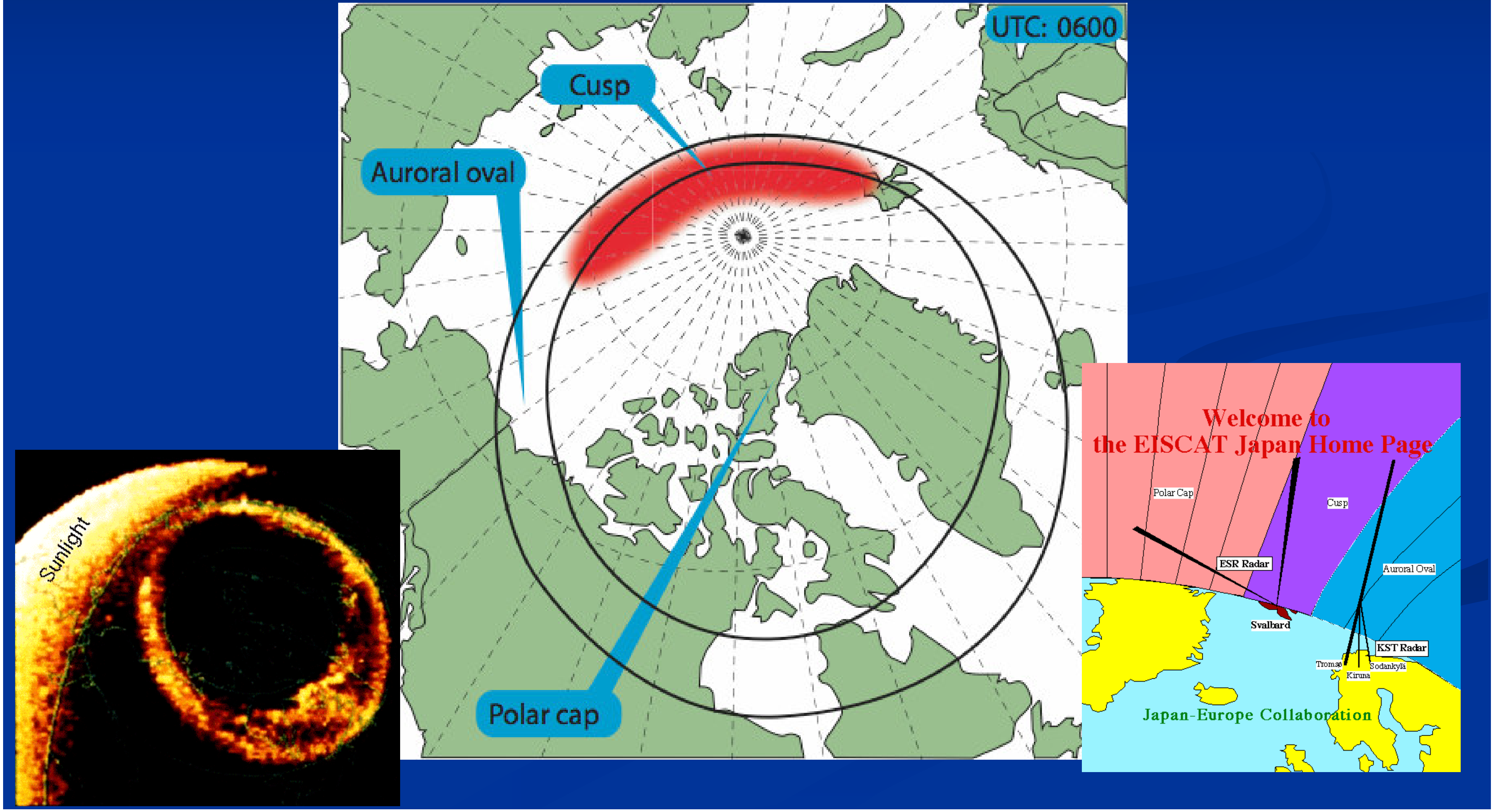


November 20, 2003

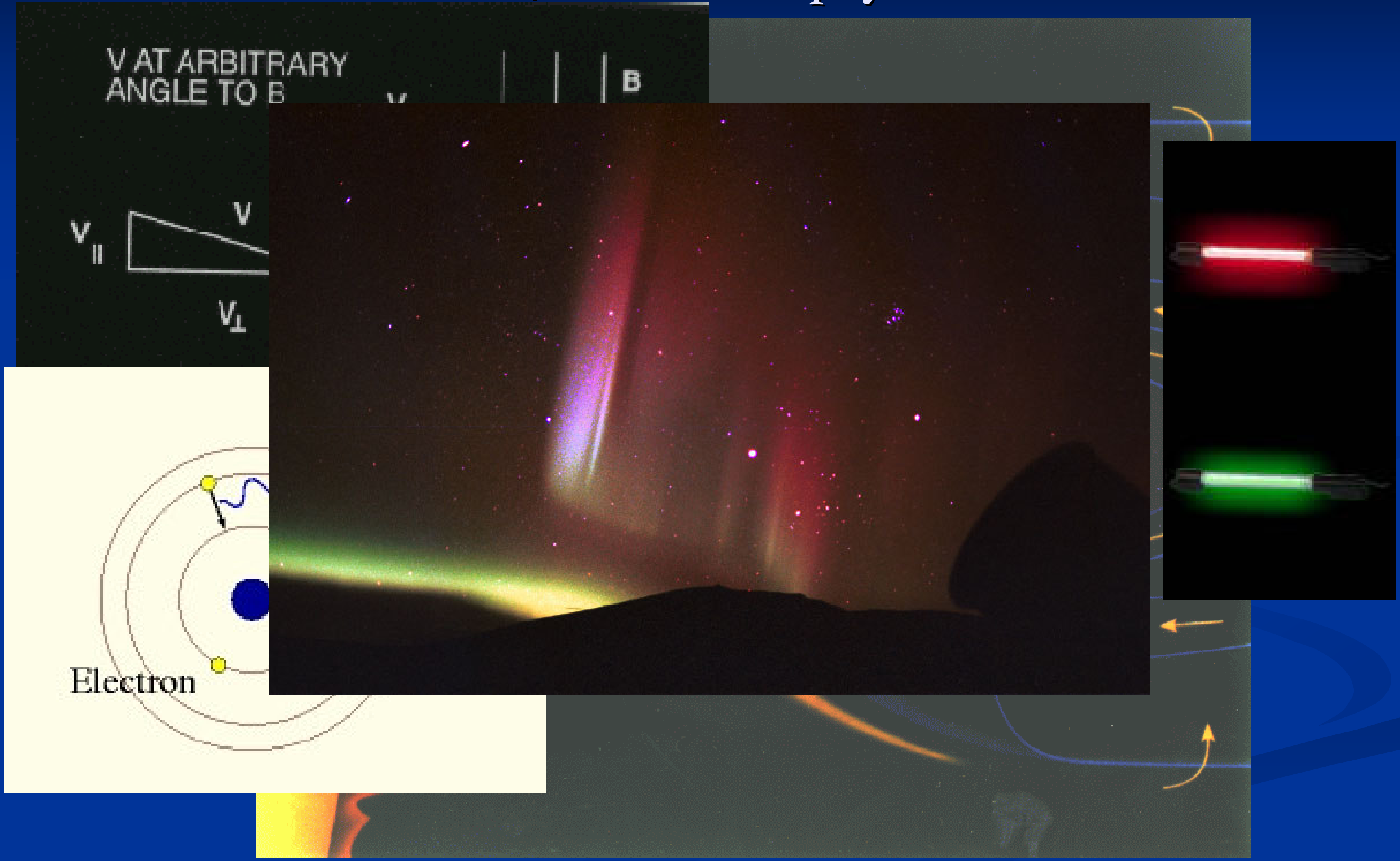


High latitudes are different

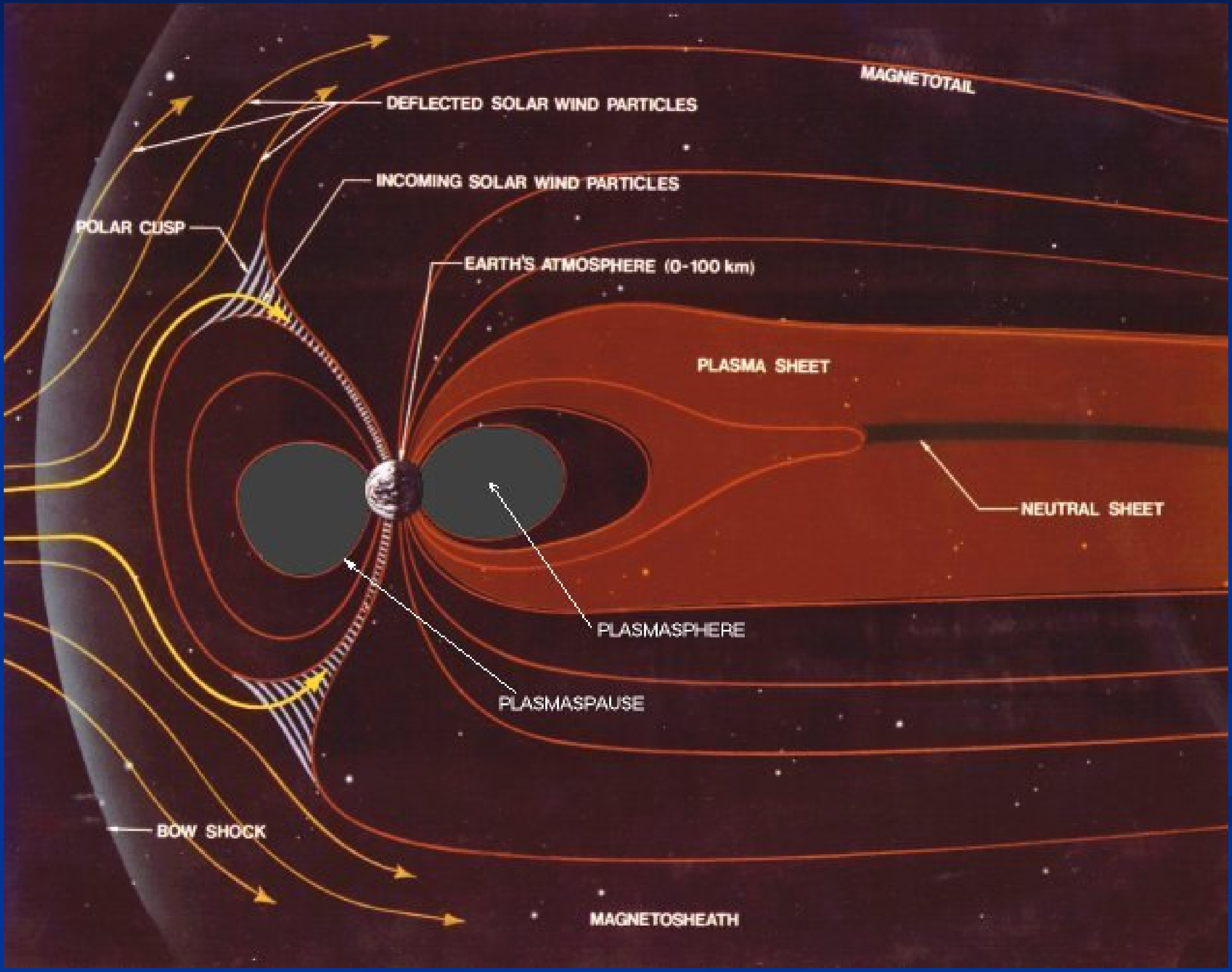
QuickTime™ and a
GIF decompressor
are needed to see this picture.



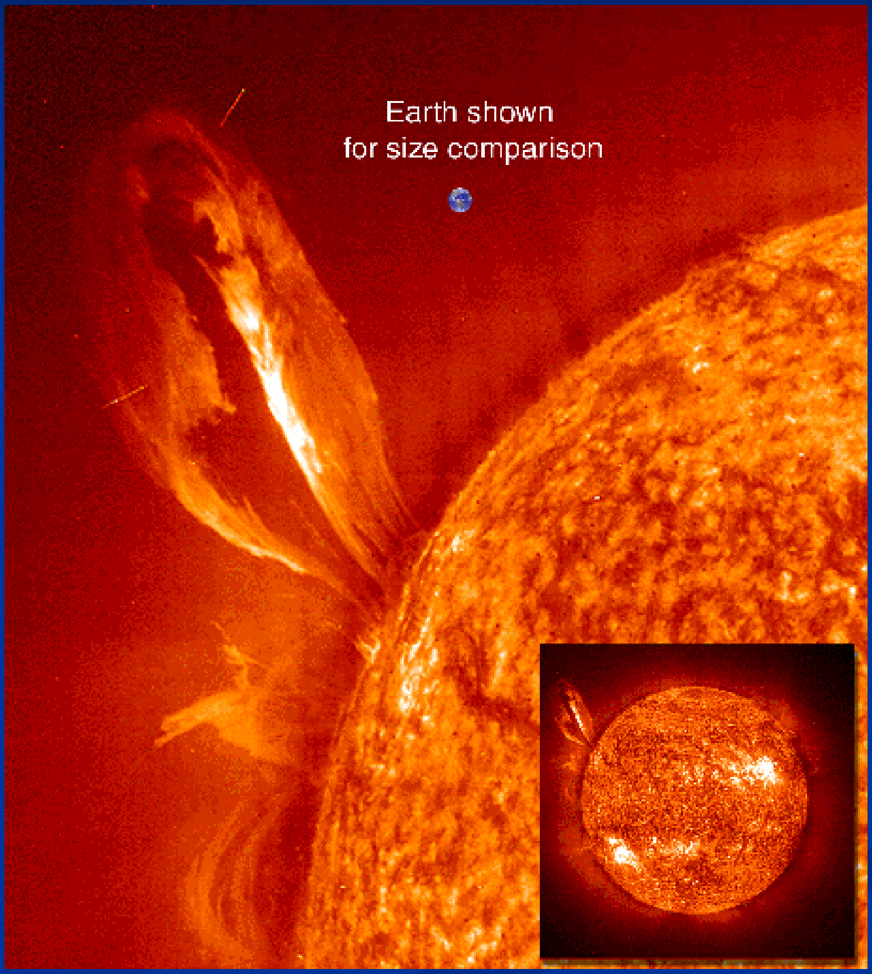
At high latitudes electron (and proton) with solar wind origin creates additional ionization, seen as aurora borealis/australis dispays



Magnetosphere

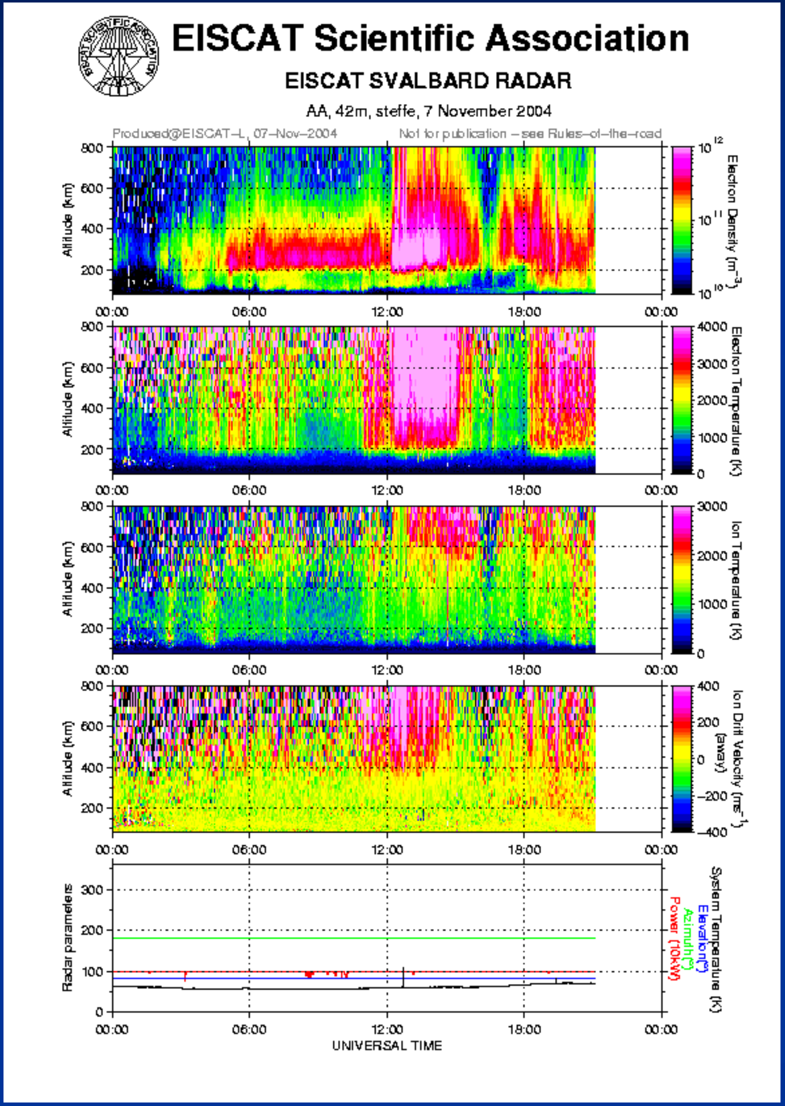


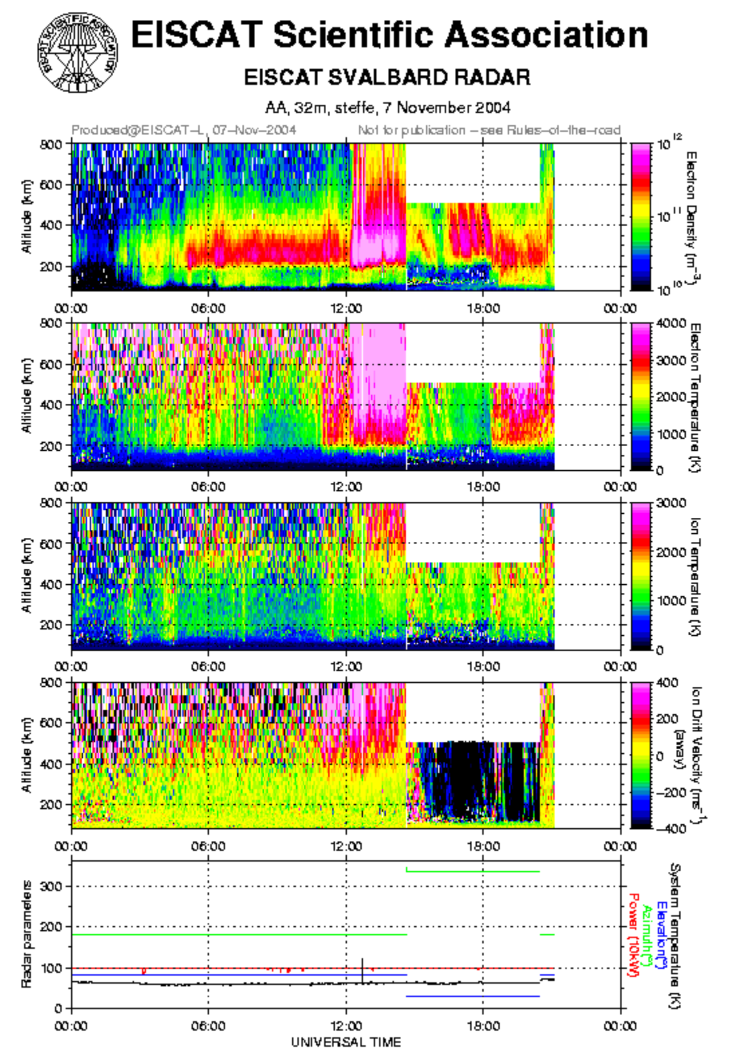
The Sun-Earth environment



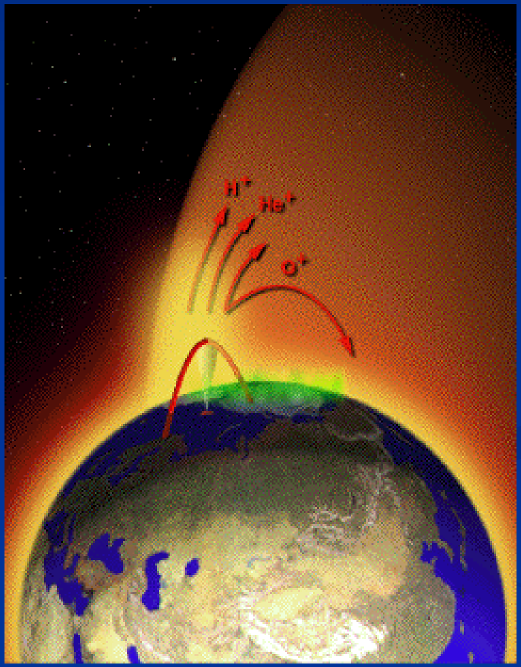
Coronal Mass Ejection (CME)

CME 7. November 2004





Ion outflow



Not a “one way” system - The interaction between the ionosphere and the magnetosphere is dynamic and complex

Auroral Activity

28 November 2000
Nome, Alaska
John Russell