Introduction to the Ionosphere (part 3)

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Major credits to: **Roger Varney**, *SRI International*
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Radio measurements of the upper atmosphere

- Propagation and Reflection Experiments:
  - Consider ionospheric plasma as a continuum
  - Ray-bending and reflection governed by variable index of refraction
- Incoherent Scatter Radar:
  - Consider ionospheric plasma as a collection of electron point targets
  - Assume plasma is stable and near thermodynamic equilibrium
  - Use statistical mechanics to describe scatter
- Coherent Scatter Radar:
  - Consider ionospheric plasma as a heterogenous, structured medium
  - Scatter from turbulence, plasma irregularities, etc.

The Appleton-Hartree equation

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

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

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.

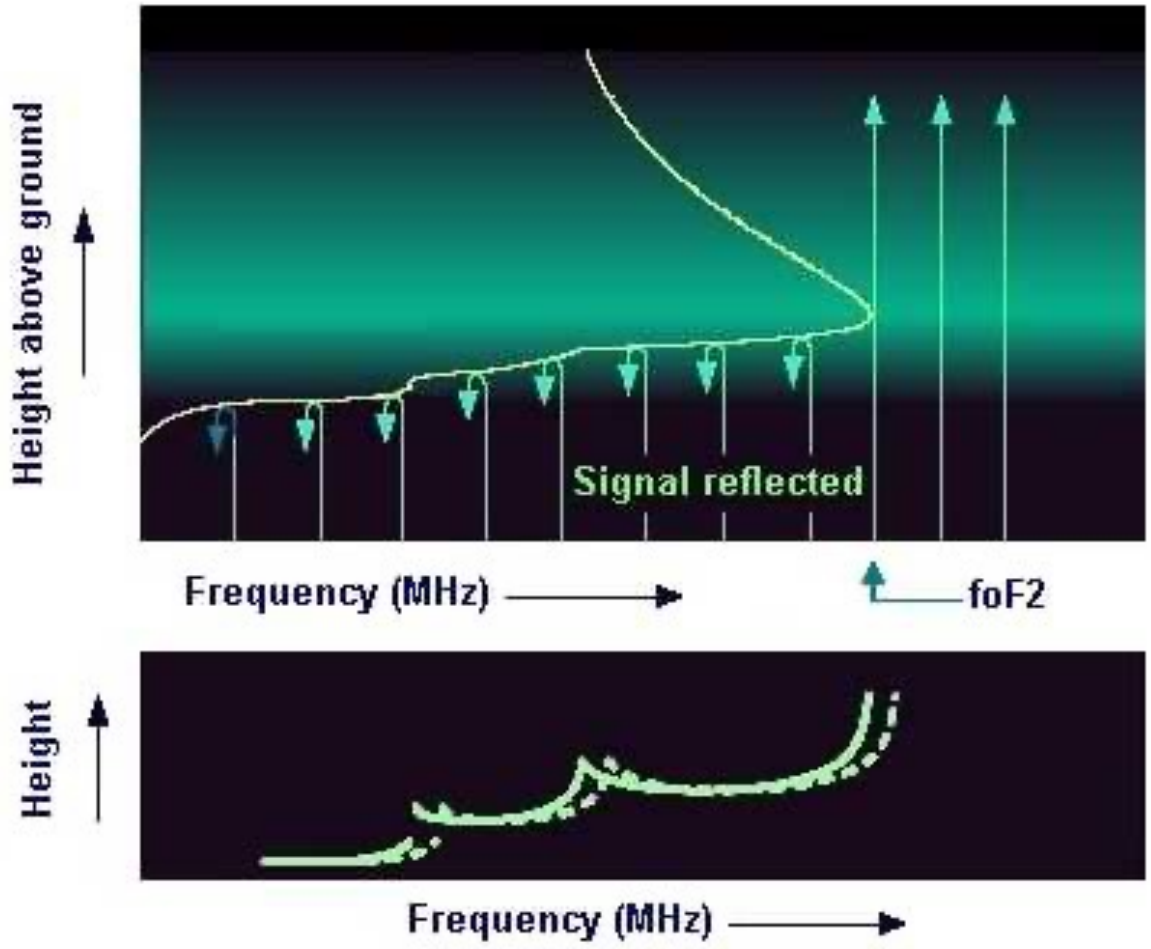
The Appleton-Hartree equation

Index of refraction in an unmagnetized plasma:

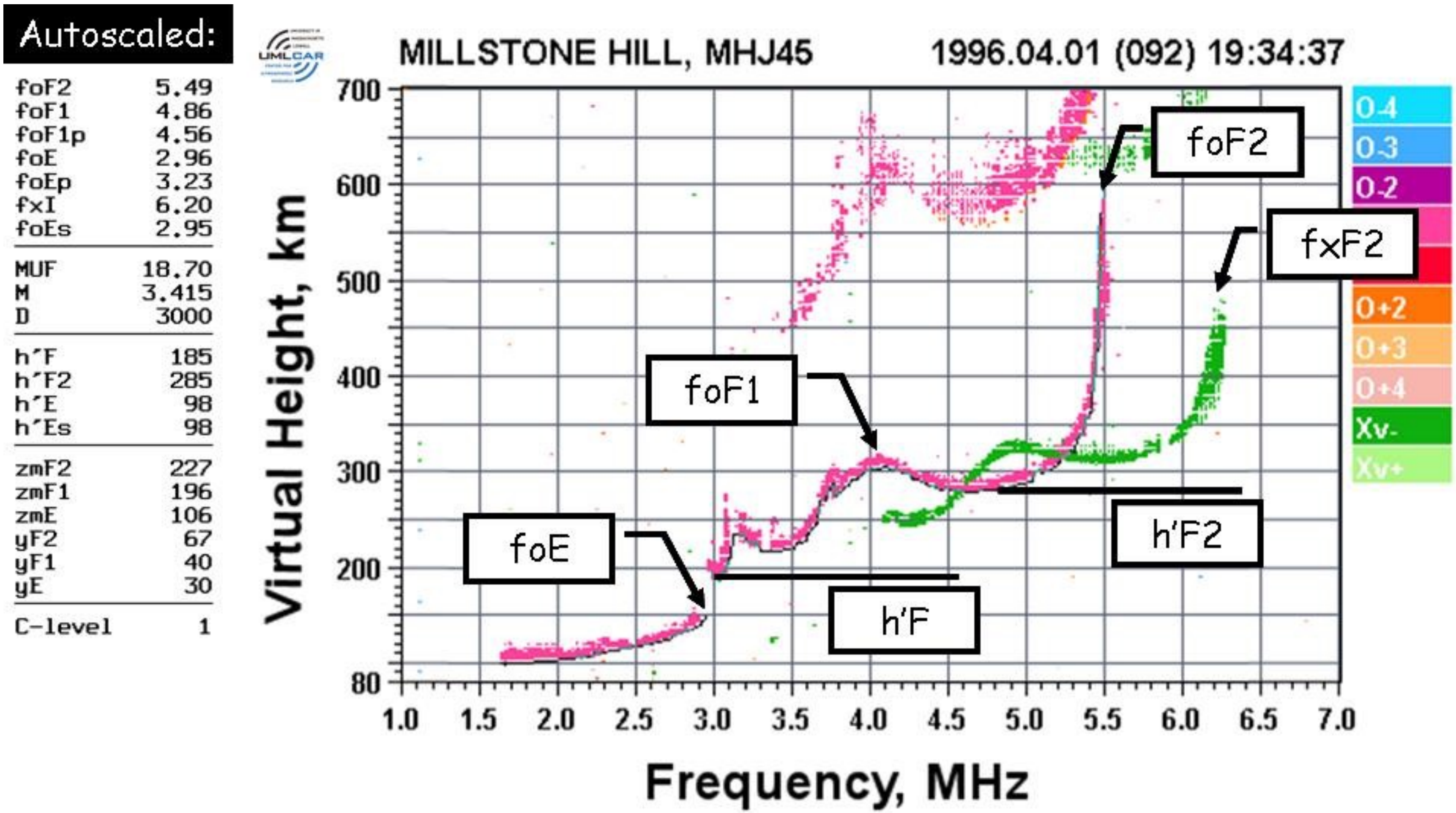
$$n^2 = 1 - \omega^2_{pe}/\omega^2$$

Electron plasma frequency: $\omega^2_{pe} = e^2 n_e/\varepsilon_0 m_e$

Reflection experiments: ionosondes



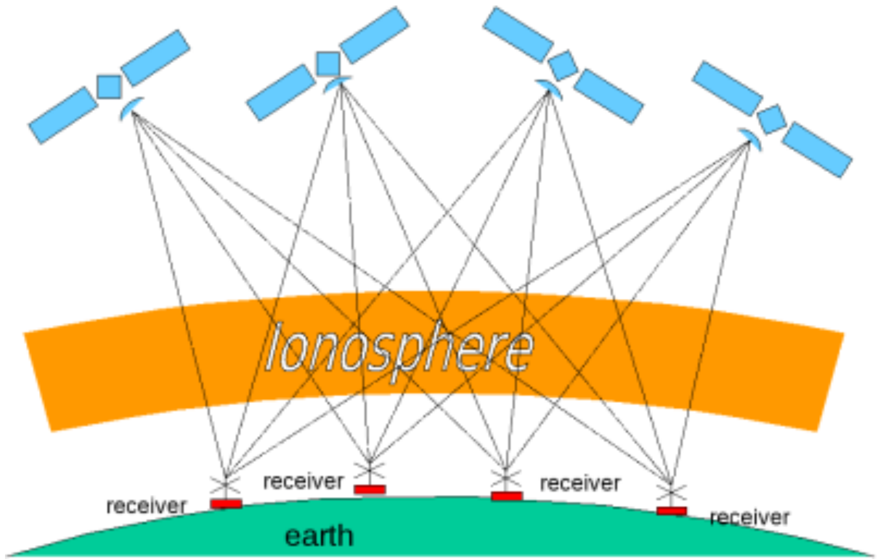
Ionograms



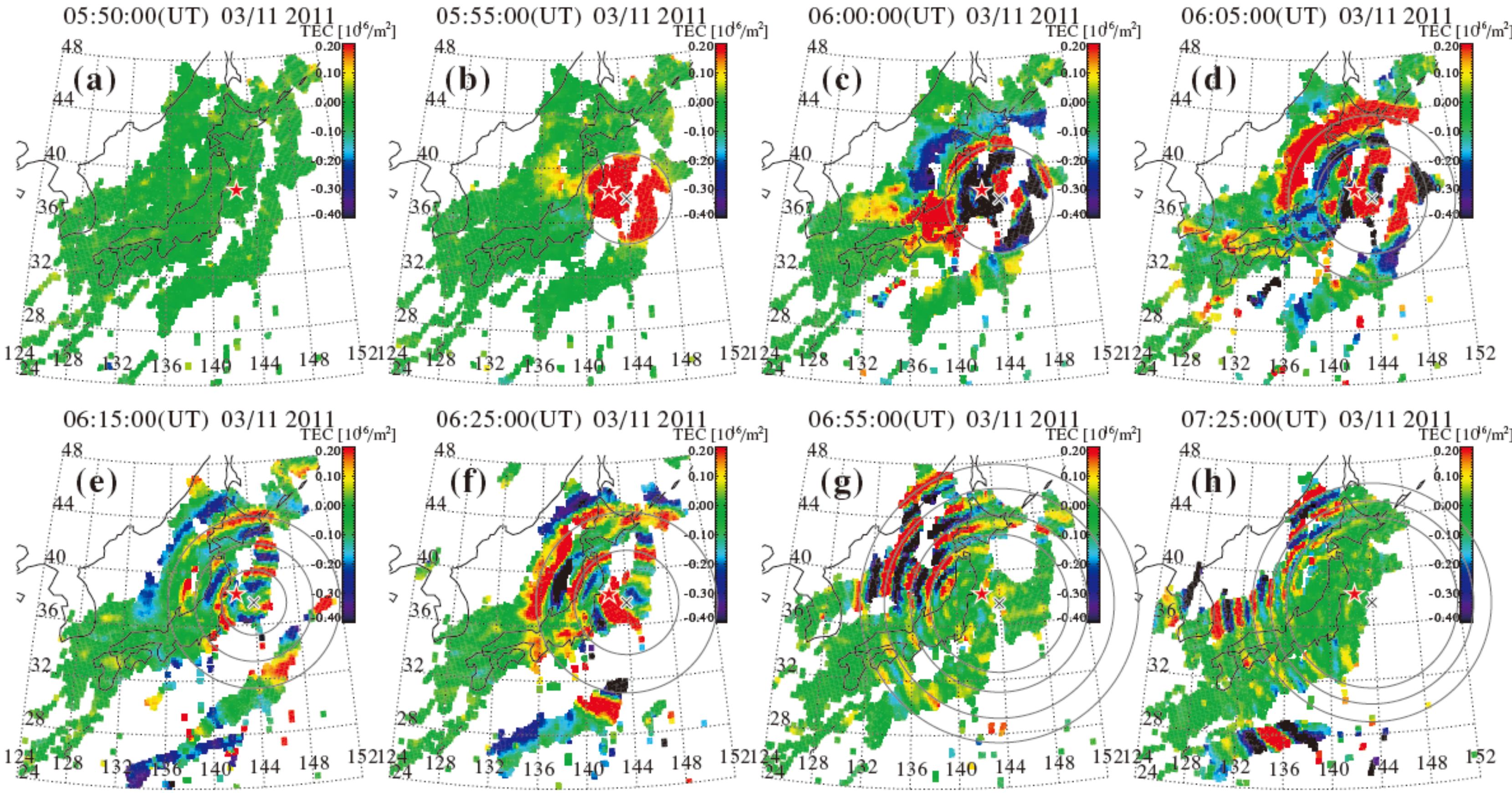
Autoscaled:
foF2 5.49
foF1 4.86
foF1p 4.56
foE 2.96
foEp 3.23
fxI 6.20
foEs 2.95
MUF 18.70
M 3.415
D 3000
h´F 185
h´F2 285
h´E 98
h´Es 98
zmF2 227
zmF1 196
zmE 106
yF2 67
yF1 40
yE 30
C-level 1
MILLSTONE HILL, MHJ45
1996.04.01 (092) 19:34:37
Virtual Height, km
Frequency, MHz
700
600
500
400
300
200
80
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
foF2
fxF2
foF1
foE
h'F2
h'F
O-4
O-3
O-2
O+2
O+3
O+4
Xv-
Xv+

GPS time difference of arrival

- Satellite radio signals have to traverse the ionosphere to reach the ground.
- Different frequencies travel at different speeds through the ionosphere. A dual frequency GPS receiver can measure the time difference of arrival of signals at different frequencies.
- Time difference of arrival gives the line integral of the electron density along the ray path (total electron content, or TEC).

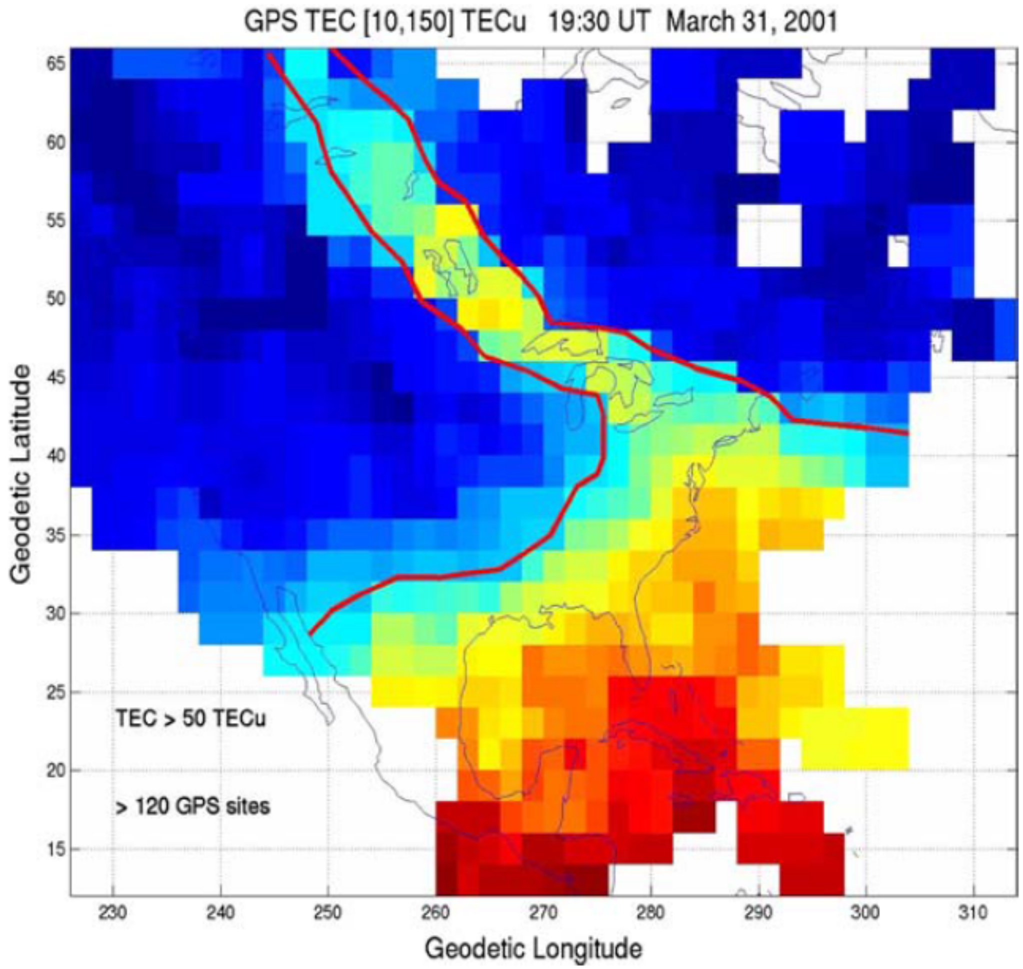


Ionospheric response to 2011 Tohoku earthquake



Tsugawa et al., 2011

Total electron content maps



Coster and Skone, 2009

Literature

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