Modelling HF Propagation

A TIGER Case Study

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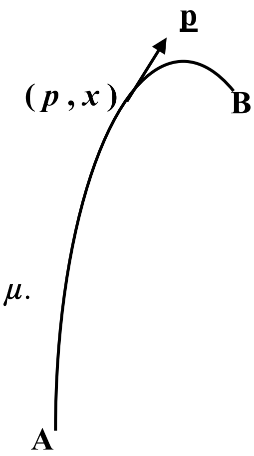
Outline

1. Ray Tracing
2. Backscatter Ionograms
3. TIGER Propagation in September 2000
4. Conclusions

Ray Equations – Hamilton/Haselgrove formulation

$$\frac{dx_i}{du} = p_i \qquad \frac{dp_i}{du} = \frac{1}{2}\frac{\partial \mu^2}{\partial x_i}$$



where $\boldsymbol{x_i}$, $\boldsymbol{i}$ = 1, 2, 3 is the coordinate of a point on the ray

$\boldsymbol{p_i}$, $\boldsymbol{i}$ = 1, 2, 3 is a vector in the wave normal direction with magnitude μ.

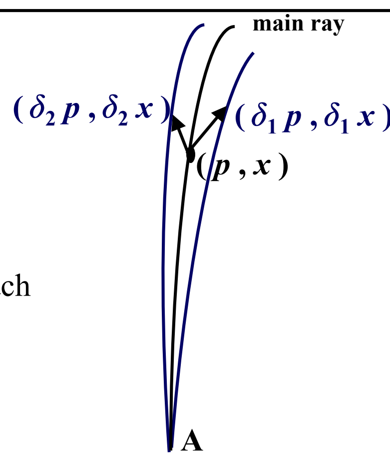
μ is the refractive index

The phase path, ***P***, given by $\dfrac{dP}{du} = \mu^2$

u is a parameter that varies monotonically along the ray path.

Usually ***u* = *P'***, the group path.

Consider a ray tube



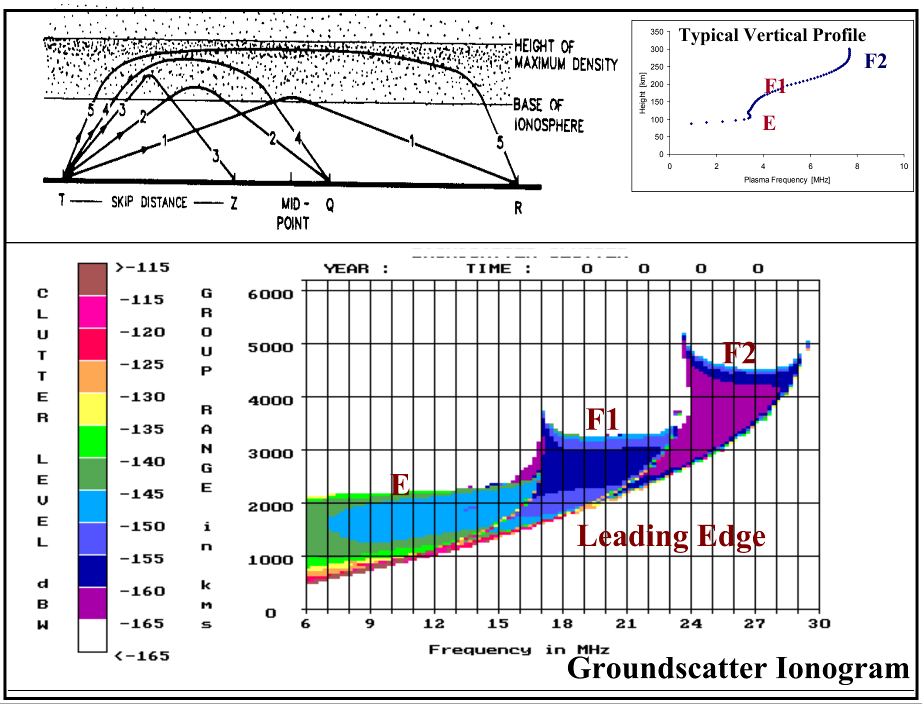
Rays adjacent to original ray can be considered perturbations of the original main ray.

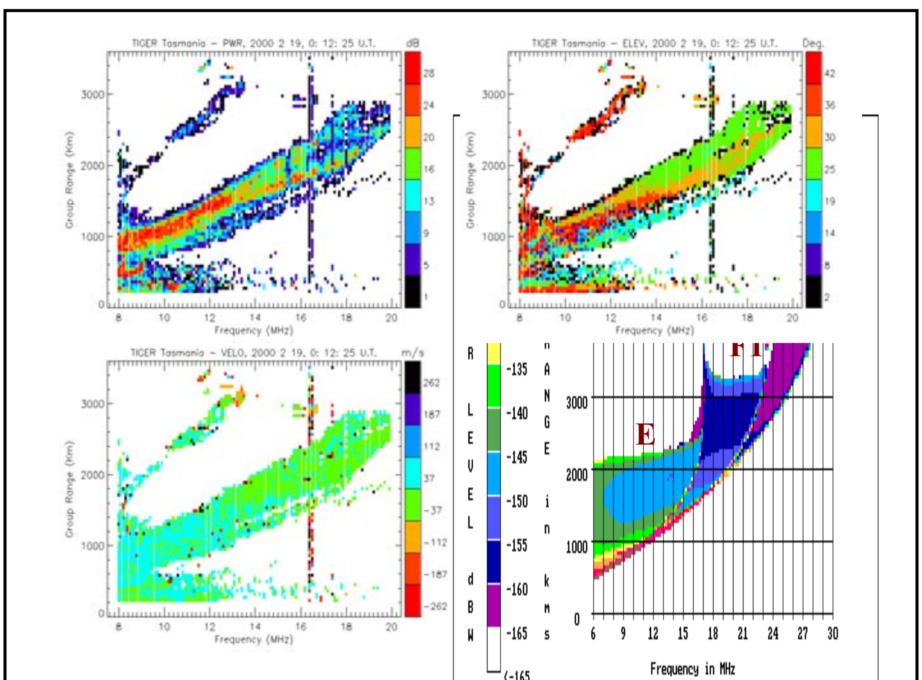
Using Hamilton's variational approach can show that

$$\frac{d}{du}\left(\delta_\beta x_i\right) = \delta_\beta p_i + p_i \frac{\partial \mu^2}{\partial x_j}\frac{\delta_\beta x_j}{\mu^2}$$

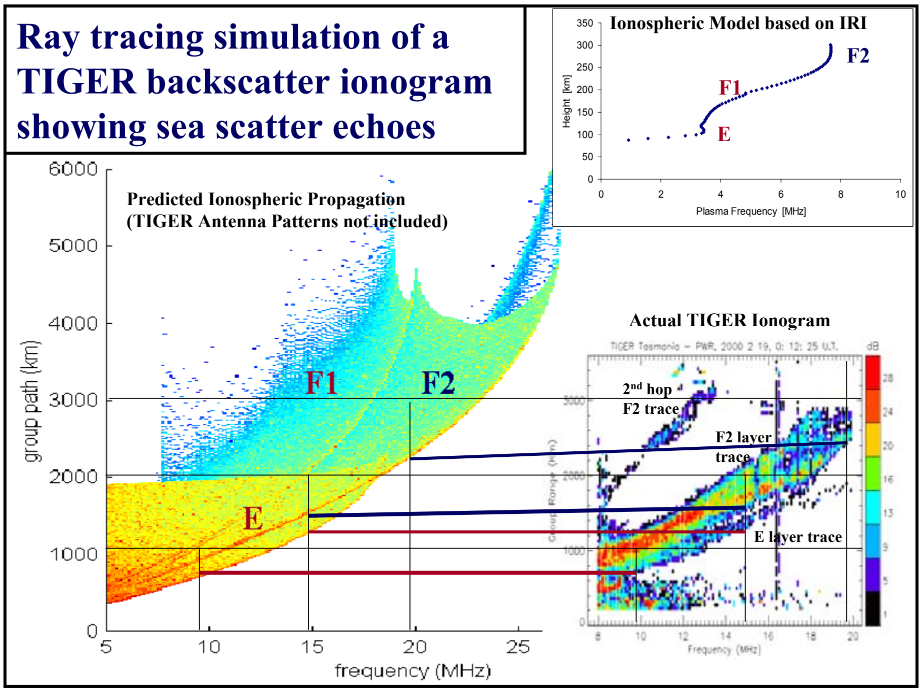
$$\frac{d}{du}\left(\delta_\beta p_i\right) = \frac{1}{2}\frac{\partial^2 \mu^2}{\partial x_i \partial x_j}\delta_\beta x_j - p_i \frac{1}{2\mu^2}\frac{\partial \mu^2}{\partial x_i}\frac{\partial \mu^2}{\partial x_j}\delta_\beta x_j \qquad \beta = 1,2$$

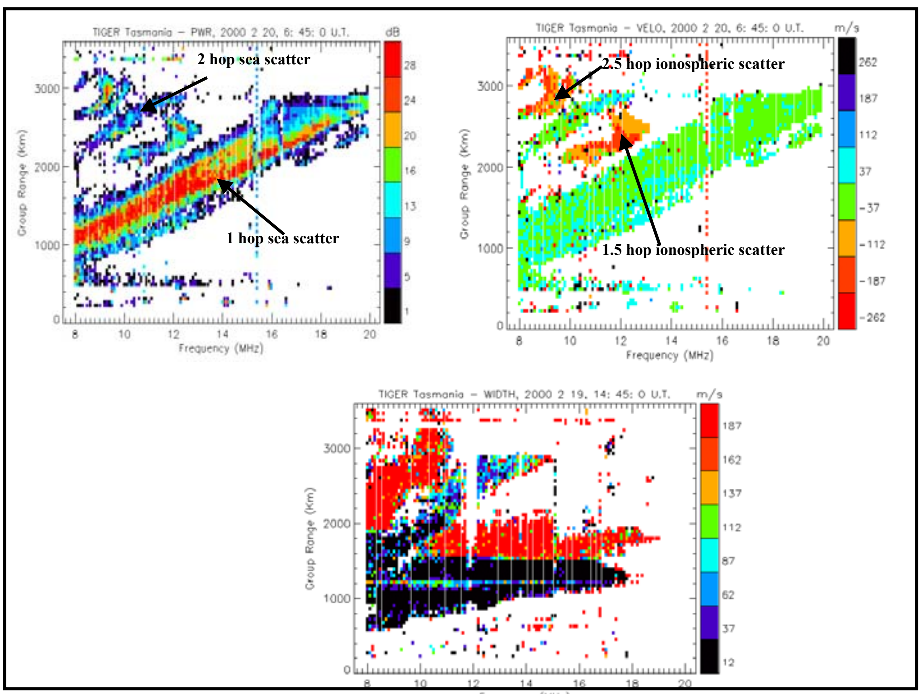
Power (ray divergence) at any point along ray is proportional to ($\delta_1 x$ x $\delta_2 x$)


HEIGHT OF MAXIMUM DENSITY
BASE OF IONOSPHERE
T — SKIP DISTANCE — Z
MID-POINT
Q
R
Typical Vertical Profile
F2
F1
E
Height (km)
Plasma Frequency (MHz)
CLUTTER LEVEL dBW
GROUP RANGE in kms
YEAR :
TIME :
Frequency in MHz
E
F1
F2
Leading Edge
Groundscatter Ionogram


TIGER Tasmania – PWR, 2000 2 19, 0: 12: 25 U.T.
dB
Group Range (km)
Frequency (MHz)
TIGER Tasmania – ELEV, 2000 2 19, 0: 12: 25 U.T.
Deg.
TIGER Tasmania – VELO, 2000 2 19, 0: 12: 25 U.T.
m/s
E
Frequency in MHz

Ray tracing simulation of a TIGER backscatter ionogram showing sea scatter echoes





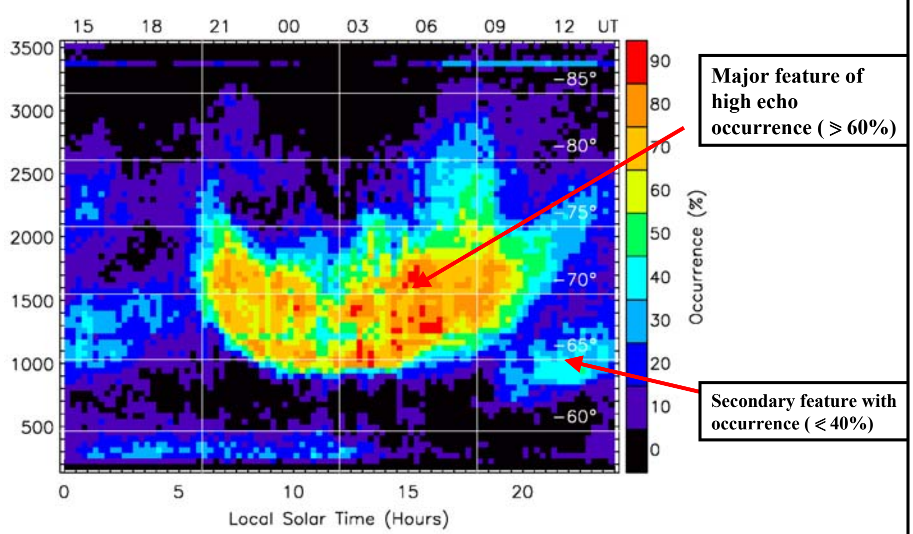
In normal SuperDARN operations a frequency at which significant scatter is occurring is automatically selected.

During Spring 2000 most common frequencies selected by TIGER were in the band 11.0 – 12.5 MHz.

How do characteristics of sea scatter and ionospheric scatter observed at these frequencies compare with those predicted by IRI?

IRI predictions based on 12 MHz
Tilted Dipole used to describe magnetic field

Sea echoes observed by TIGER during Spring of 2000
Percentage occurrence along Beam 4 for 11-12.5 MHz



Sea echoes observed by TIGER during Spring of 2000
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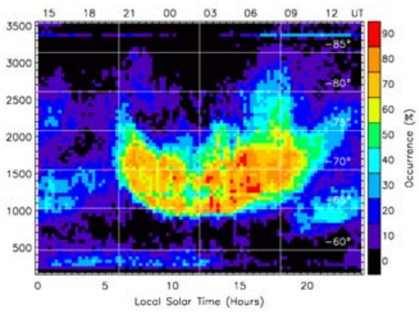
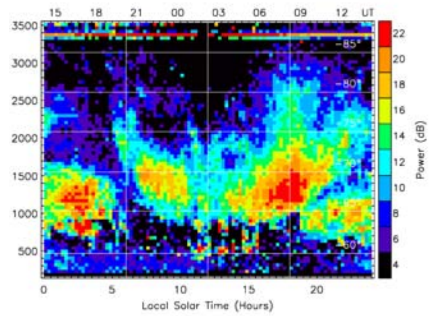
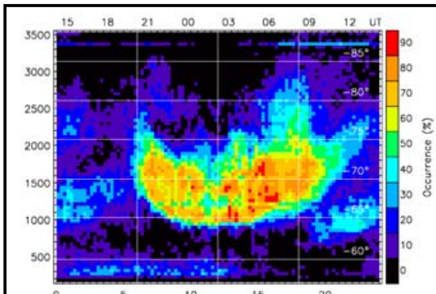


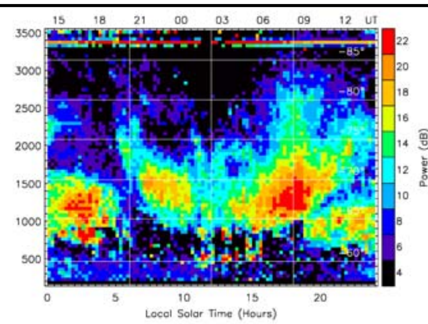
Occurrence



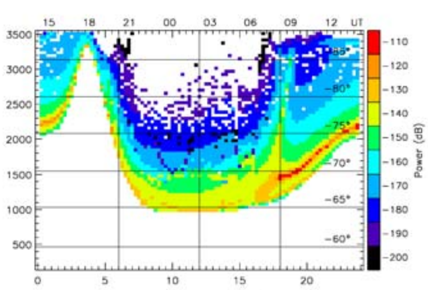
Power

Comparison of IRI and Observations (Apples and Oranges)





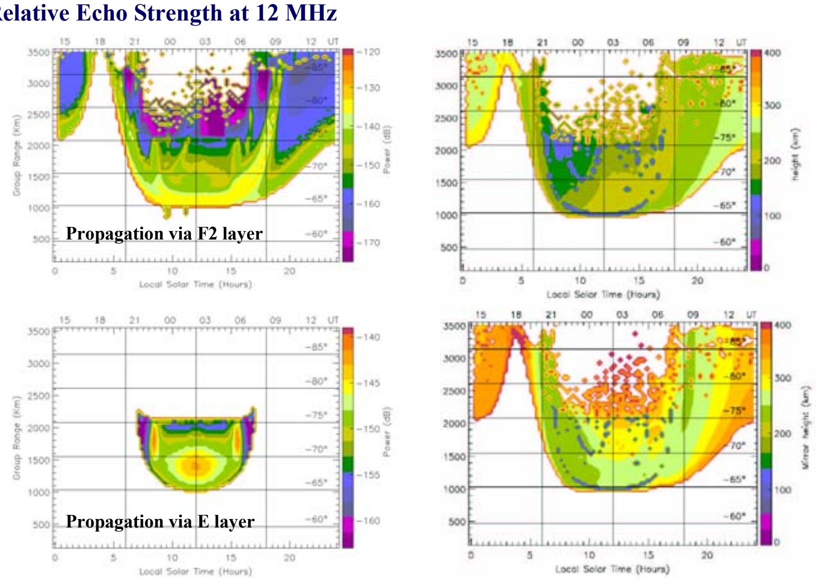
Power



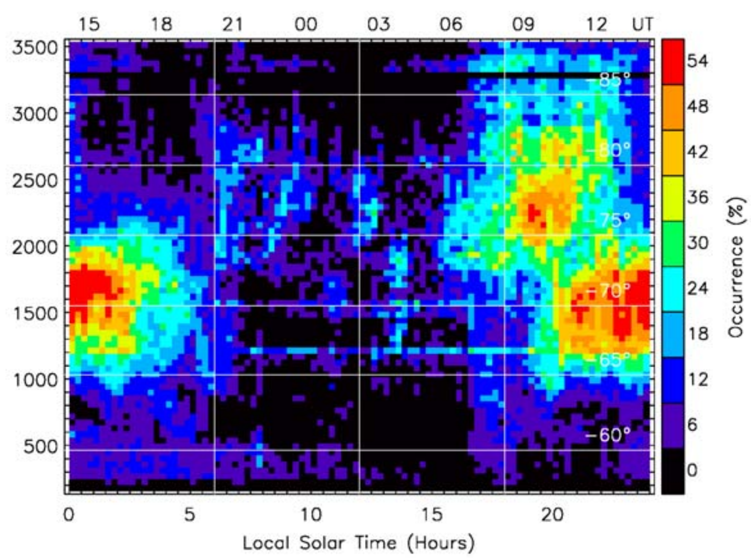
IRI Predicted
Power

Simulation using International Reference Ionosphere (IRI)

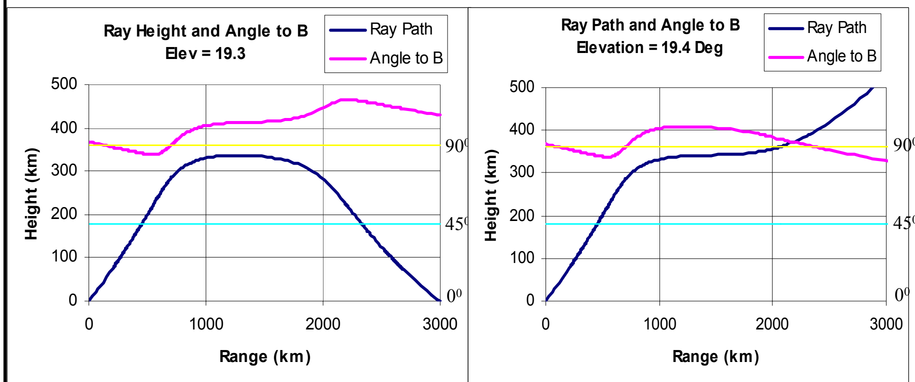
Relative Echo Strength at 12 MHz

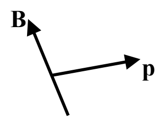


Ionospheric Scatter Occurrence



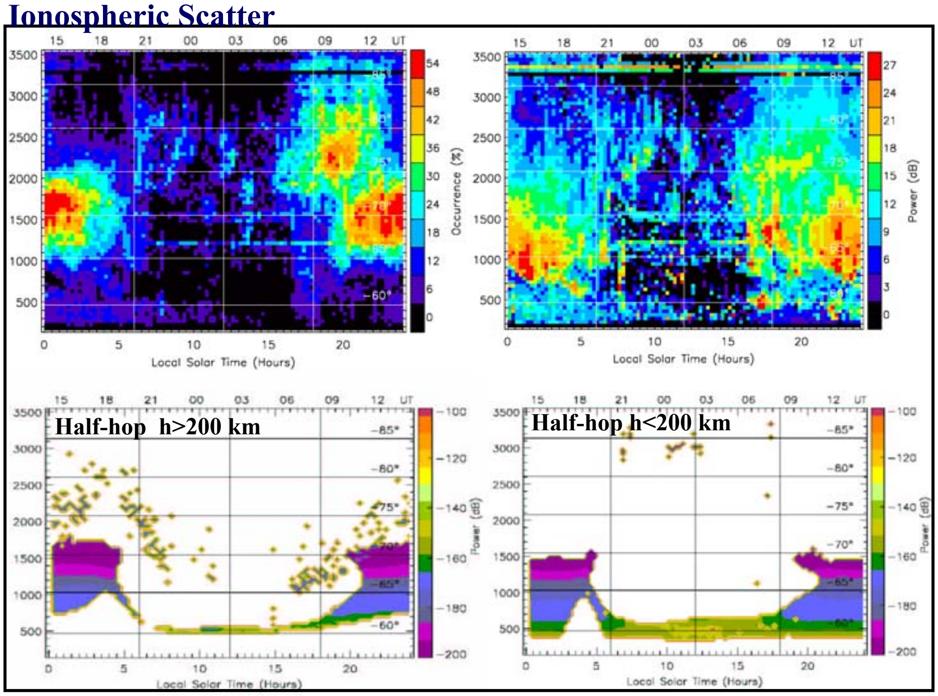
Ionospheric Scatter:
can occur at normal incidence to field lines



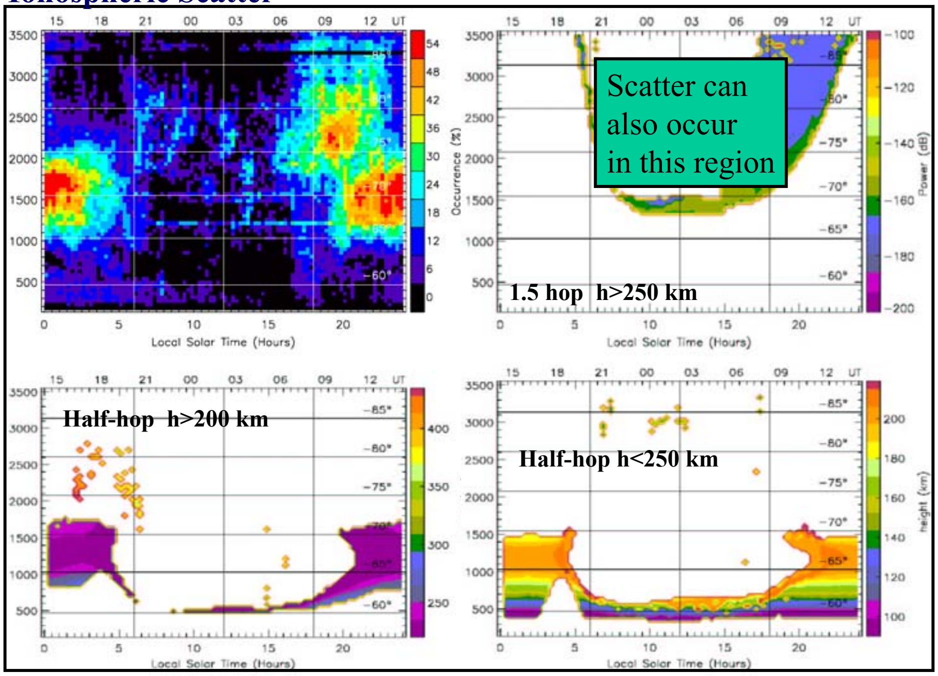


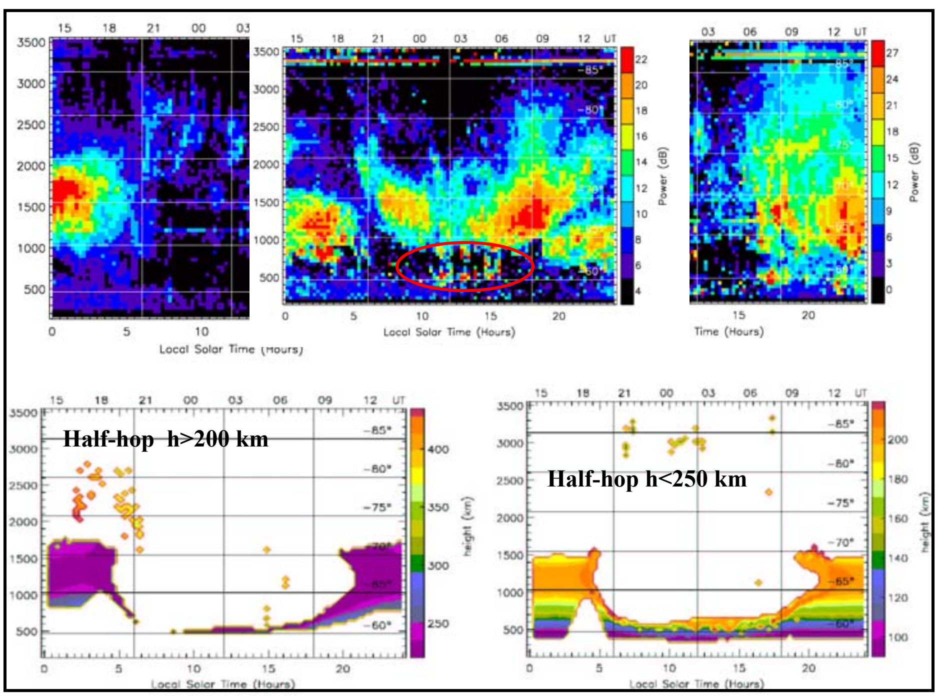
Since **B.p** = 0 at more than one location along ray will consider two height regimes: above and below 200 km

Ionospheric Scatter

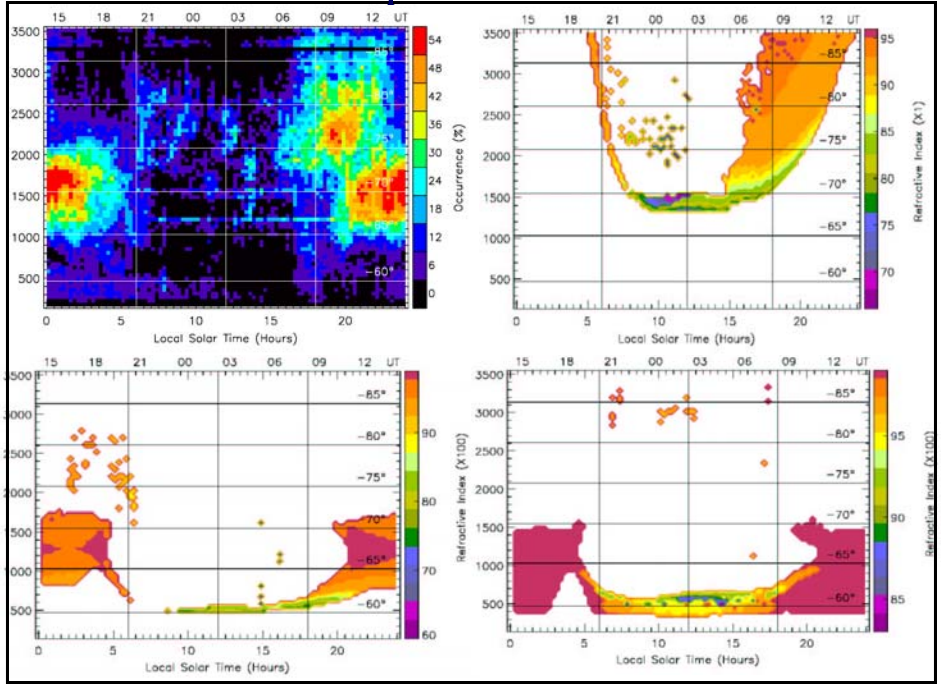


Ionospheric Scatter





Refractive Index at Scatter points

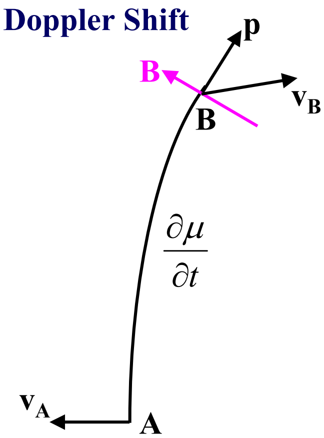


Effect of Background Ionosphere on Doppler Shift

$$P = \int_A^B \mu \cos\alpha \; ds$$

$$\frac{dP}{dt} = \int_A^B \frac{\partial \mu}{\partial t} \cos\alpha \; ds + \left[\mathbf{p}.\mathbf{v}\right]_A^B$$

$$\Delta f = -\frac{f}{c}\frac{dP}{dt}$$



If time variation of phase path due only to reflection/scatter point

$$\Delta f = -\frac{f}{c}\mu_B v_{Blos} \qquad v_{Blos} = \frac{1}{\mu_B}\frac{c}{f}\Delta f$$

Conclusions

For period considered (Spring 2000):

A. Sea-Scatter

- Location of daytime sea scatter predicted by IRI
- Echo power variations similar to IRI variations in ionospheric focussing
- Night-time echoes identified as sea-scatter not predicted by IRI

B. Ionospheric Scatter

- Ionospheric scatter occurs largely in regions where IRI predicts 0.5 and 1.5 hop scatter
- Night-time echoes identified as sea-scatter also occur where IRI predicts 0.5 hop scatter
- Scatter occurs in regions where $\mu > 0.9$, so scatter irregularity wavelength no greater than 10% larger than free space half-wavelength (12.5 m) and irregularity velocity no greater than 10% larger than “free space” value.

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