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

\[ \frac{dx_i}{du} = p_i, \quad \frac{dp_i}{du} = \frac{1}{2} \frac{\partial \mu^2}{\partial x_i} \]

where \( x_i, \ i = 1, 2, 3 \) is the coordinate of a point on the ray
\( p_i, \ i = 1, 2, 3 \) is a vector in the wave normal direction with magnitude \( \mu \).
\( \mu \) is the refractive index

The phase path, \( P \), given by
\[ \frac{dP}{du} = \mu^2 \]

\( u \) 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

\[ \frac{d}{du}(\delta_x x_i) = \delta_x p_i + p_i \frac{\partial \mu^2}{\partial x_j} \frac{\delta_x x_j}{\mu^2} \]

\[ \frac{d}{du}(\delta_x p_i) = \frac{1}{2} \frac{\delta^2 \mu^2}{\partial x_i \partial x_j} \delta_x x_j - p_i \frac{1}{2} \frac{\partial \mu^2}{\partial x_i} \frac{\partial \mu^2}{\partial x_j} \delta_x x_j \quad \beta = 1, 2 \]

Power (ray divergence) at any point along ray is proportional to \( (\delta_x x \delta_x x) \)
Ray tracing simulation of a TIGER backscatter ionogram showing sea scatter echoes.

Predicted Ionospheric Propagation (TIGER Antenna Patterns not included)

Actual TIGER Ionogram

1 hop sea scatter

2 hop ionospheric scatter

1.5 hop ionospheric scatter
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

[Image of a graph showing occurrence percentages along local solar time]
Sea echoes observed by TIGER during Spring of 2000
Percentage occurrence along Beam 4 for 11-12.5 MHz

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

Propagation via F2 layer

Propagation via E layer

Ionospheric Scatter Occurrence
**Ionospheric Scatter:**
can occur at normal incidence to field lines

![Graph showing ray height and angle to B](image1)

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

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**Ionospheric Scatter**

![Graph showing time vs. power for different height regimes](image2)

**Half-hop $h>200$ km**

**Half-hop $h<200$ km**
Ionospheric Scatter

Scatter can also occur in this region.
Refractive Index at Scatter points

\[
P = \int_{A}^{B} \mu \cos \alpha \, ds
\]

\[
\frac{dP}{dt} = \int_{A}^{B} \frac{\partial \mu}{\partial t} \cos \alpha \, ds + \left[ p \cdot v \right]_{A}^{B}
\]

\[
\Delta f = -\frac{f}{c} \frac{dP}{dt}
\]

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

\[
\Delta f = -\frac{f}{c} \mu B v_{Blos} \quad v_{Blos} = \frac{1}{\mu B} \frac{c}{f} \Delta f
\]
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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