PHYSICS AND ENGINEERING PHYSICS

Estimating index of refraction in the scattering region using SuperDARN angle of arrival measurements

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Doppler velocities for scattering

- SuperDARN measures the Doppler shift $\Delta\omega_D$ of a transmission at frequency ω.
- The equation that has been assumed relates the measured $\Delta\omega_D$ obtained from the slope of the autocorrelation function phase with lag to the speed v_S of the scatterer by the usual equation

$$\frac{\Delta\omega_D}{\omega} = \pm \frac{2\, v_S}{c}$$

Scattering from a refractive medium

- However, when the Doppler shift is obtained from a scatterer located where the refractive index is n_S, then the correct Doppler equation is:

$$\frac{\Delta\omega_D}{\omega} = \pm \frac{2\, v_S}{c/n_S}$$

- Using the above, we see that the correct speed is given by:

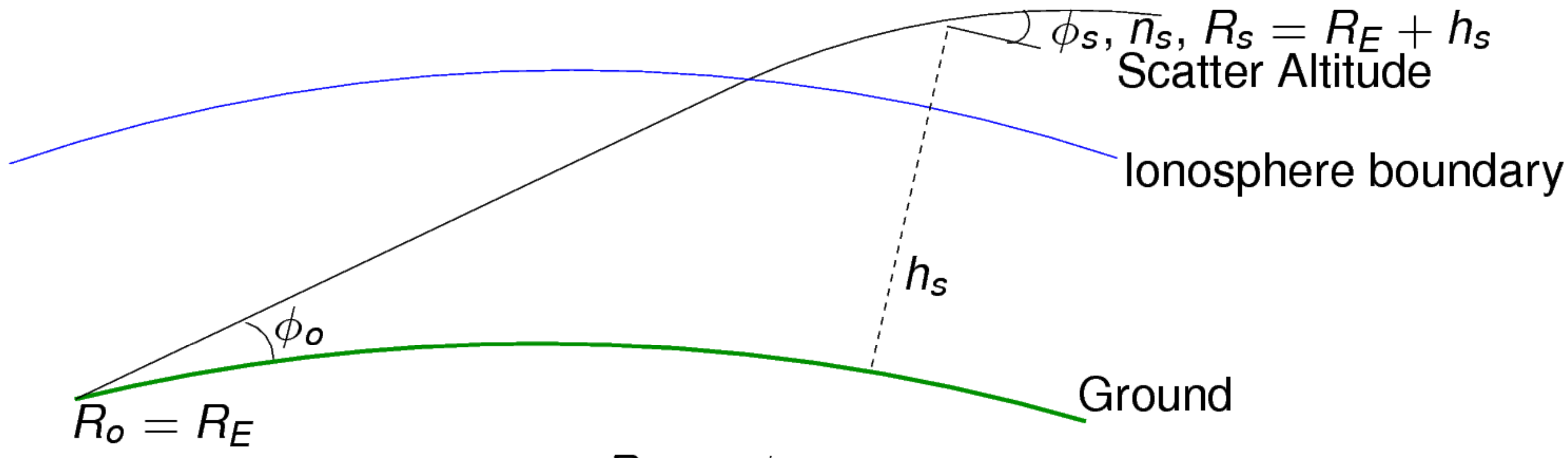
$$v_S = \pm \frac{c\, \Delta\omega_D}{2\, \omega} \frac{1}{n_S}$$

- Since $n_S < 1.0$, the speed is higher than that normally assumed for $n_s = 1.0$, and can result in substantial corrections (11% for $n_S = 0.9$, 25% for $n_S = 0.8$).

Simple example: Index of refraction from Appleton-Hartree Eqn

- Typical peak N_e values in the F-region are from about $10^{11} – 10^{12}$ m $^{-3}$
- Assuming a SD transmitter frequency of 10.0 MHz and $N_e = 5 \times 10^{11}$ m^{-3}, then n_S for the X-mode is about 0.76 (the horizontal linear transmitted polarization state is the X-mode for QT propagation).
- If the scatterers are in a region of strong upward FAC where the electron density may be higher than above, the refractive index could well be lower than 0.76.

Raytracing in a Spherical Geometry



$$n_s = \frac{n_o R_o \cos\phi_o}{R_s \cos\phi_s}$$

$$n_s = \frac{R_E \cos\phi_o}{(R_E + h_s)\cos\phi_s}$$

Scattering occurs usually where φ_S is such that the ray is about 90° to the magnetic field lines, and h_S is the height at which that ideal aspect sensitivity occurs.

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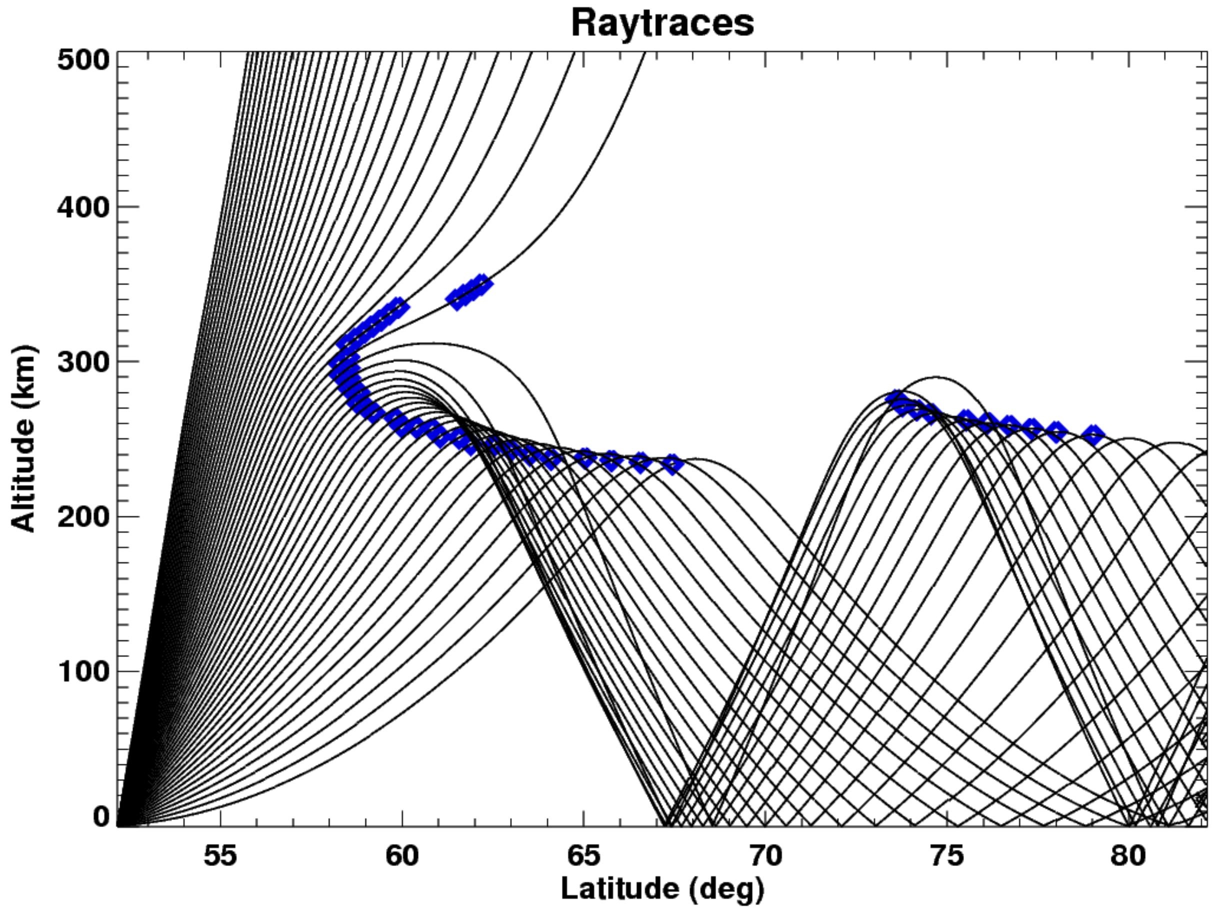
Raytracing showing scatter within 1° of perpendicularity to B (Saskatoon radar)



Ray paths have been evaluated for several 1-D and 2-D profiles. At the blue locations, the scattering is within 1° of perfect aspect sensitivity; the elevation angle and profile n_s are noted there.

Profiles Used

- 24 2-D profiles were simulated, as follows:

  * 8 IRI profiles scaled using the f_0F2 peak values from ISIS 2 topside soundings

  * 1 from Millstone Hill

  * 3 direct (unscaled) IRI models

  * 2 mid-latitude trough models, each at 4 different latitudes

  * 4 profiles were constructed with high gradients

- 20 different 1-D profiles were generated from IRI

  * 10 daytime profiles with peaks from 10^{11} to 10^{12} m^{-3}

  * 10 nighttime profiles also scaled to peaks 10^{11} to 10^{12} m^{-3}

- A total of 125 different profiles and frequency combinations were used, with simulations done at 9.5, 12.5 and 14.5 MHz

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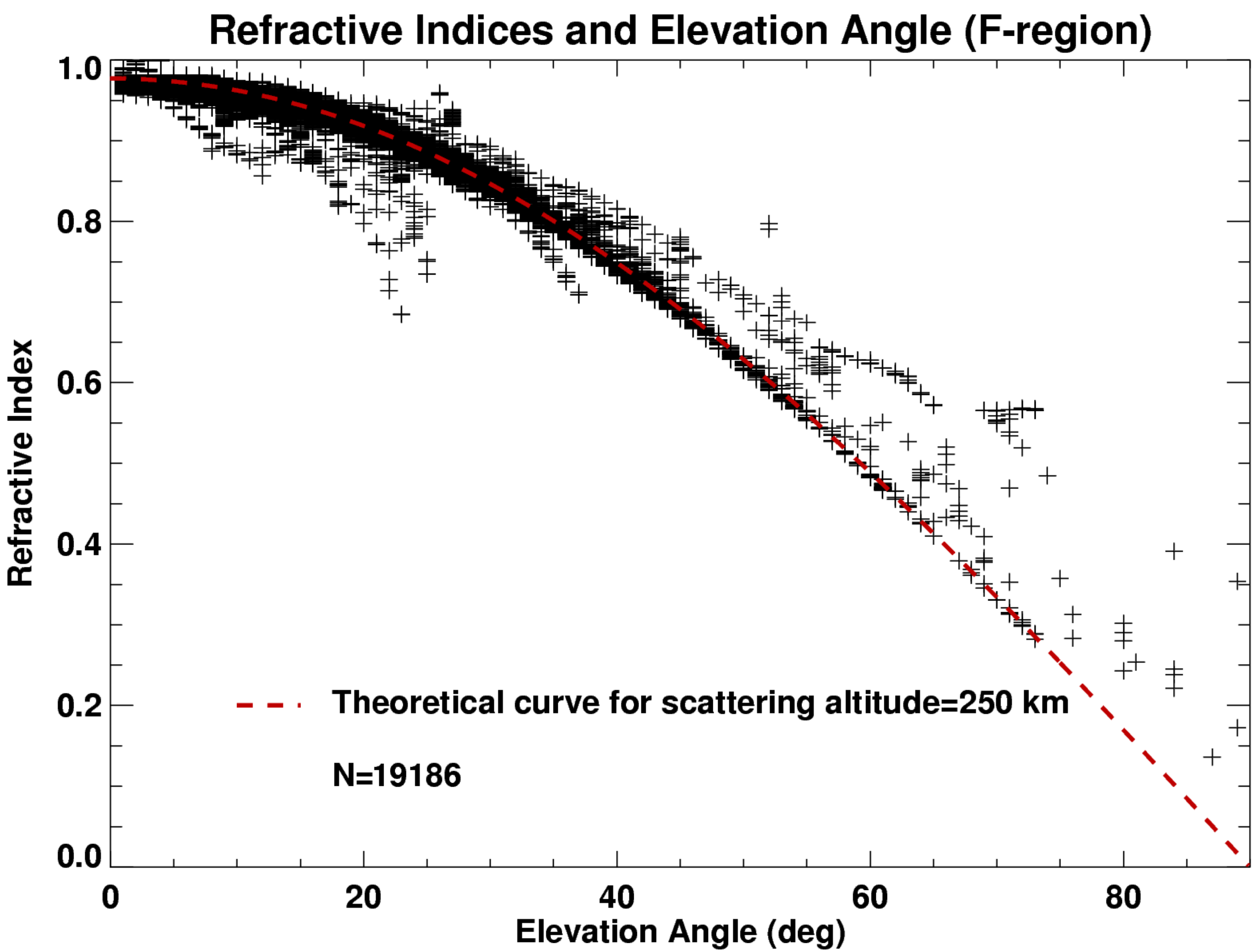
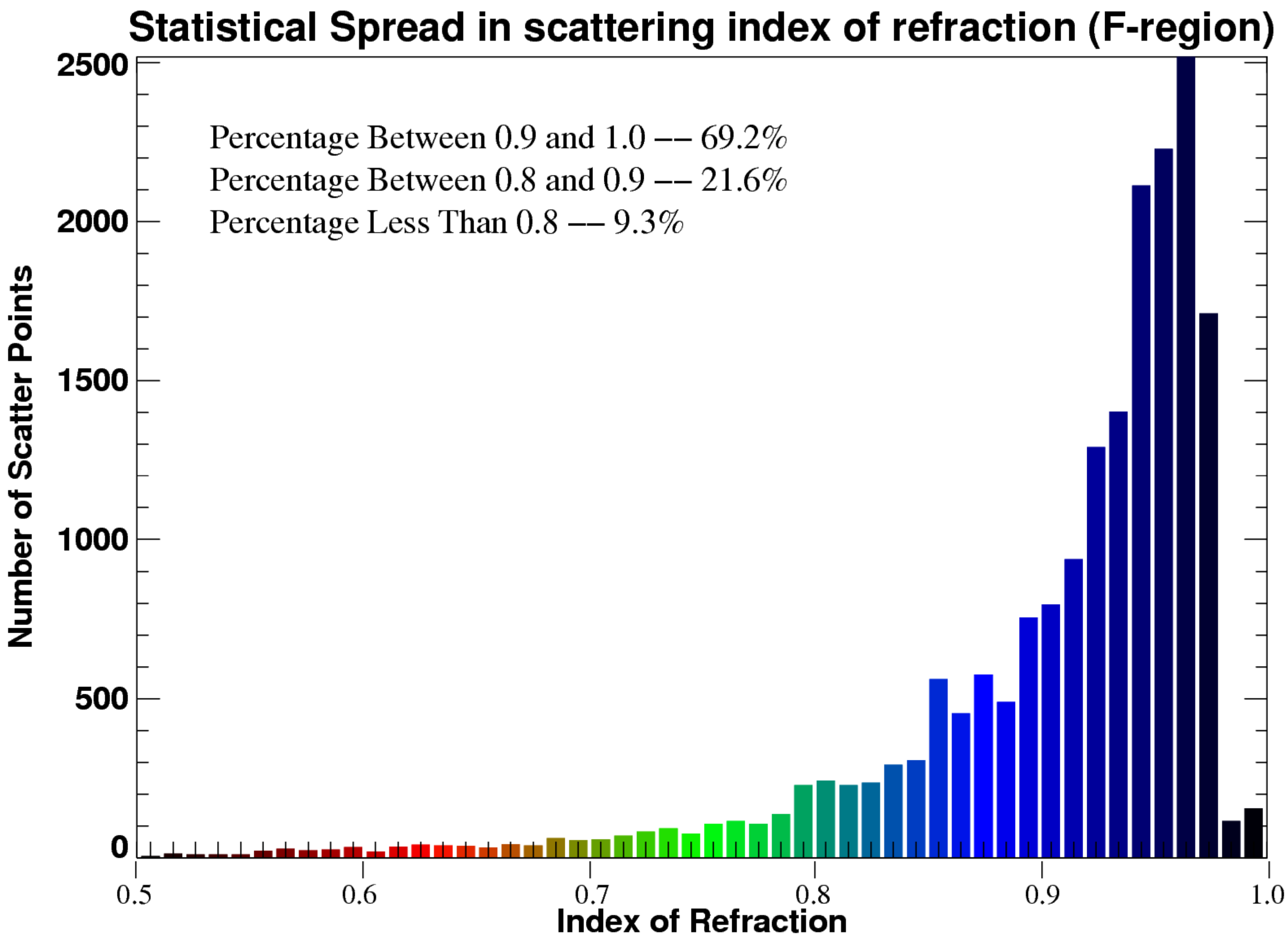
Refractive indices and Elevation Angles (F-region > 150 km and Dip Angle ψ~ 80°)



Statistical Spread of n_s (F-region) - weighted mean is 0.905



DMSP – SuperDARN v_S comparison (work in progress)

- Previous studies have indicated that SD values of v_S were about 25% (or more) lower than values measured by DMSP.
- Mapping E/B along the dipole B lines from the F-region (SD) altitudes up to DMSP at 840 km results in an E/B correction of 12-14%.
- Including the refractive index at the scattering height h_S can easily add a further 11-25 % to the SD speed (for n_s of 0.9 to 0.8), bringing the SD values and the DMSP values into good agreement.

Future Work Planned

- EISCAT (and AMISR) – SuperDARN - ISR comparisons (using v and n values from the ISRs)
- CADI-SD comparisons

  * CADI makes N_e measurements that give the index of refraction profile

  *Comparisons of CADI n_S with SD elevation angles will be made

- SuperDARN sounding mode

  * Since n_S depends on frequency, and elevation angle also depends on f, the sounding frequency sweeps should reveal the trend of n_S with elevation angle

- SuperDARN velocity-elevation angle comparison

  * a detailed comparison of elevation angles and the velocities measured may reveal more about the relationship between elevation angle and velocity

Conclusions

- The inclusion of the refractive index at the scattering location will lead to an increase in the inferred v_S values
- The ray-tracings show a reasonably strong and stable dependence of n_S on elevation angle, so a "reasonable guesstimate" of n_S at any time can be made by using the measured SD elevation angles at that time.
- These results lead to much better agreement between DMSP and SuperDARN velocities.