SuperDARN and the Index of Refraction

The Super Dual Auroral Radar Network (SuperDARN) is an international scientific collaboration consisting of about 30 paired-Doppler coherent scatter radars operated by the United States, Canada, the United Kingdom, Japan, Australia, France, Russia, South Africa, and China (Gosling et al., 1995; Chappell et al., 2007). The radars operate in a frequency band (2-30MHz) in the region of the critical frequencies in the ionosphere. The radar operates at the frequency of the critical frequency (20-50MHz) of the order of the critical frequencies in the ionosphere, taking advantage of the non-unity index of refraction at these frequencies, as described in the Aluminum equation:

\[ f = \frac{1}{2\pi} \sqrt{\frac{1}{\epsilon_1} - \frac{1}{\epsilon_2}} \]

where \( f \) is the radar frequency, \( \epsilon_1 \) is the plasma frequency, \( \epsilon_2 \) is the gyrofrequency, and \( \theta \) is the incident angle (the angle between the radar vector and the magnetic field).

The Frequency-Shift Technique

Work by Gillies et al. (2012) described a frequency-shifting technique, using SuperDARN radars to estimate the index of refraction in the scattering region using the Aluminum equation (valid for the F-region). The Aluminum equation (1) can be rearranged to:

\[ \epsilon_2 \sin \theta = \sqrt{\epsilon_1 - \epsilon_0} \]

where \( \epsilon_0 \) is the dielectric constant of the scattering region. Using the frequency-shift technique, Gillies et al. (2012) demonstrated that SuperDARN radars can independently calculate the electron density from the scattering region using this technique.

Other Results (Preliminary)

Figure 8 is similar to Figure 7 except the Kodiak derived electron density is derived using the elevation angle data, and the SuperDARN data as described in Gillies et al. (2012). Here, the SuperDARN derived electron density was put through a median filter to remove noise.

A Close Look at the Frequency-Shift Technique

Equation 4 must be applied appropriately, once, as depicted in Figure 3 there are regions of the equation that are non-physical in the planned regime:

\[ \frac{1}{f_1} > \frac{1}{f_2} \]

For example, if we consider a 60 MHz radar at 20 km altitude, the critical frequency in the plasma frequency is 30 MHz. The path for each frequency can be tested using a computer (not shown here).

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Multi-Frequency-Shift Technique

Previous experiments exploring the frequency-shift technique have only used one frequency to calculate the electron density from the scattering region. In order to get a better estimate of the electron density, a two-frequency technique is used, as described in Equation 4. The two-frequency technique is:

\[ \frac{1}{f_1} > \frac{1}{f_2} \]

for two different frequencies resulting in a two-frequency data set.

The results obtained by the two-frequency technique are shown in Figure 7. The SuperDARN derived electron density is compared with the Kodiak derived electron density, and the results are shown in Figure 8.

Results (Preliminary)

A two-frequency-electron-density plot of each SuperDARN beam was created and used to compare with the frequency-shift technique. The results obtained by the two-frequency technique were compared with the Kodiak derived electron density, and the results are shown in Figure 8. The SuperDARN derived electron density is consistent with the Kodiak derived electron density, which is expected.

Future Work

• Preliminary data suggests using 3 frequencies is acceptable and provides more data accuracy.
• Electron angle derived electron density shows better trends than frequency-shift data, but suggests that the background is coming from multiple altitudes simultaneously.
• Comparison of SuperDARN and PFISR electron density shows some qualitative agreement; however, significant further analysis is required.

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References

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Hussey, G. C., Gillies, G. C., Sofko, G. J., Ponomarenko, P. A., and McWilliams, K. (2011). Improvement of HF coherent radar line-of-sight velocities by estimating the refractive index in the F-region auroral arc and again, Kodiak derived electron density is consistent with PFISR measurements. It is important to note that all frequency data are represented qualitatively in the dataset.

Figure 3. A scatter plot displaying the relationship between frequency ratio, \( f_2/f_1 \), velocity ratio, \( v/v_0 \), and the square of the plasma frequency to the transmitted frequency ratio, \( f_2/f_1 \). The black line is the asymptote. The region distant from the plasma frequency is the right-hand region and the left-hand region.

Figure 4. The experiment consists of colocated measurements using the Kodiak, Alaska SuperDARN radar and the Poker Plate Scatter Radar (PFISR). The data was collected during a 4-hour period of the PINOT (Polar Ionospheric Observations in the Thermosphere) experiment on 31 December 2012.

Figure 5. The Saskatoon SuperDARN radar beneath the aurora during the 1 June 2013 geomagnetic storm. Note the 16 antenna transmitting array to the left and the 24 antenna receiving array to the right.

Figure 6. PFISR horizontal electron density distribution (left) versus Kodiak backscattered power (right). Kodiak was operating at a frequency of 10.75MHz.

Figure 7. Electron density derived from Kodiak using the frequency-shift technique for various frequency differences (symbols, see legend) compared with PFISR electron density measurements for various PFISR beams.