Solar Control of $F$-Region Radar Backscatter: Further Insight from Observations in the Southern Polar Cap

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1. Abstract

The role of solar wind and illumination in production of small-scale $F$-region plasma irregularities is investigated using a 4-year data set collected by the Super Dual Auroral Radar Network (SuperDARN) facility at the McMurdo station, Antarctica (MCM). Statistical analysis of ionospheric echoes detected by MCM shows that radar backscatter from the polar $F$ region occurs in wide and persistent bands that exhibit systematic changes with local time, season, and solar cycle. It is demonstrated that all variations considered together form a distinct pattern. A comparison with $F$ region model densities and raytracing simulations shows that this pattern is largely controlled by the $F$ region solar-produced ionization during the day. During the night, however, MCM observations reveal a significant additional source of plasma density in the polar cap as compared with the model. An example of conjugate radar observations is presented that supports the idea of polar patches being this additional source of ionization on the nightside. Echo occurrence within the band exhibits a clear peak near the solar terminator, which suggests that small-scale irregularities form in turbulent cascade from large scales. Further, echo occurrence is enhanced for particular IMF orientations during the night. Observations indicate that solar illumination control of irregularity production is strong and not restricted to the nightside. Indirect solar wind control is also exerted by the IMF-dependent convection pattern, since the gradient-drift instability favors certain orientations between the plasma density gradients and convection velocity.

2. Introduction

SuperDARN observes small-scale (~10 m) density irregularities in the ionosphere. Here, we focus on the extent of solar control on irregularity production in the polar ionosphere. This includes both direct solar control (solar illumination) and indirect (due to IMF conditions). Solar illumination smoothes density gradients and reduces observed echoes in the auroral region [Kurthomrei and Greenwald, 1997; Knudsen et al., 2004]. However, preliminary observations with MCM found low nighttime echo occurrence relative to daytime [Bristow et al., 2011]. In addition, it has been found that a strongly negative IMF $B_x$ component results in high echo occurrence [Ballatore et al., 2001]. High-latitude SuperDARN radars rely on refraction for the beam to be perpendicular to the magnetic field (necessary to observe irregularities) [Chisham et al., 2007]. This means the echo occurrence is also dependent on ionospheric electron density.

3. Objectives

- Quantify the location of $F$-region backscatter
- Analyze the effects of solar illumination on irregularity production in the $F$ region
- Establish a relationship between IMF and echo occurrence

4. Band Model

$$R(t) = A \cos \left( \frac{2\pi(t - B)}{24} \right) + C$$

- A clear band of high echo occurrence is evident in each month that can be modeled by a simple cosine function
- The band moves further away from the radar in low density conditions
- March and September have echoes throughout the night – does not agree with raytracing simulation

This suggests that the diurnal variations in the band’s position are due primarily to radar propagation effects and irregularity production can be studied more accurately considering only occurrence within the modeled band. Also, there is an additional source of nighttime plasma density, allowing backscatter to be observed throughout the night in the spring and fall.

5. Band Characterization and Solar Illumination Control

- All parameters exhibit a clear peak in winter months
- In summer months, the amplitude, width, and position of the band decrease
- The location of the maximum band range consistently matches the strong minimum in occurrence
- The points with the highest $F$-region electron density have the lowest daytime echo occurrence

6. IMF Control

The occurrence is not strongly dependent on IMF direction during daytime hours. At nighttime, positive $B_x$ and negative $B_y$ and $B_z$ correspond to high occurrence. The trend is particularly strong for IMF $B_y$.

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7. Role of Polar Patches

- In the first event, the structures observed by RKN match the regions of high (daytime) density observed by RISR
- Backscatter observed by MCM is persistent in the first event and “patchy” in the second
- Polar patches regularly contribute to the nighttime density and improve propagation conditions to increase the amount of nighttime backscatter observed. Highly variable IMF $B_y$ promotes the generation of patches.

8. Summary

- The high occurrence band can be modeled by a cosine function
- Band range increases for low density conditions
- There is a maximum in echo occurrence near the terminator
- IMF only affects nighttime echo occurrence
- Negative IMF $B_y$ and $B_z$ components promote high echo occurrence
- Polar patches could cause increased nighttime plasma density and allow for continuous backscatter observation in the spring and fall