Spatial Distribution of Irregularity Occurrence Rate in the Subauroral F Region as Observed by the SuperDARN Radars

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Abstract : In order to estimate the distribution of the irregularity appearance, we have investigated the scattering occurrence rate of the SuperDARN radars. The most significant result is that the distribution of scattering occurrence rate, which is approximately identical to the irregularity occurrence rate, has a clear peak around the duskside terminator in the subauroral region. On the contrary, a weak enhancement appears around the dawnside terminator only in the winter and no detectable peak is found in the other seasons. The dependence of the distribution on the level of geomagnetic disturbance as estimated by the Kp index was also examined.

I Introduction

The HF radars of SuperDARN transmit the radio waves whose frequency ranges from 8 to 20MHz. As the waves traverse the E and F regions of the ionosphere, HF signal can be scattered backward by the decameter-scale irregularities when the aspect condition is satisfied. Scattering occurrence rate depends on both the irregularity existence and the condition of HF wave propagation. Hence, the observed "scattering occurrence rate" is considered to be the lower bound of the actual "irregularity occurrence rate", which provides an important information about the formation process of the irregularities. In this paper, we report the results of a statistical analysis of scattering occurrence using the data from radars located in northern hemisphere and estimate the distribution of the irregularity appearance.

II Method of Statistical Analysis

We used the data of Saskatoon, Kapuskasing and Goose Bay radars obtained in common time operation during 39 months from July 1995 to September 1998. At first, range filter is applied to eliminate the E region scatter and echoes that are considered to be Ground Scatter are excluded on the basis of their l-o-s velocity magnitude and spectral width. Finally, we remove the echoes which do not have sufficiently strong signal ($<$ 3dB signal-to-noise ratio) in order to extinguish the ghost due to the radio interference. After the noise reduction described above, data of the radars are mapped into both geographic coordinate and invariant latitude/magnetic local time (MLT) coordinate systems.

III Results of the Analysis

Figure 1 shows the maps of monthly scattering occurrence rate in geographic coordinate system. Two white lines indicate the range of the terminator position at the ground level in each month. Most striking feature is that the scattering occurrence rate peaks at lower-latitude region between 55° and 62° within a few local time on the evening side of the duskside terminator in all months. In these higher scattering occurrence rate regions, plasma density gradient created by the solar EUV radiation is considered to be strong, which suggests that the density gradient around the terminator plays an important role in the formation of subauroral irregularities. In contrast with the case of dusk meridian, no appreciable peak of scattering occurrence exists around the dawn side terminator during the periods except for winter.

Figure 2 shows the maps of monthly scattering occurrence rate in invariant latitude/MLT coordinate system. Two white circles indicate the equatorward and poleward edge of the auroral oval [*Feldstein*, 1963] as modeled by *Holzworth and Meng* [1975] for $Q = 0$ (most quiet condition), respectively. In all months, a peak of scattering occurrence rate is seen in the dusk meridian whose invariant latitude is slightly lower than the equatorward edge of the auroral oval. These regions of higher scattering occurrence coincide the density depleted region called mid-latitude trough [*Spiro et al.*, 1978; *Moffett and Quegan*, 1983]. In general, mid-latitude trough is located outside of the auroral oval and the poleward edge of mid-latitude trough is usually close to the equatorward edge of the auroral oval. Poleward boundary of the duskside peak region corresponds to the equatorward edge of the auroral oval, which suggests that the enhancement of irregularity occurrence in the duskside subauroral region is related to the structure of the mid-latitude trough as well as the terminator.

The next factor we consider is the dependence of the subauroral irregularity occurrence on the geomagnetic disturbance level. Upper four panels, from (a) to (d), of Figure 3 show the distributions of scattering occurrence rate in geographic coordinate system for quiet condition ($0 \leq$ Kp $\leq 2+$). A peak of scattering occurrence is found on the evening side of the dusk terminator throughout the year. Bottom four panels, from (e) to (f), of Figure 3 show the distributions for disturbed condition ($3- \leq$ Kp ≤ 9). One notable feature is that the apparent peak of scattering occurrence around the terminator almost disappears in spring (March) and summer (June).

Upper four panels, from (a) to (d), of Figure 4 show the scattering occurrence rate distributions in invariant latitude/MLT coordinate system for quiet condition ($0 \leq$ Kp $\leq 2+$). Two white lines in each panel indicate the Feldstein oval for $Q = 0$. The peak of scattering occurrence is found within the dusk side mid-latitude trough in all month periods. These peak regions are expected to be the same as those found around terminator in geographic coordinate system. These results indicate that the intersection area of duskside terminator with the mid-latitude trough is the most active source region of irregularities in the case under quiet condition. Bottom four panels, from (e) to (f), of Figure 4 show the distributions in invariant latitude/MLT coordinate system for disturbed condition ($3- \leq$ Kp ≤ 9). Here, the auroral oval was drawn for $Q = 3$. As noted in Figure 3, the peak of scattering occurrence is associated with the dusk terminator only in winter for magnetically disturbed condition.

IV Discussion

Ruohoniemi et al [1988] identified a distinctive backscatter around the dusk terminator in the subauroral ionosphere using the data of SuperDARN Goose Bay radar and called this activity as "dusk scatter event". Characteristics of the dusk scatter event is quite similar to the feature of the scattering occurrence peak in our statistical results. That is, the enhancement of scattering occurrence obtained in our statistical study corresponds to the dusk scatter event reported by *Ruohoniemi et al.* [1988].

The asymmetry of irregularity occurrence between dawn and dusk sides is also a notable result deduced from our statistical study. In general, the latitudinal location of the mid-latitude trough has a dawn - dusk asymmetry in accordance with the structure of the plasmapause. The model of mid-latitude trough by *Collis and Haggstrom* [1988] and two-dimensional electron density profile reported by *Holt et al.* [1984] show that the mid-latitude trough is positioned more equatorward and outside of the SuperDARN observation area in dawn meridian. The absence of the mid-latitude trough in the dawn side SuperDARN observation area is probably the cause of the asymmetry in the occurrence between both sectors.

Main statistical result about the Kp dependence is that the peak of the scattering occurrence can not be found around the dusk terminator in spring, summer and fall during disturbed condition. In general, according to the expansion of the auroral oval, the location of the mid-latitude trough is also shifted equatorward. Thus, the mid-latitude trough is located outside of the SuperDARN observation area at the time of terminator passage in the season except for winter during disturbed condition. Exactly, the reason why the peak around the terminator is not obtained in spring, summer and fall for disturbed condition is due to the absence of the mid-latitude trough at the time of terminator passage.

We discussed several generation mechanisms of irregularities based on the gradient-drift instability process. Which one is the best, however, is still an open question. In order to determine the mechanism creating the irregularity enhancement, simultaneous observation of the background parameters such as electric field, plasma density and plasma temperature by the satellites or incoherent scatter radar is needed.

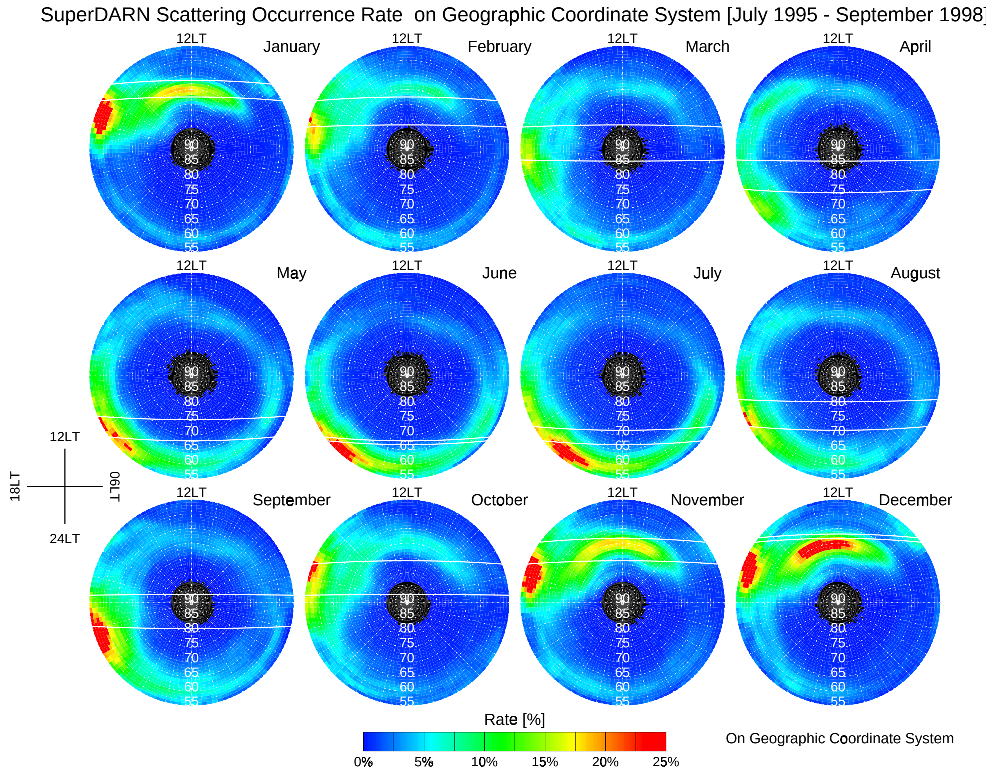

Figure 1: Monthly scattering occurrence rate as a function of geographic latitude (from 55° - 83°) and local time. Two white lines indicate the range of the terminator position at the ground level in each month period.

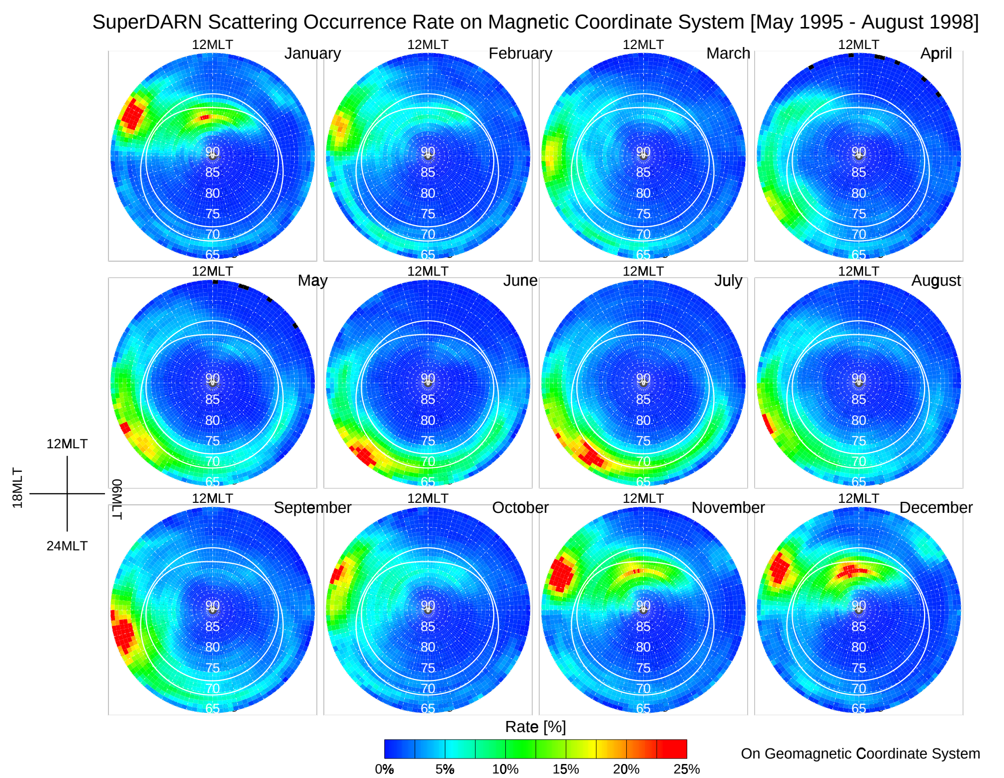

Figure 2: Monthly scattering occurrence rate as a function of invariant latitude (from 65° - 89°) and magnetic local time (MLT). Two white circles indicate the equatorward and poleward edge of auroral oval for $Q = 0$ (most quiet condition).

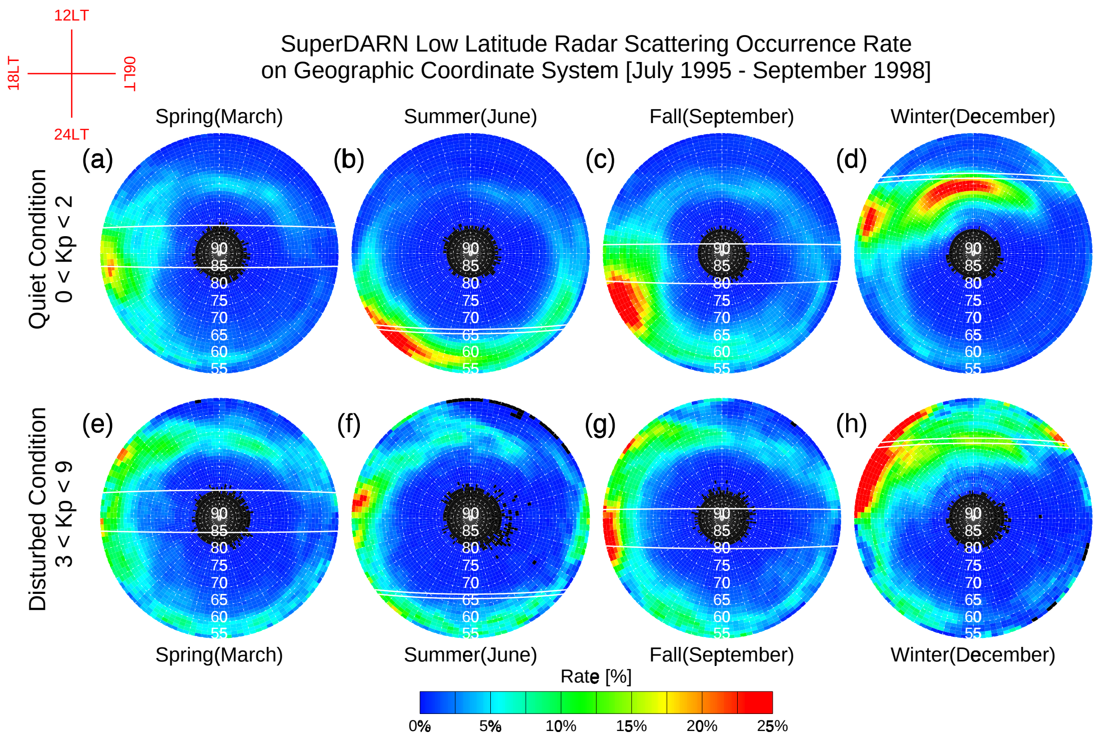

Figure 3: Upper four panels, from (a) to (d), show the distributions of scattering occurrence rate in geographic coordinate system for quiet condition ($0 \leq \mathrm{Kp} \leq 2+$). Bottom four panels, from (e) to (f), show the distributions for disturbed condition ($3- \leq \mathrm{Kp} \leq 9$).

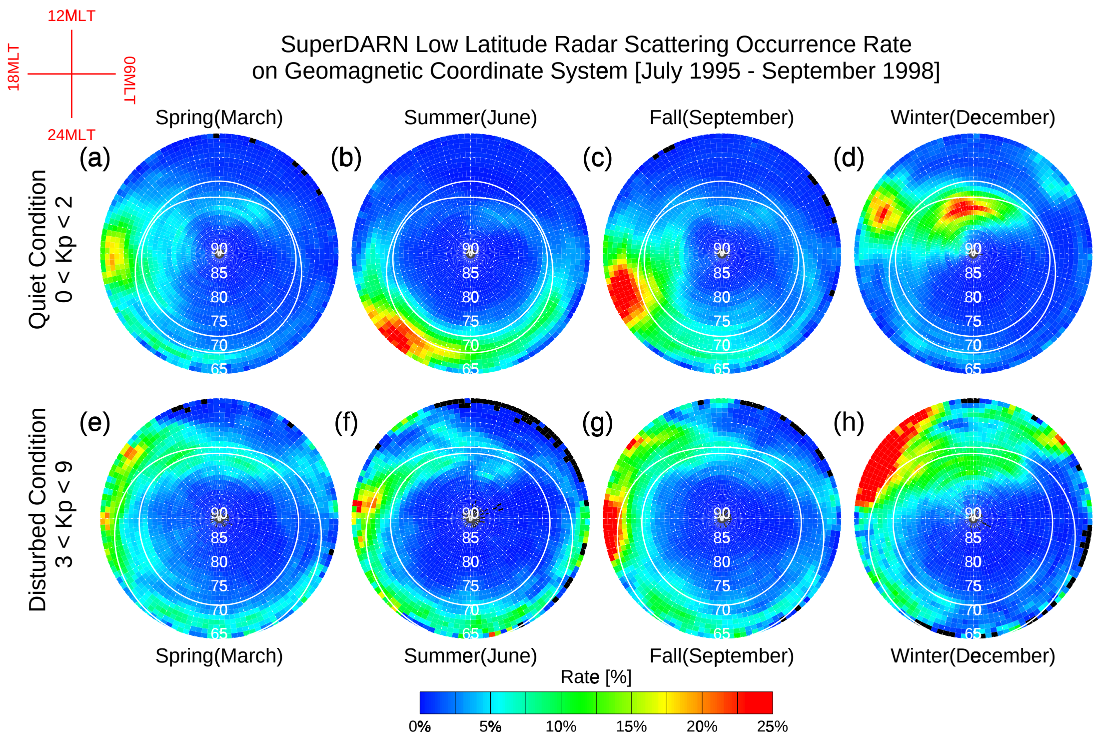

Figure 4: Upper four panels, from (a) to (d), show the distributions of scattering occurrence rate in geomagnetic coordinate system for quiet condition ($0 \leq \mathrm{Kp} \leq 2+$). Bottom four panels, from (e) to (f), show the distributions for disturbed condition ($3- \leq \mathrm{Kp} \leq 9$).