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LONG TERM VARIATIONS OF RADIO AURORAL ACTIVITY

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Abstract: Long term variations of radio auroral activity are investigated from auroral radar data obtained at Syowa Station during 1978–1990. The diurnal variation of radio auroral activity shows a maximum in the post-midnight period with a small peak in the evening. Similar to the case of magnetic activity, the occurrence rate of radio aurora shows semi-annual variations with summer (December) and winter (June) time minimums. For post-midnight radio aurora, summer minimums are more pronounced than winter minimums. The magnetic activity controls the occurrence of evening time radio aurora more notably than post-midnight radio aurora. For the solar cycle variation, a double-peaked modulation is seen during 11-year sunspot cycle, with a major peak in the declining phase of the sunspot cycle and a secondary peak in the increasing phase.

1. Introduction

Reflections of radio waves from the auroral ionosphere are generally called radio aurora. It is well accepted that nearly all the radio aurora is caused by plasma instabilities in the *E* region. There are two driving mechanisms for irregularities in a partially ionized plasma, namely the two-stream and gradient drift instabilities. The principal factor controlling the generation of these plasma instabilities is the intensity of ambient electric field. The plasma density is also an important factor, since the density gradient is essential in the gradient drift instability. Thus, occurrence or non-occurrence of radio aurora is dependent on the level of geomagnetic activities and the structure of the ionosphere.

The physical condition of the magnetosphere tends to be modulated by the solar activity, because solar wind parameters which control solar wind-magnetosphere interactions depend on the sunspot number. Thus, the modulation of radio auroral activity with the 11-year sunspot cycle period will be a natural expectation.

It is well known that the geomagnetic activity shows a double-peaked modulation during the 11-year cycle, with the major peak in the declining phase of the sunspot cycle and a secondary peak in the increasing phase (SILVERMAN, 1986; GORNEY, 1990). Major geomagnetic storms also occur most frequently in the declining phase of the sunspot cycle (FEYNMAN, 1983). These phasings between the sunspot number and the geomagnetic activity can be explained through the variation of solar wind speed. Previous investigations have shown that extreme solar wind streams exceeding 600 km/s appear much frequently in the declining phase years (GORNEY, 1990). The interplanetary magnetic field (IMF) has been found to correlate poorly with the level of geomagnetic activity over long time scale (GORNEY, 1990), although individual events may be triggered by the IMF. Similarly to the geomagnetic activity, the radio auroral activity will show a double-peaked modulation during the 11-year cycle.

An additional factor which controls the radio aurora activity in a long time scale will be the ionospheric condition. The variation of the ionospheric parameters due to the change of solar EUV flux can give annual and solar cycle variations in the radio auroral activity. In this paper, statistical results are shown for the occurrence probability of radio aurora, from the analysis of auroral radar data at Syowa Station during 1978–1990.

2. Observations

An auroral radar observes return echoes from ionospheric density fluctuations generated by plasma waves in the auroral *E* region. The auroral radar at Syowa Station observes radio aurora at the frequency of 50 MHz. The radar system used for the present observation is a coherent pulsed Doppler radar with the peak power of 20 kW. This radar has two antenna beams, one directed toward the geomagnetic south (GMS) and the other toward the geographic south (GGS). At Syowa Station (69°00′S, 39°35′E), the direction of the geographic south is deviated 30° toward west from the geomagnetic south. Antenna beamwidth is about 4° in the horizontal plane.

The observing condition for radio aurora is restricted to the direction of 90° aspect angle, because iso-electron-density contours stretch along the magnetic field line. At Syowa Station, this condition is fulfilled around the position of 300 km range in the GMS beam. In the present statistical analysis, therefore, intensity data of return echoes from this position were used.

In these thirteen years, 1978–1990, the data have been obtained almost in continuous base. However, there were many short intervals of no observation during these years. The Occurrence probability of radio aurora was calculated considering these observational conditions. At first, "occurrence" or "non-occurrence" of radio aurora was digitized for every one-hour intervals through the observing period. If there were at least one appreciable echo in the one-hour interval, it was designated as occurrence of echo. The occurrence probability of radar echo is hereafter defined as the ratio of "occurrence" days to the total number of days concerned, and this probability was calculated for each UT hour intervals.

Figure 1 shows examples of diurnal variations for the occurrence probability (annual mean) of radio aurora. It is seen in this figure that there appear a major peak in the post-midnight, and a minor peak in the evening (LT = UT + 3 hours). In general, coherent radar echoes observed at high-latitude *E* regions can be classified into several types (TANAKA *et al.*, 1990). However, diffuse echoes occur most frequently and they contribute mainly to statistical results in this paper.

Results for the long term variation of radio auroral occurrence are shown in Figs. 2 and 3. These figures show monthly mean occurrence rates of radio aurora for selected local time intervals during 0–2 UT and 15–17 UT. The intervals 0–2 UT and 15–17 UT are selected to investigate the characteristics of post-midnight and evening radio aurora. Semi-annual and solar cycle variations can be seen from these figures.

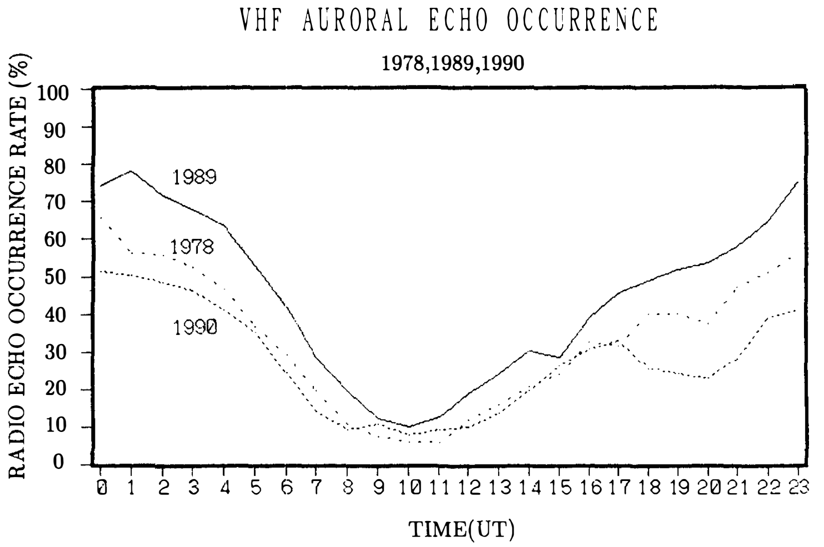

Fig. 1. Diurnal variations of the radio aurora occurrence rate for 1978, 1989 and 1990. Annual averages are shown for one hour intervals.

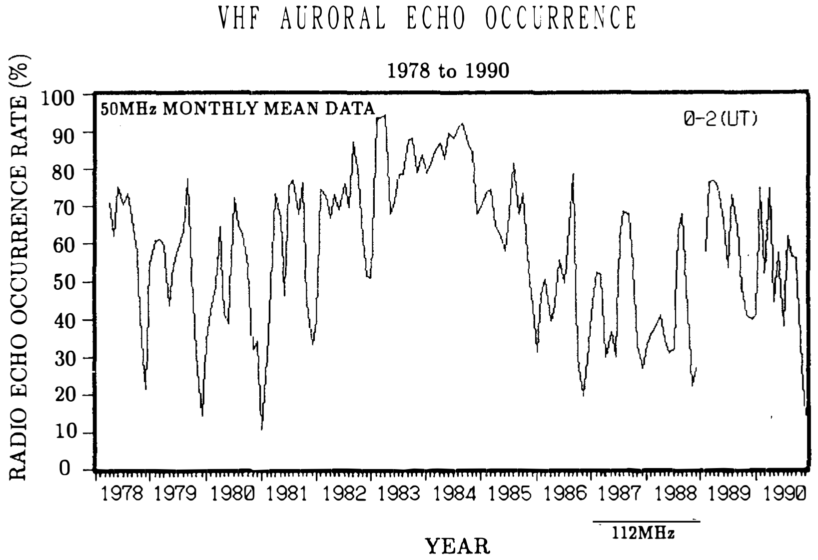

Fig. 2. Long term variation of the radio aurora occurrence rate for 0–2 UT (3–5 LT). Monthly averages are shown. The double-peaked modulations during the 11-year cycle together with semi-annual variation can be seen.

The appearance of radio aurora increases during the equinox period. In Fig. 2, summer (December) minimums are more pronounced than winter (June), especially near solar maximum (November 1979) and minimum (September 1986) years. The long term variation of the *aa* index for the same years 1978–1990 is shown in Fig. 4. In general, variations of magnetic disturbances also show semi-annual component due to the variation of relative angle between the solar wind flow and the axis of earth's dipole magnetic field. Comparing Fig. 4 with Figs. 2 and 3, the semi-annual variation of *aa* index resemble more closely to that of Fig. 3 than Fig. 2. In the variation of *aa* index, for instance, summer minimums are absent in 1989 and 1990. These features are well

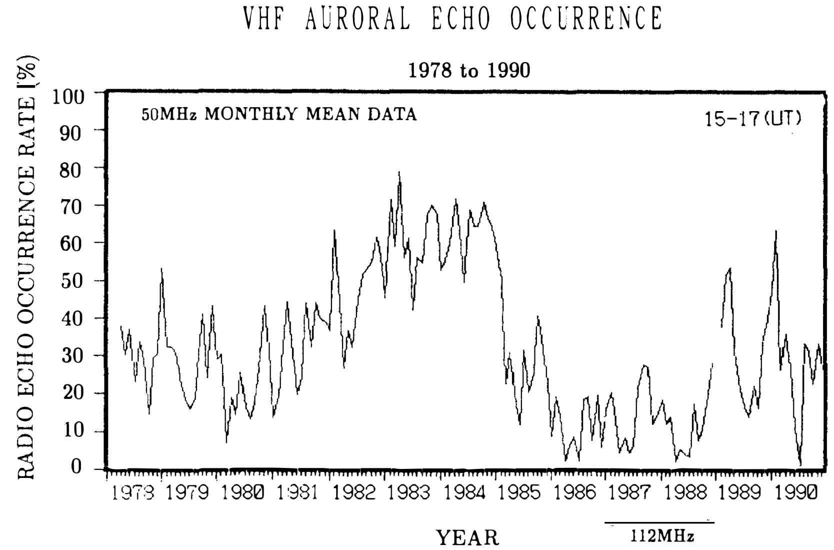

Fig. 3. Long term variation of the radio aurora occurrence rate for 15–17 UT (18–20 LT). Monthly averages are shown. Summer time minimums are not so deep as for 0–2 UT (3–5 LT).

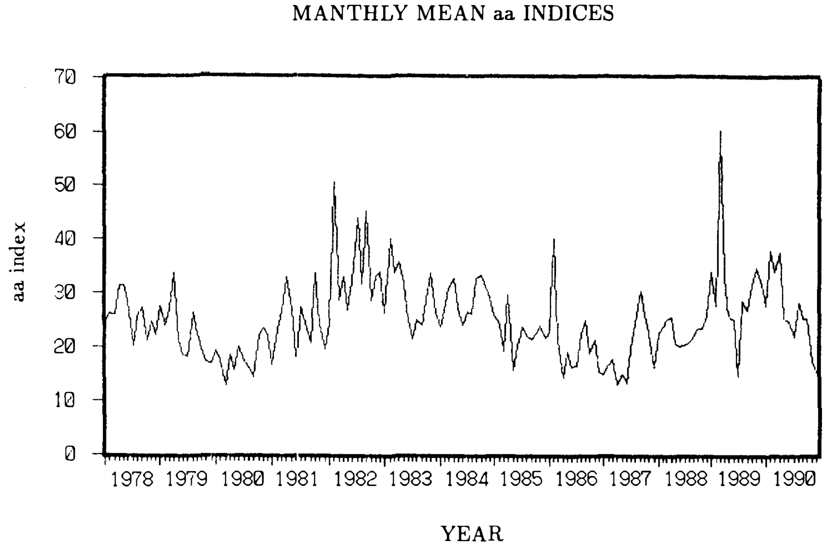

Fig. 4. Long term variation of the aa index. Monthly averages are shown. The double-peaked modulation in the 11-year sunspot cycle and semi-annual variations are seen in this figure.

reflected to Fig. 3. However, summer minimum are seen in Fig. 2 even in these years. Thus, the evening radio aurora is influenced by the variation of *aa* index more severely than post-midnight radio aurora.

As the solar cycle variation, a major peak around the declining phase of the sunspot cycle and a secondary peak around the increasing phase are noticeable in Figs. 2 and 3. These features are similar to the long term variations of the *aa* index shown in Fig. 4, where their values are high in 1982–1984. Similar intervals are also seen both in Figs. 2 and 3. However, some discrepancies are noticeable between the variations of the *aa* index and radio aurora. The occurrence rates of radio aurora are relatively high in 1984, whereas the *aa* indices in the same year are considerably lower than those in 1982–1983. In Fig. 2, the occurrence rate is almost saturated during 1984. At this period, the semi-annual variation is not seen due to the saturation effect.

3. Discussion and Conclusion

Diurnal variations of the radio auroral activity shown in Fig. 1 exhibit two peaks in the evening and post-midnight periods. In general, radio auroral echoes are classified either as diffuse or discrete. The diffuse echoes are long lasting and have wide-ranging latitudinal and longitudinal extent, whereas the discrete auroral echoes, which are associated with the substorm expansion phase, are short-lived and come from an appreciably small echoing region than the diffuse echoes (FEJER and KELLEY, 1980). Thus, the diffuse echoes are responsible for most of the radar aurora. The diffuse radar aurora occur in two oval regions, one equatorward of the visual auroral oval in the evening and the other poleward in post midnight (FEJER and KELLEY, 1980). Diurnal variations of the radio auroral activity shown in Fig. 1 coincide with the above morphology for the location of diffuse aurora.

In the present observation, the backscattering waves propagate nearly perpendicular to the electrojet current. These waves seem to be secondary waves from primary irregularities. Thus, all observations are made in the nonlinear state. Under such condition, the threshold electric field necessary to generate radar echoes is quite different for the post-midnight and evening periods (SIREN *et al.*, 1977). During the post-midnight period, substantial radar echoes occur for southward electric field of only 10 mv/m, while echoes do not occur until the northward electric field reaches 25 mv/m during the evening period. As the result, the occurrence probability of radar echoes in Fig. 2 is higher than that in Fig. 3, throughout the observing period.

A summer-winter asymmetry is seen in the occurrence rate of radio aurora in the post-midnight period. On the other hand, evening radio aurora is controlled strongly by the geomagnetic activity. This result indicates a dominating role of the electric field for the generation of radar echoes in the evening period, through the two-stream instability. The result also suggests the control of ionospheric parameters for the generation of radio aurora at post-midnight. In the post-midnight period, the threshold electric field for 50 MHz echoes is as low as 10 mv/m (SIREN *et al.*, 1977). Such a field cannot excite the two-stream instability. In this case, the gradient drift instability on the topside of *E* region is the cause of primary irregularities. According to the theoretical results, the threshold electric field for the gradient drift instability become strong under the condition of large ionospheric plasma density and small density gradient on the topside *E* region (FEJER and KELLEY, 1980). At Syowa Station, a sunlit condition is maintained throughout a day, around the summer solstice. This condition restricts the generation of the gradient drift instability.

Similarly to the case of the *aa* index, the double-peaked modulation during the 11-year cycle is seen in the occurrence of radio aurora. These characteristics also indicate the role of the geomagnetic activity for the generation of radio aurora. Around the solar minimum, polar holes predominate for several years. Open magnetic field structure in the hole region is responsible for the fast solar wind stream. However these high speed wind are restricted to high-latitude regions, and low speed regions dominate in the equatorial region. In the increasing phase of the solar activity cycle, the polar holes usually shrink and disappear at the solar maximum. In these periods, however, they occasionally spread toward the equator and cause high speed flow around the equator. In the solar maximum period, the mean speed of the solar wind appears to be low over the entire solar surface. During the declining phase, reappearing polar holes occasionally extend down to the equator, causing the emission of high-speed solar wind near the equatorial region. From the solar wind data shown by RICKETT and COLES (1991), these situations are well observed in 1983 and 1984.

Comparing long term variations of the *aa* index and the occurrence rate of radio aurora, some minor discrepancies can be observed in their relative relations. While mean level of the *aa* index was almost flat during 1982–1984, the occurrence rate of radio aurora increased monotonically during the same interval. The decreasing rate of radio aurora from 1984 to 1985 seems to be more rapid than the *aa* index. The cause of this discrepancy is not clear at present. Another important parameter than the solar wind velocity which controls the environment of the magnetosphere, is the interplanetary magnetic field (IMF). In short time scales, the correlation between the solar wind speed and geomagnetic activity is rather poor. In short time scales, the magnitude and direction of IMF are major factors for controlling the level of geomagnetic activity. These effects on the statistical results must be considered in more detail for further investigations.

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