DUAL SATELLITE OBSERVATIONS OF AURORAL HISS AND SAUCER EMISSIONS ABOVE THE SOUTHERN AURORAL ZONE

Kazuyuki NAKAGAWA, Takashi SHIBATA and Takeo YOSHINO

University of Electro-Communications,
5-1, Chofugaoka 1-chome, Chofu-shi, Tokyo 182

Abstract: Global distributions of auroral hiss and VLF saucer emissions have been examined by using VLF data obtained from the three satellites, EXOS-A, ISIS-1 and -2. These VLF data were received at Syowa Station in Antarctica. From the observations of hiss and saucer emissions on five pairs of satellite paths in which the two satellites traversed the auroral zone with a time difference within one hour, it is seen that the location of the hiss and saucer emission regions do not change too much during that time. Furthermore, it is seen that the equatorward boundary of the hiss emission region is located near the position of the auroral oval statistically given by THOMAS and BOND (Planet. Space Sci., **26**, 691, 1978) for each value of *Kp* index. These results suggest that the hiss and saucer emission regions exist not only statistically but also they are maintained over the time scale of one hour.

1. Introduction

Global distributions of auroral hiss and saucer emissions have been studied by many investigators by using the wave data observed on polar-orbiting satellites. GURNETT (1966) and HUGHES *et al.* (1971) demonstrated that the auroral hiss emissions are observed in a zone encircling the geomagnetic pole. The latitudinal width of the zone is $\sim 10^\circ$ and under geomagnetically quiet conditions the zone is located at $\sim 70^\circ$ invariant latitude (INV) in the night side and $\sim 78^\circ$ INV in the day side. On the other hand, YOSHINO *et al.* (1980) showed from the ISIS-1 and -2 VLF data that the saucers are also observed in a zone encircling the geomagnetic pole. The zone is located at $\sim 60^\circ$–75° magnetic latitude (MLAT) in the night side, and at $\sim 75^\circ$–85° MLAT in the day side.

These hiss and saucer emission zones were obtained from a statistical analysis method. Hence, it is important to make clear whether or not these statistical emission zones exist simultaneously with time intervals within an hour. In order to examine this respect, the simultaneous measurements by detectors on board multiple polar orbiting satellites which traverse various local time sectors of the auroral zone will be one of the most useful methods. From an analysis of concurrent wave data obtained on the OV1-17 and Ogo 6 satellites, KELLY *et al.* (1975) showed that the ELF waves are occurring simultaneously in a wide local time region from 06 to 18 MLT. In the present paper we have examined the global distributions of auroral hiss and saucer emissions by using VLF data from the three satellites, EXOS-A, ISIS-1 and -2, passing through over Syowa Station in a short time interval. The telemetry signals from two satellites can not be received simultaneously since Syowa Station satellite data acquisition facilities have only one tracking antenna. Therefore, we have selected a pair of satellite pathes in which two satellite traversed the auroral zone with a time difference within one hour. Five pairs of satellite paths received at Syowa Station in 1978 satisfy this condition. By using these data, the distributions of hiss and saucer emission regions over the southern polar region are presented first, and their relationship to the statistical emission zones is discussed.

2. Instrumentation and Data Analysis

The satellite data used in the present paper are VLF wideband data received at Syowa Station in 1978. ISIS-1 and -2 are multiexperiment ionospheric satellites on polar orbits. The both satellites have similar on board wave measurement instruments, 73 m tip-to-tip electric dipole antenna and wideband VLF receiver with an effective band-width of 50 Hz to 30 kHz. The telemetry signals from the ISIS-1 and -2 satellites have been received on a routine basis since April 1976 at Syowa Station. On the other hand, the EXOS-A (Kyokko) satellite was launched at 0700 UT on February 4, 1978. Its plasma wave detector has one wideband channel with the frequency range 0.4–30 kHz and eleven bandpass filtered channels in the frequency range 45 kHz–3 MHz. The plasma wave detector is connected to an electric dipole antenna with a 4.5 m tip-to-tip length and two Faraday cups which measure the electron density fluctuation. Although the wide-band channel of EXOS-A has a bandwidth of 400 Hz to 30 kHz, natural VLF waves are usually not observed in the frequency range higher than 15 kHz due to a low sensitivity in this frequency range. Telemetry reception of the EXOS-A VLF data started at Syowa Station on February 7, 1978. Table 1 gives orbital data of the three satellites. ISIS-1 and -2 are polar-orbiting satellites with an inclination of $\sim$88°, while the orbital inclination of EXOS-A is $\sim$65°. Therefore, EXOS-A moves longitudinally above the auroral zone. So it is expected that the paths of EXOS-A and ISIS-1 or -2 cross each other near overhead

Table 1. Orbital data of ISIS-1, -2 and EXOS-A in June 1978.

Satellites	ISIS-1	ISIS-2	EXOS-A
Inclination (deg)	88.4	88.2	65.4
Apogee (km)	3512	1424	3968
Perigee (km)	575	1354	645
Period (min)	128.2	113.6	134.2

of the auroral zone. Thus a comparison of the VLF data obtained from EXOS-A with the ISIS-1 or -2 VLF data is suitable for studying spatial distributions of hiss and saucer emissions.

The satellite VLF data received at Syowa Station were recorded by a seven-channel data recorder together with time code signal (NASA 36 bit format), VLF data observed on the ground and AGC level at the satellite telemetry signal. From these magnetic tapes, frequency-time (f-t) spectra were made by means of a real-time FFT analyzer. The numbers of ISIS-1, -2 and EXOS-A received at Syowa Station throughout 1978 are 50, 54 and 321, respectively. We selected pairs of paths under a condition that ISIS-1 or -2 traversed over the auroral oval within one hour from the EXOS-A observation time. Ten pairs of the satellite paths satisfy such a condition. However, five of them are of no use because the spectra were affected by interference noises or EXOS-A traversed at low latitudes, probably lower than the equatorward boundary of the auroral oval.

When we compare the two satellite data, we need to know the exact locations of the satellites. Note that the altitudes of the three satellites are different. The ISIS-2 has a circular orbit of ~1400 km. And the ISIS-1 and EXOS-A have elliptical orbits. The perigee and apogee heights are 575 and 3512 km for ISIS-1 and 645 and 3968 km for EXOS-A. In order to compare the VLF data obtained on these satellites at the different altitudes, geomagnetic invariant latitude appear to give the most convenient representation for the satellite locations since the VLF whistler mode waves tend to propagate along the magnetic field lines. In the present paper geomagnetic invariant latitude was calculated by using the international geomagnetic reference field (IGRF) 1975 model. And geomagnetic local time (MLT) is calculated from the geomagnetic longitude by the relation,

$$\mathrm{MLT}=12.0+(\phi-\phi s)/15.0 \quad \text{(hours)} \tag{1}$$

where ϕ and ϕs are the geomagnetic longitudes (in degrees) of a given point and the noon meridian, respectively. In Section 4, latitude-MLT coordinates are described.

3. Magnetic Activities during Satellite VLF Observations

It is well known that characteristics of plasma and the intensities of electric and magnetic fields in the magnetosphere are changing rapidly in a close relation to substorm activity. Therefore, even though the VLF data from the two satellites were obtained within one hour, it is likely that the condition of the magnetosphere changed greatly during a time difference between the observation periods of the two satellites. Hence as a measure of magnetic activity, we have investigated the magnetograms observed at Syowa Station and seven stations located in the northern auroral zone, Cape Chelynskin, Baker Lake, Narssarssuaq, Tixie Bay, Leirvogur, Dixon Island and Kiruna. Presented in Fig. 1 are the H-component variations recorded at Syowa

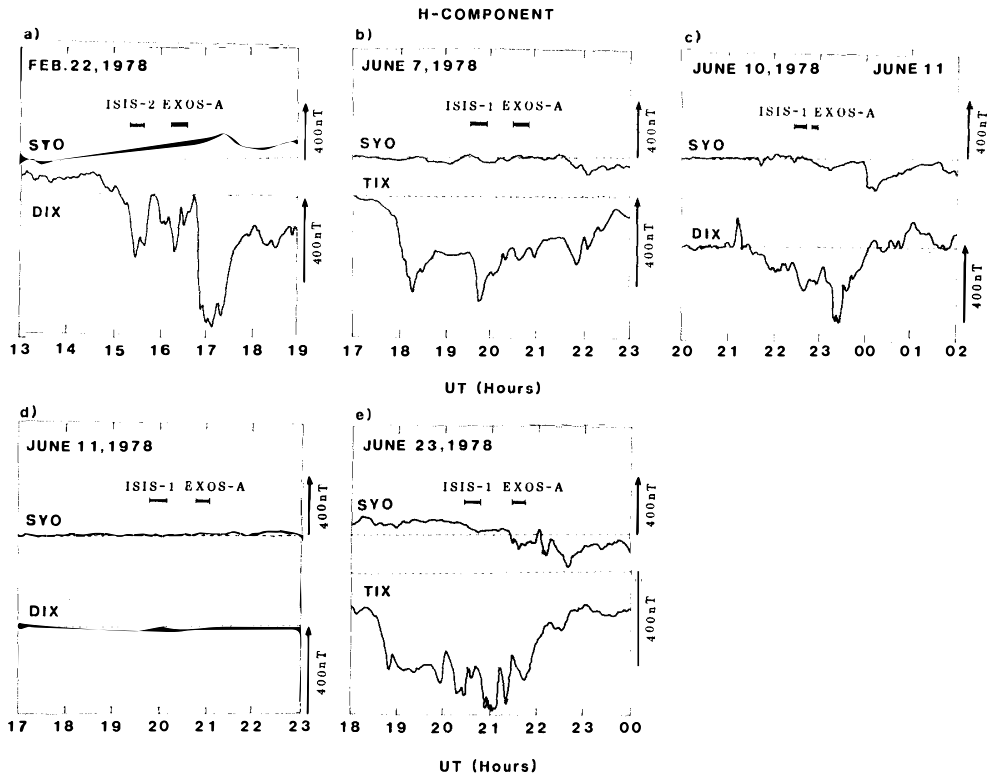

Fig. 1. Magnetic activity during five VLF emission events observed on dual satellites. The H-component variations at Syowa Station and an auroral-zone station located near magnetic local midnight are presented for each event. Broken lines in the figure show quiet time levels of H-component variations at each station, while thick solid lines indicate the observation periods of EXOS-A and ISIS-1 or -2.

Station and an auroral zone station located near the magnetic local midnight for each event. Broken lines in Fig. 1 show quiet time level of the H-component variation at each station and thick solid lines with the satellite names show satellite observation periods. Since the geomagnetic longitude of Syowa Station is 79.4°, geomagnetic local time (MLT) at Syowa Station is equal to UT+33 min. That is, MLT at Syowa Station is nearly equal to UT. Since Tixie Bay and Dixon Island are located at 191.4° and 161.6° in geomagnetic longitude, the magnetic local midnight of Tixie Bay and Dixon Island corresponds to ~16 and ~18 UT, respectively. Thus, it can be concluded in Fig. 1 that the four VLF events except the June 11, 1978 event were observed during substorm times. The June 11, 1978 event was observed during quiet time with *Kp* index of 1−.

4. Observation of Auroral Hiss and Saucer Emissions on Dual Satellites

Presented in Figs. 2–8 are the examples of spatial distributions of hiss and saucer

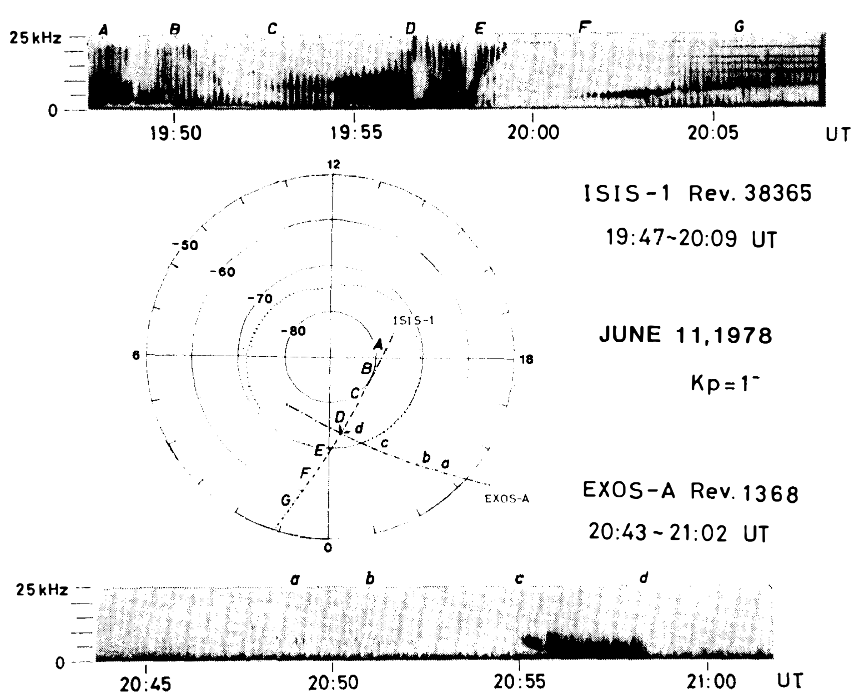

Fig. 2. Frequency-time spectra of VLF hiss emissions observed on EXOS-A and ISIS-1 on June 11, 1978 and polar plots of magnetic foot points are plotted in the invariant latitude-magnetic local time coordinates. A broken-line circle shows the maximum occurrence probability contour of the modal auroral oval for Kp = 1 given by TOHMAS and BOND (1978). The lavels A to G and a to d written above the f-t spectra correspond to the locations of the satellites indicated by the same labels on their ground tracks.

emissions observed on the two satellites. Auroral hiss emissions are seen for all of these paths, while VLF saucers are seen only in the June 7, 1978 event given in Figs. 3–5. As mentioned in the preceding section, only the June 11, 1978 event occurred during quiet time. The *f-t* spectra of this event are shown in Fig. 2 in which the magnetic foot points of the two satellites are also illustrated in the invariant latitude-magnetic local time coordinates. Here the locations of the ISIS-1 and EXOS-A satellites indicated by labels A to G and a to d, respectively, correspond to the observation time of VLF waves indicated by the same labels on the *f-t* spectra. A broken-line circle shows a maximum occurrence probability contour of the modal austral auroral oval for $Kp = 1$ which was obtained by THOMAS and BOND (1978) with a spherial harmonic analysis method. The periodic intensity fluctuations which are seen in the ISIS-1 VLF spectrum result from an intensity modulation due to the satellite spin of 2 rpm. Furthermore, it should be noticed that the intensity level of hiss emissions in the frequency range higher than 15 kHz is quite low in the EXOS-A VLF spectrum. As mentioned in Section 2, this is due to the low sensitivity of the instrument in this frequency range. Considering these factors, it is found that the

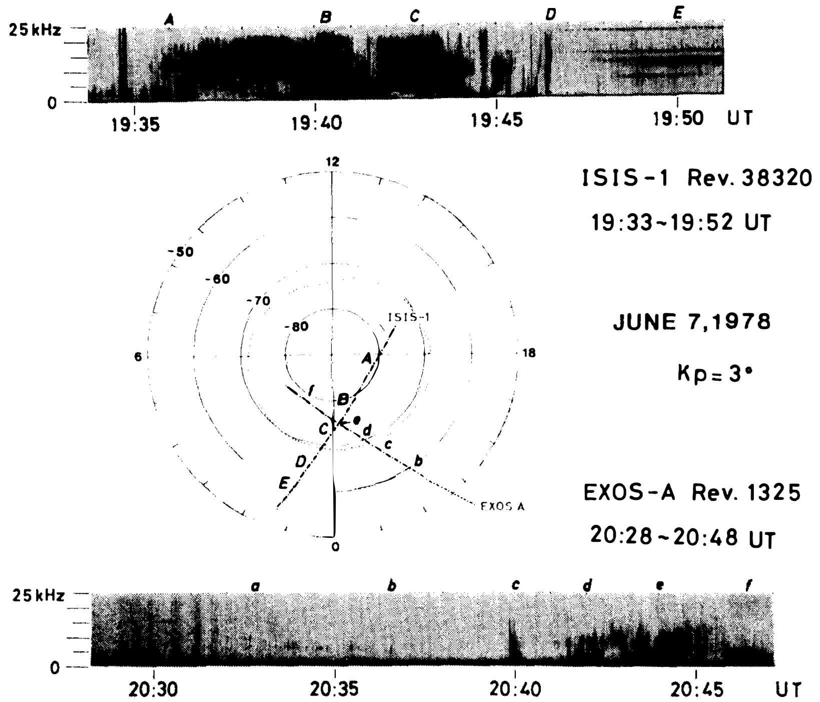

Fig. 3. Frequency-time spectra of VLF hiss and saucer emissions oberved on EXOS-A and ISIS-1 on June 7, 1978, and polar plots of magnetic foot points of the satellites. The modal auroral oval for Kp=3 given by THOMAS and BOND (1978) is indicated by a circle of a broken line.

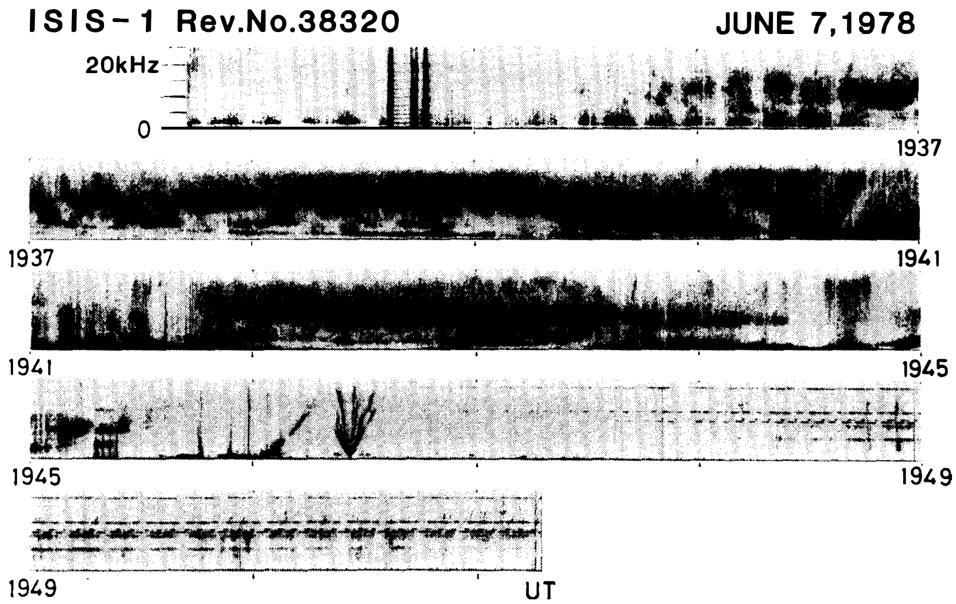

Fig. 4. Extended frequency-time spectra of VLF hiss and saucer emissions observed on ISIS-1 on June 7, 1978 (cf. Fig. 3). Note that VLF saucers occurred at 1946:30 UT.

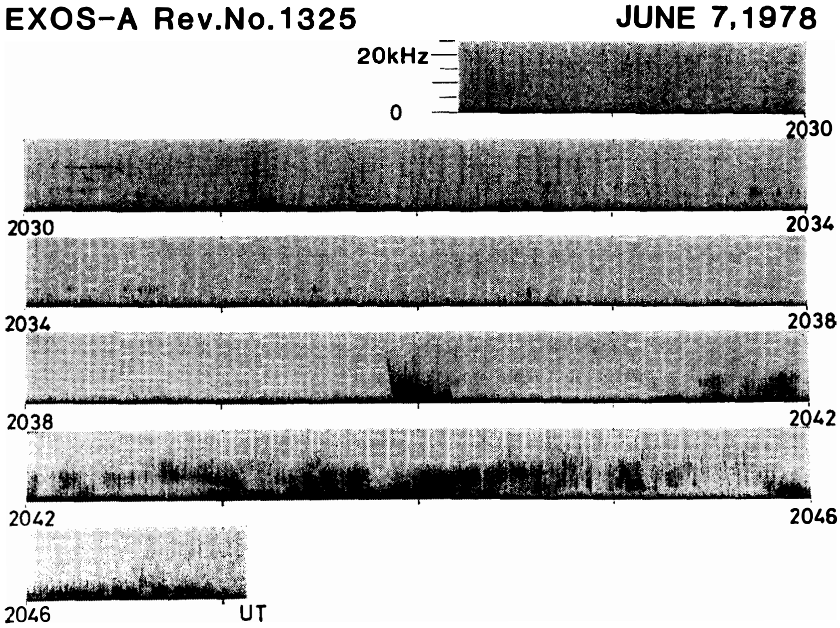

Fig. 5. *Extended frequency-time spectra of VLF hiss and saucer emissions observed on EXOS-A on June 7, 1978 (cf. Fig. 3). Note that VLF saucers occurred at 2040:00 UT.*

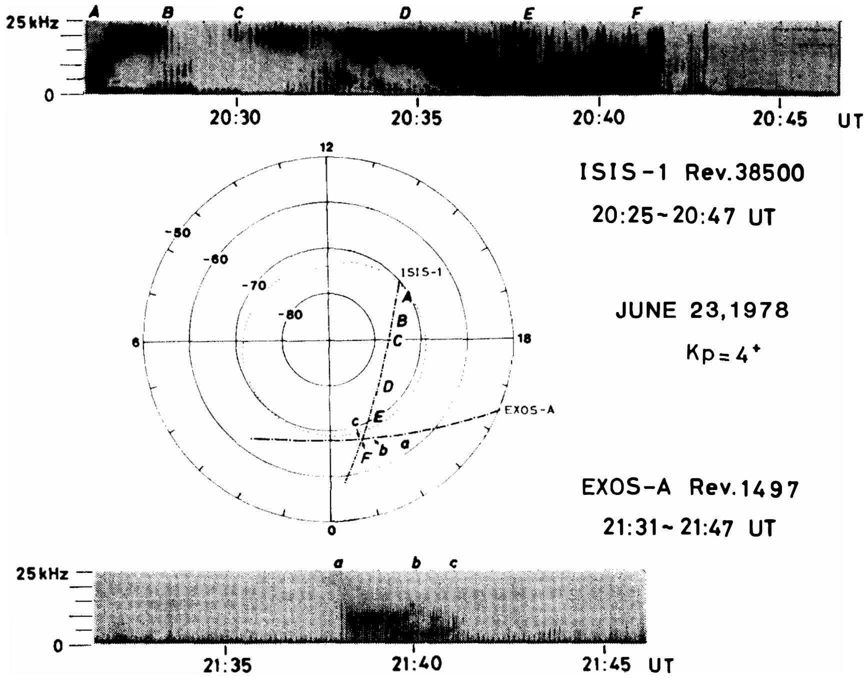

Fig. 6. *Frequency-time spectra of VLF hiss emissions observed on EXOS-A and ISIS-1 on June 23, 1978, and polar plots of magnetic foot points of the satellites. The modal auroral oval for Kp=4 given by THOMAS and BOND (1978) is indicated by a circle of a broken line.*

latitudes of the equatorward boundaries of the V-shaped hiss which appeared on both the satellites were nearly the same with each other (see the interval C to E in the ISIS-1 spectrum and the interval c to d in the EXOS-A spectrum). It is also found that the equatorward boundaries of these emission regions were located near the modal auroral oval for $Kp=1$.

Typical examples showing a spatial relationship between the hiss and saucer emission regions are presented in Figs. 3–5. Both the satellite data show that the saucer emission regions are located adjacent to the equatorward boundaries of the hiss emission regions, and the invariant latitudes of the saucer emission regions, which are indicated by labels D and c, are almost the same with each other. Note that the equatorward boundaries of the hiss emission regions are very close to the location of the modal auroral oval for $Kp=3$. It is also apparent in Fig. 3 that hiss emissions occurred successively inside the model auroral oval in the magnetic local time interval from 18 to 02 MLT.

The example of hiss emissions presented in Fig. 6 was observed during substorms, as shown in Fig. 1. Auroral hiss emissions with V-shaped structures are seen in both the ISIS-1 and EXOS-A data. The latitude of the equatorward bound-

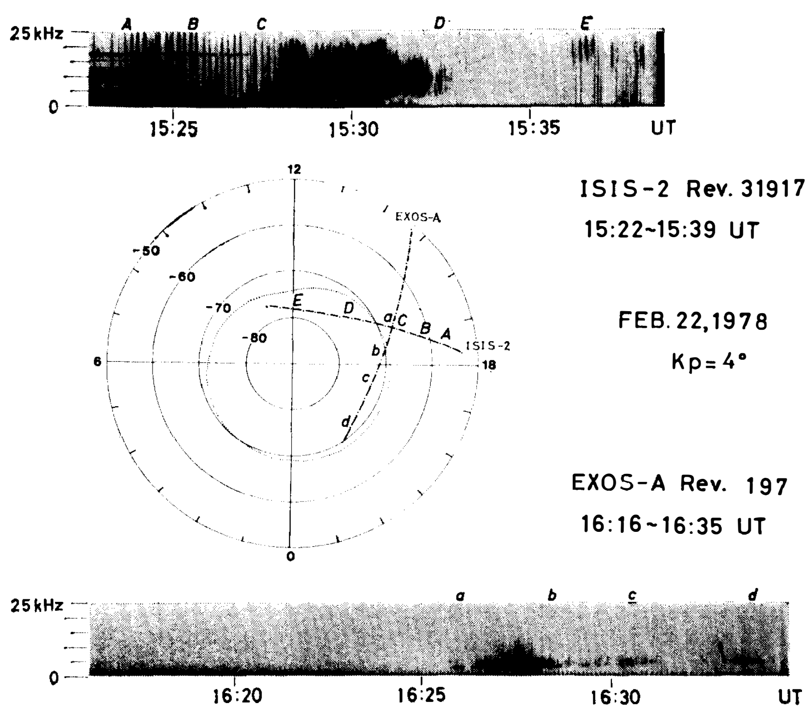

Fig. 7. Frequency-time spectra of VLF hiss emissions observed on EXOS-A and ISIS-2 on February 22, 1978, and polar plots of magnetic foot points of the satellites. The modal auroral oval for Kp=4 given by THOMAS and BOND (1978) is indicated by a circle of a broken line.

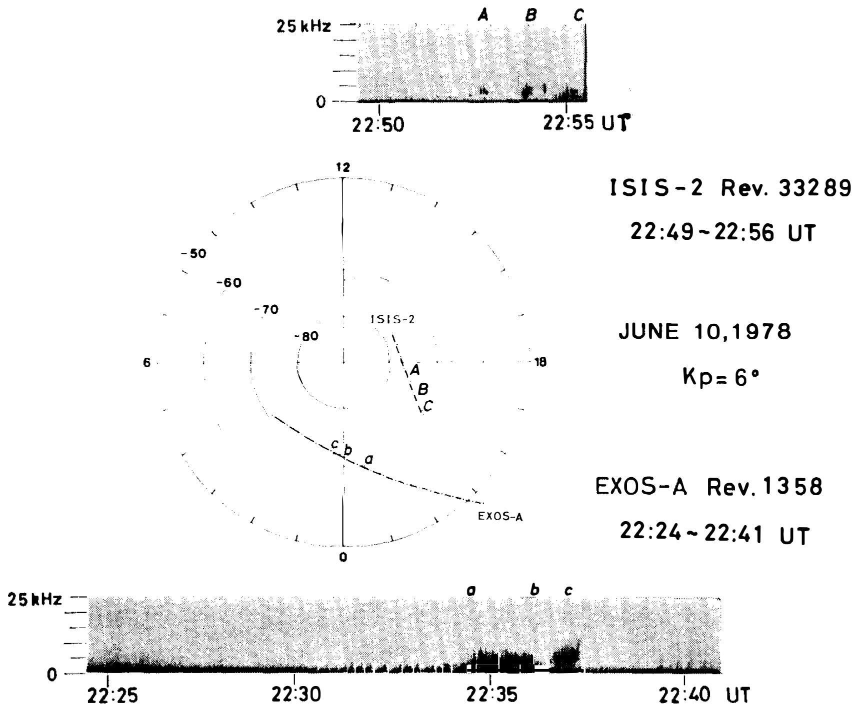

Fig. 8. Frequency-time spectra of VLF hiss emissions observed on EXOS-A and ISIS-1 on June 10, 1978, and polar plots of magnetic foot points of the satellites. The modal auroral oval for Kp=6 given by THOMAS and BOND (1978) is indicated by a circle of a broken line.

ary of the hiss emission region is ~68° INV for ISIS-1, while it is ~63° INV for EXOS-A. Such a difference may be related to a development of substorms.

Presented in Fig. 7 is an example of the afternoon event. It is noticed again that the equatorward boundary of the hiss emission region observed on ISIS-1 coincides with that observed on EXOS-A (see the locations of ISIS-1 and EXOS-A labeled by C and a). These locations are also close to the position of the modal auroral oval. The last example is given in Fig. 8. The time difference between the observation periods of ISIS-2 and EXOS-A was only 8 min. However, ISIS-2 traversed far away from the EXOS-A orbit. This event occurred during high magnetic activity. The Kp index was 6. Weak hiss emissions were observed on both the satellites. These hiss emission regions were located near the modal auroral oval for $Kp=6$.

5. Discussions

Dual satellite observations of VLF emissions presented in Figs. 2–8 showed that the locations of hiss emission regions do not change too much during a time difference between observations of the dual satellites except the June 23, 1978 event given in

Fig. 6. Furthermore, it is important to note that hiss emissions were observed not only during quiet time but also at various stages of substorm activities. These observation results suggest that the hiss emission zone statistically given by GURNETT (1966), HUGHES *et al.* (1971), and YOSHINO *et al.* (1980) was maintained over the time scale of one hour. It is also found that the equatorward boundary of the hiss emission region was located near the modal auroral oval which was given statistically for each level of *Kp* index by THOMAS and BOND (1978). Since the auroral oval tends to expand equatorward in proportion to the *Kp* value (THOMAS and BOND, 1978; NAGATA *et al.*, 1976), a good correspondence between the equatorward boundary of the hiss emission region and the location of the auroral oval suggests that the hiss emission region also moves equatorward in proportion to the *Kp* value. Such a tendency is seen in the five events presented here.

Another interesting result is that a spatial relationship between the hiss and saucer emission regions observed on ISIS-1 at ~01 MLT was quite similar to that observed on EXOS-A at ~20 MLT. That is, on both the satellites, saucers were observed at ~65° INV in the region adjacent to the equatorward boundary of the hiss emission region (cf. Fig. 3). The EXOS-A satellite traversed the emission region ~one hour after the ISIS-1 passing. Therefore, it seems likely that hiss and saucer emissions are occurring fairly stationarily with the same spatial relationship as mentioned above.

The present analysis seems to support that the hiss zone exists not only statistically but also is maintained stationary over one hour. However, in order to confirm this, VLF observations on multiple satellites should be carried out further in the polar region.

Acknowledgments

We are indebted to Dr. R. E. BARRINGTON, CRC, ISIS Working Group and NASA, for their kind support to the telemetry of ISIS-VLF data at Syowa Station, Antarcitica.

We wish to thank Dr. H. FUKUNISHI of the National Institue of Polar Research and Dr. K. MAKITA of Takushoku University for their variable discussions and suggestions. It is a pleasure to acknowledge the members of the 19th wintering party of the Japanese Antarctic Research Expedition for their work of the satellite tracking and data acquisition at Syowa Station.

References

GURNETT, D. A. (1966): A satellite study of VLF hiss. J. Geophys. Res., **71**, 5599–5615.

HUGHES, A. R. W., KAISER, T. R. and BOLLOUGH, K. (1971): The frequency of occurrence of VLF radio emissions at high latitudes. Space Res., **11**, 1323–1330.

KELLEY, M. C., TURRATAVI, B. T. and MOZER, F. S. (1975): Properties of ELF electromagnetic waves in and above the earth's ionosphere deduced from plasma wave experiments on the OV1–17 and Ogo 6 satellites. J. Geophys. Res., **80**, 4603–4611.

NAGATA, T., HIRASAWA, T. and AYUKAWA, M. (1976): Auroral oval and polar substorms observed by a satellite and ground-based observations in antarctica. Proceedings of IAGA Meeting on Unmanned Observations in Antarctica, 25–43.

THOMAS, I. L. and BOND, F. R. (1978): A spherical harmonic analysis of the austral auroral oval. Planet. Space Sci., **26**, 691–695.

YOSHINO, T., FUKUNISHI, H., SATO, N., OZAKI, T. and IWASE, M. (1980): Nankyoku-iki ni okeru VLF hisu・sôsâ no hassei ryôiki (Occurrences of VLF hiss and saucer emissions in the southern polar region). Nankyoku Shiryô (Antarct. Rec.), **68**, 146–160.

(Received October 1, 1980)