Coordinated Ground-Satellite Observations of VLF Hiss Emissions at Syowa Station
—Relationships between Hiss and Aurora—

Kazuo MAKITA*, Hiroshi FUKUNISHI** and Takeo YOSHINO***

昭和基地における VLF エミッションの地上・人工衛星同時観測
—ヒスとオーロラとの関連—

巻田和男*・福西　浩**・芳野赳夫***

要旨：1976 年南極昭和基地において，ISIS 1，2 人工衛星からの VLF 観測データの受信が行われた．これらの VLF エミッションのデータと地上で同時刻に観測された VLF エミッションおよびオーロラの観測データとの比較を行った．一般に，ISIS 2 が高緯度領域から低緯度領域に移動していくにつれ，ヒスエミッションとソーサーエミッションが順々に観測される．解析結果によると，ヒスエミッション領域からソーサーエミッション領域に移る境界付近が，地上で見られるもっとも低緯度側のオーロラ・アークを通る磁力線の位置に対応していることが明らかになった．

地上で観測されたヒスエミッションのスペクトラムと人工衛星で受信されたヒスエミッションのスペクトラムを比較した結果，地上と人工衛星とを磁力線で結んだ領域で観測されるヒススペクトラムは似ておらず，むしろ，人工衛星のサブサテライトポイントが，昭和基地と同じ地磁気緯度付近にある時に観測されるヒススペクトラムが互に類似していることがわかった．このことはヒスエミッションが，人工衛星の高度 (h=1400 km) から地上まで磁力線に沿って伝搬していないことを示している．Ray path の計算を行った結果，地上で受信されるヒスエミッションは，人工衛星の高度からノンダクトな伝搬路をとることが推定された．

Abstract: ISIS VLF data were received at Syowa Station, Antarctica in 1976. These data were compared with VLF and auroral data simultaneously observed on the ground. In general, hiss and saucer emissions were succesively observed on ISIS 2, when ISIS 2 moved from the polar cap towards the low latitude. It is found that the geomagnetic field lines through a northernmost auroral arc are located between the occurrence regions of hiss and saucer emissions. It is also found that spectra of hiss emissions observed on the ground (Syowa) are not similar to those of VLF emissions observed in the region connected with field line at the satel-

* 東京大学理学部地球物理研究施設．Geophysics Research Laboratory, University of Tokyo, 11–16, Yayoi 2-chome, Bunkyo-ku, Tokyo 113.

** 国立極地研究所．National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173.

*** 電気通信大学．University of Electro-Comunications, 5–1, Chofugaoka, 1-chome, Chofu 182

lite altitude, but are similar to those of VLF emissions observed near the same geomagnetic latitude as that of Syowa Station The result suggests that auroral hiss emissions do not propagate along the geomagnetic field lines from the statellite height (~1400 km) to the ground The calculation by means of the ray theory suggests that hiss emissions propagate along a non-ducted path from the satellite height to the ground

1. Introduction

From the observations of low-altitude polar-orbiting satellites, it has been shown that there are several types of electrostatic and electromagnetic waves (auroral hiss, saucer, LHR emissions, etc.) on auroral field lines (GURNETT, 1966; MCEWEN and BARRINGTON, 1967, TAYLOR and GURNETT, 1968; LAASPERE and JOHNSON, 1973; JIRICEVK and TRISKA, 1976).

GURNETT and FRANK (1972) showed from data observed by a VLF receiver and a low-energy proton and electron differential energy analyzer on Injun 5 that occurrences of V-shaped hiss are related to precipitating electrons with a few hundred eV in the inverted 'V' events, while auroral light emissions are generally related to precipitating electrons with energies of 1 to 10 keV in the inverted 'V' events. LAASPERE and HOFFMAN (1976) also showed that VLF hiss emissions are related to precipitating electrons with energies of a few hundred eV by using VLF and particle data from OGO 4.

MOSIER and GURNETT (1972) examined the relationship between five VLF hiss events measured with Injun 3 and auroras observed on the ground (Fort Churchill). One of these five events occurred near auroral arcs with significant changes in the hiss spectrum in the immediate vicinity of auroral arcs. In the remaining four events, auroral hiss emissions were not associated with any detectable auroral light emissions. From this result, MOSIER and GURNETT (1972) suggested that auroral hiss and auroral light emissions are usually generated by electrons with somewhat different energies, and that when the energy spectrum of precipitating electrons includes high energy components, VLF hiss and auroral-light emissions are simultaneously generated.

MOSIER (1971) showed by means of the Injun 5 Poynting flux measurement technique that auroral hiss emissions propagate downward (toward the earth), while saucer emissions propagate upward, *i. e.*, they suggested that a part of VLF hiss is generated above Injun 5, while saucer is generated below the satellite. GURNETT and FRANK (1972) reported that saucer emissions are usually observed on a lower latitude side than the V-shaped VLF hiss region. However, they did not discuss the relationship between the location of saucer emissions observed on satellite and the locations of auroras observed on the ground In this paper, we will examine such a relationship by using VLF data obtained with ISIS 2 and auroral data observed at Syowa.

In order to understand the relationships between VLF hiss emissions observed on the ground and on the satellite, coordinated ground and satellite observations of VLF hiss are very important. However, there have not been enough simultaneous ground-satellite observations. GURNETT (1966) examined only two events and indicated a lack of correspondence between VLF emissions observed on Injun 3 and on the ground (Great Whale River). SRIVASTAVA (1974) compared eight VLF emission events observed on Injun 5 with VLF data obtained at College and Barter Island. However, he also was unable to find a good correspondence between the ground and satellite data. In this paper, using the simultaneous dynamic spectrum data of VLF emissions observed on ISIS 2 and on the ground, we will examine the conditions in which VLF emissions are simultaneously observed on the satellite and on the ground.

2. Instrumentation and Data Analysis

The ISIS 2 satellite was launched on April 1, 1971 on a circular polar orbit with an inclination of 88.18°, an apogee altitude of 1424 km and a perigee altitude of 1354 km. VLF wave data measured by a wide-band (50 Hz ~ 30 kHz) receiver with an electric dipole antenna of 79 m length were received at Syowa Station, Antarctica in 1976.

Simultaneous ground-based data of auroras and VLF emissions were obtained at Syowa and Mizuho Stations. Syowa Station is located at −70.03° and 79.39° in the geomagnetic coordinates, while Mizuho Station is located about 260 km poleward from Syowa Station along the same geomagnetic meridian. The geomagnetic coordinates of Mizuho are −72.32° and 80.62°. The 51 ISIS 2 VLF orbits were received at Syowa Station in the period from May to September, 1976. However, there are only seven events in which the same geomagnetic field lines pass through the ISIS 2 and auroras observed by an all-sky camera at Syowa Station.

3. Coordinated Observations of VLF Hiss Emissions and Auroras

Fig. 1 shows the 8 kHz VLF intensity records of Syowa Station. Large enhancements in the 8 kHz intensity were observed in the four events (B, E, F, G). However, the 8 kHz intensity was low in the remaining three events (A, C, D). In the G event, the location of ISIS 2 was far away from Syowa Station when a large enhancement of the 8 kHz intensity was observed at Syowa Station. Therefore, this event is not a good example for comparing between the VLF emissions observed on the ground and on a satellite. We describe the three events (B, E, F) in detail as a case study and the remaining four events (A, C, D, G) are presented in Appendices I ~ IV.

3. 1. September 17, 1976 event

Fig. 2 gives frequency-time spectra of VLF emissions on ISIS 2 and all-sky photographs taken at Syowa Station. The foot point of the geomagnetic field lines through ISIS 2 was computed at an altitude of auroras using the 1975 IGRF model. Here,

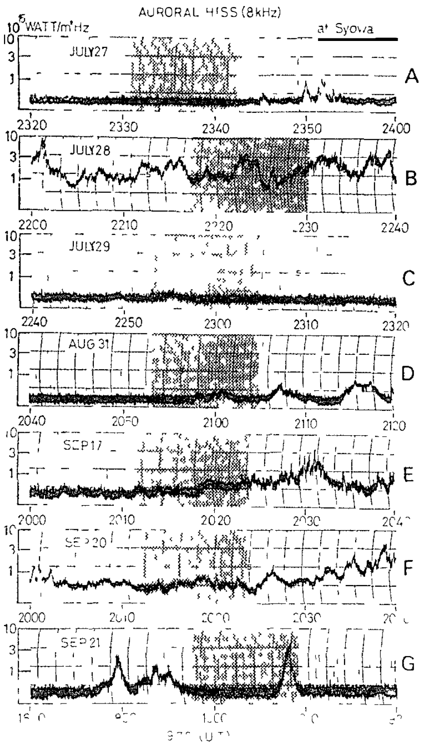

Fig 1 The 8 kHz intensity observed at Syowa Station Shadow regions show the period of simultaneous ground-satellite observations of VLF hiss emissions

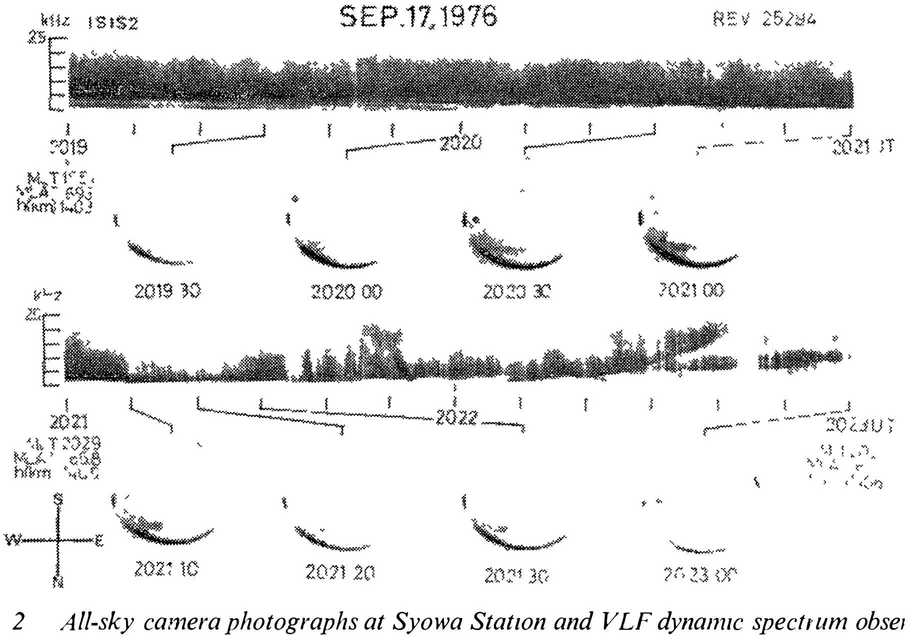

Fig 2 All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2 The satellite foot point along the geomagnetic-field line is plotted on the all-sky camera photographs with circles

the altitude of auroras is assumed to be 100 km The position of the satellite foot point at 100 km level is illustrated by a circle on all-sky photographs in Fig 2 It is apparent in Fig 2 that wide-band hiss emissions were observed continuously on ISIS 2 when the

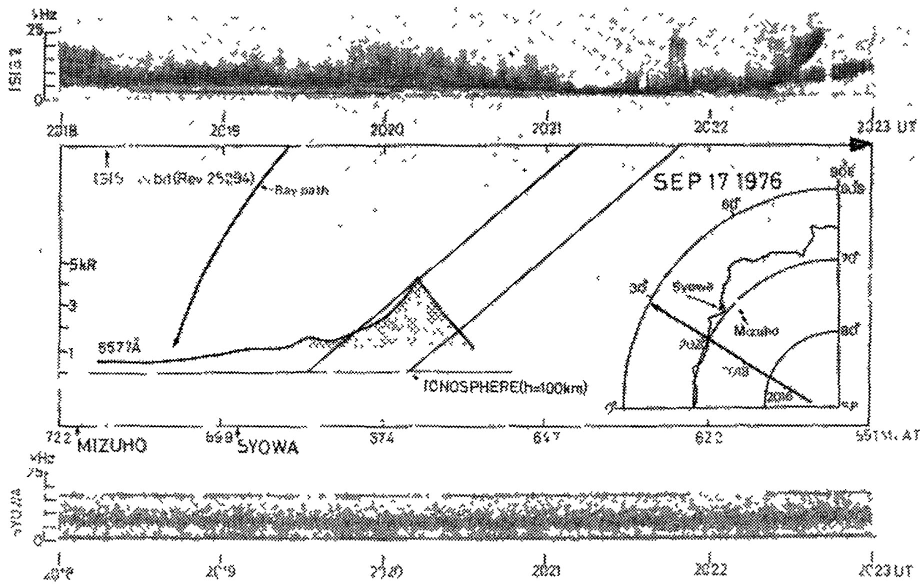

Fig 3. Relationships between auroral hiss emissions simultaneously observed at an altitude of ~1400 km and on the ground. Top and bottom panels give frequency-time spectra of VLF waves on ISIS 2 and on the ground (Syowa), respectively. The middle panel shows the intensity profile of 5577 Å emissions which were observed by a meridian-scanning photometer at Syowa Station at 20h20m UT. The location of auroral arcs is indicated by dotted areas. Geomagnetic field lines through arcs and a calculated ray path of an 8 kHz whistler mode wave are also illustrated schematically. The location of ISIS 2 is shown by the ground track of the subsatellite point in the middle panel. The locations of Syowa and Mizuho Stations are given at the bottom of the middle panel.

satellite was located in the latitude region higher than the location of the northernmost auroral arc, while saucer emissions were observed just after the satellite traversed the northernmost auroral arc at 20h21m53s UT.

Such a relationship is presented again in Fig. 3. The frequency-time spectra of VLF emissions observed on ISIS 2 and on the ground (Syowa Station) are given at the top and bottom panels in Fig. 3, respectively. The middle panel shows the orbit and the geomagnetic latitude of the subsatellite point of ISIS 2, and the locations of Syowa and Mizuho Stations. The middle panel also shows the locations of auroral arcs and the geomagnetic field lines through arcs. The *f–t* spectrum at the bottom in Fig. 3 indicates that auroral hiss emissions with a narrow-band structure were observed continuously at Syowa Station during ISIS passage.

If the VLF emissions observed on the ground result from the VLF waves which propagate along the geomagnetic field lines, the *f–t* spectrum on ISIS 2 at ~20h21m10s UT would be similar to the spectrum on the ground. The spectrum of auroral hiss obtained from ISIS 2 at 20h21m10s UT showed a narrow-band structure with a center frequency of 2 kHz and a band-width of 1 kHz. However, the power spectrum

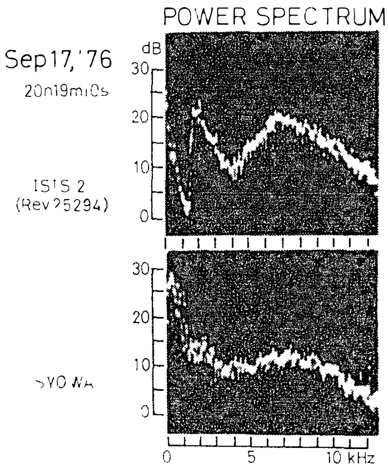

Fig 4 Power spectra of VLF emissions simultaneously observed at 20h19m10s UT on the ISIS 2 and on the ground Top and bottom panels give the power spectra of ISIS 2 and the ground (Syowa) respectively

observed on the ground at the same time had a different band structure with a center frequency of 8 kHz and a band-width of 5 kHz. The spectrum similar to the spectrum on the ground was seen on ISIS 2 when the subsatellite point of ISIS 2 was located near the same geomagnetic latitude as that at Syowa Fig 4 shows the power spectra observed both on ISIS 2 and on the ground at ~20h19m10s UT Hiss spectrum on the ground showed a band structure with a center frequency of 7 kHz and a band-width of 5 kHz. VLF emissions obtained from ISIS 2 had two band structures with center frequencies of 2 and 7 kHz. The spectral band around 7 kHz is similar to the spectrum observed on the ground

3. 2. September 20, 1976 event

Figs 5 and 6 give relationships among VLF emissions at the altitude of ~1400 km, auroras and auroral hiss emissions observed on the ground. The lower cutoff frequency of VLF emissions at the satellite altitude shows a clear latitude dependence (*cf* Fig. 6). In the high latitude region, the cutoff frequency decreased with decreasing latitude, reaching a minimum at 20h18m50s UT, and then the cutoff frequency increased

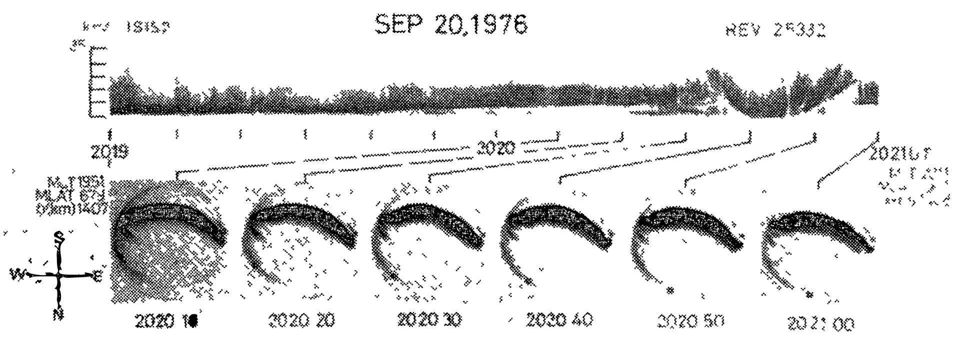

Fig 5 All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2 The notation is the same as that in Fig 2

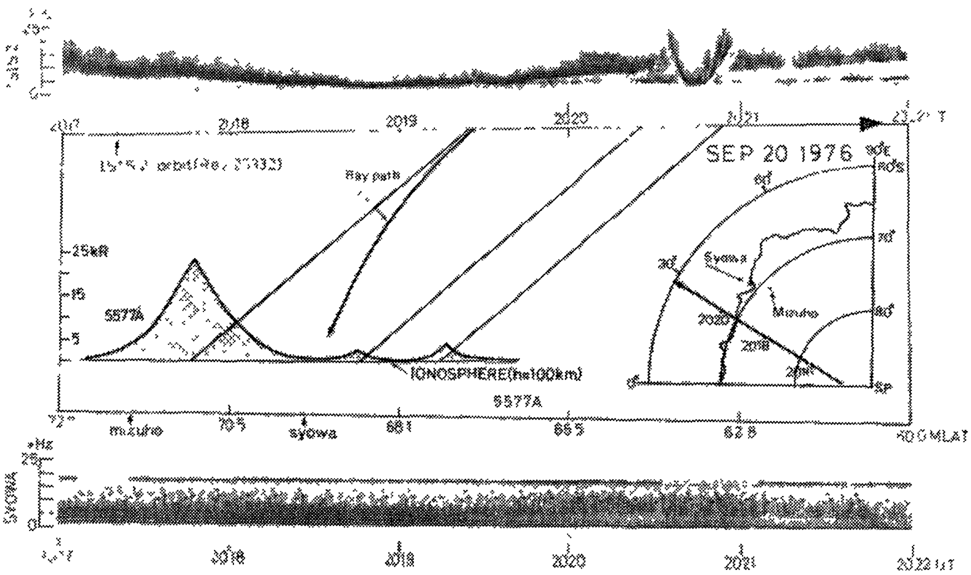

Fig 6 Relationships between auroral hiss emissions simultaneously observed at altitude of ~1400 km and on the ground The intensity profile of 5577 Å emissions were observed at 21h20m UT The notation is the same as that in Fig 3

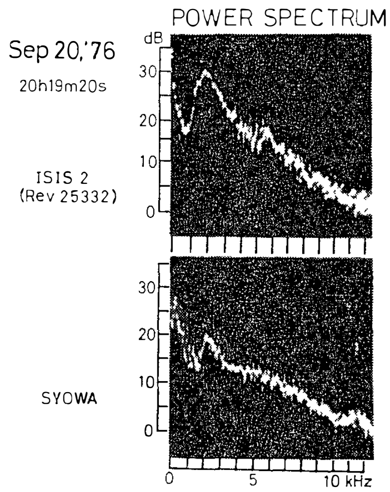

Fig 7 Power spectra of VLF emissions simultaneously observed at 20h19m20s UT on the ISIS 2 and on the ground. Top and bottom panels give the power spectra of ISIS 2 and the ground (Syowa) respectively

toward low latitudes. Saucer emissions were observed at 20h20m45s UT when the satellite traversed the geomagnetic field lines threading the northernmost auroral arc

Fig. 7 shows the hiss spectra observed on satellite and on the ground at 20h19m20s UT. ISIS 2 hiss spectrum has a peak frequency of 2 kHz and a narrow band-width of 1 kHz. The ground hiss spectrum also shows a similar peak frequency at 2 kHz and a band width of 1 kHz. These results strongly suggested that VLF emissions with similar spectral structure as those at satellite altitude are observed when the ground station is located near the same geomagnetic latitude as that of the satellite.

3.3. July 28, 1976 event

Figs. 8 and 9 show the relationship between VLF emissions observed on ISIS 2 and auroras and VLF emissions observed on the ground. In this event, multi-auroral arcs were seen and intense auroral hiss emissions with a band structure were observed at Syowa Station. The center frequency varied from 5 kHz to 10 kHz within a few

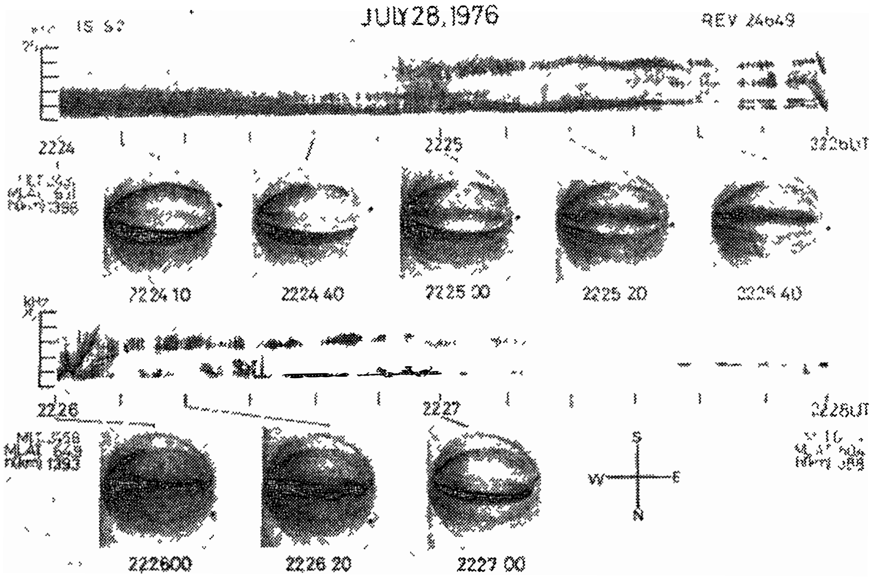

Fig. 8 All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2. The notation is the same as that in Fig. 2.

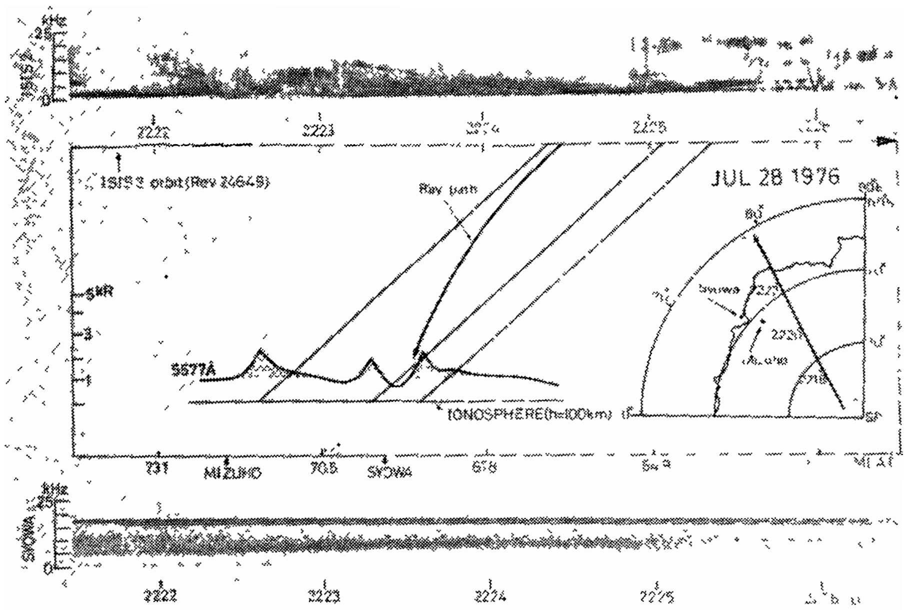

Fig. 9 Relationships between auroral hiss emissions simultaneously observed at an altitude of ~1400 km and on the ground. The intensity profile of 5577 Å emissions was observed at 22h25m UT. The notation is the same as that in Fig. 3.

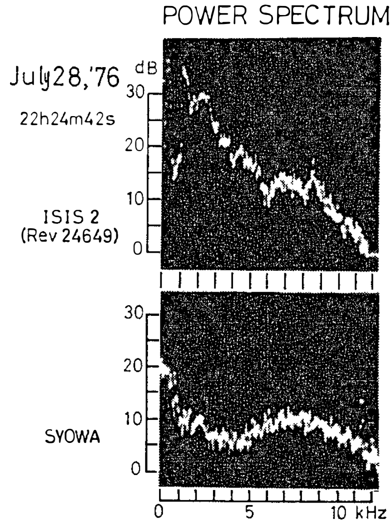

Fig. 10. Power spectra of VLF emissions simultaneously observed at 22h24m42s UT on the ISIS 2 and on the ground. Top and bottom panels give the power spectra of ISIS 2 and the ground (Syowa) respectively

minutes. Auroral hiss emissions with the similar spectral structure were also observed at Mizuho Station (the *f–t* spectrum is not given here). The ISIS 2 orbit was outside of the all-sky camera coverage from Syowa. However, the location of ISIS 2 is within 100 km from the edge of the all-sky photographs. In the following discussion, the auroral arcs are assumed to extend toward the outside of the all-sky camera coverage along the latitude.

Fig. 10 shows the power spectra of auroral hiss at 22h24m42s UT, when the ground hiss spectrum had a peak frequency of 7.5 kHz and a band-width of 5 kHz. ISIS 2 hiss spectrum was more complicated than that on the ground, having intensity peaks around 2 kHz. However, a band structure around 7 kHz seems to correspond to the ground hiss spectrum. On the other hand, if VLF waves propagate along the geomagnetic field line, the *f–t* spectrum on ISIS 2 at about 22h25m20s would be similar to the spectrum on the ground. The hiss spectrum on ISIS 2 had a band structure emission with a peak frequency of 2 kHz. This spectrum was quite different from the spectrum on the ground which showed a narrow-band emission with a peak frequency of 7.5 kHz and a band width of 5 kHz.

When the satellite passed the region which is connected to the bright arcs through the geomagnetic field lines at 22h24m55s UT, impulsive VLF emissions with wide-band frequency components from ~1.0 kHz to 25.0 kHz were observed. These emissions were continuously observed until 22h27m00s UT. Saucer emissions were observed after 22h26m00s UT, when ISIS 2 passed near the field lines threading the northernmost faint arc.

4. Summary and Discussions

Simultaneous observations of VLF emissions on ISIS 2 and the ground were carried out at Syowa Station in 1976. From these observations, 7 events were selected in order to study the relationship between VLF emissions and auroras We have already described the relationship on the typical 3 events in the previous section The remaining 4 events are given in Appendices I～IV The results are summarized as follows.

1) Occurrence regions of hiss and saucer emissions observed with ISIS 2 are localized in latitude Hiss emissions are generally observed on the higher latitude side of the geomagnetic field lines through the northernmost auroral arc, while saucer emissions are observed on the lower latitude side of these field lines

2) In general, hiss emissions are continuously observed during the ISIS 2 traverse across the auroral zone on the night side The latitude range of hiss emissions is about a few thousands kilometers, while the latitude range of saucer emissions is much narrower than that of the hiss emissions A typical latitude range of the saucer emission region is about a few tens kilometers

3) The hiss spectrum on ISIS 2 similar to the ground hiss spectrum at Syowa Station was seen when the subsatellite point was located near the same geomagnetic latitude as that of Syowa Station. However, the ISIS VLF spectrum observed on the Syowa field lines was quite different from the ground VLF spectrum

The observed result that saucer emissions occur on the lower latitude side of the field lines through the northernmost auroral arc is consistent with JAMES' result (1976). He has suggested that saucers are excited by upward ionospheric thermal electrons. In order to examine JAMES' suggestion, it is necessary to measure simultaneously both low-energy electrons and VLF waves.

GURNETT and FRANK (1972) and LAASPERE and HOFFMAN (1976) reported that hiss emissions are closely associated with precipitating electrons with energies of a few hundred eV From DMSP auroral particle observations, MENG *et al* (1977, 1978) showed that a large number of soft electrons with energies of several hundred eV precipitate in a wide latitude range around auroral arcs In our ISIS 2 VLF observations, hiss emissions are frequently observed in the wide latitude range higher than the field lines through the northernmost auroral arc From these results, it is suggested that soft precipitating electrons efficiently excite the auroral hiss emissions

In order to examine the relationships between VLF emissions observed on ISIS 2 and on the ground, we calculated the ray path of an 8 kHz whistler mode wave propagating from 3000 km to 200 km altitude In this calculation was used the ray tracing program developed by KIMURA and YAMAGISHI (private communication) Assuming a diffusive equilibrium model, an electron density profile was obtained approximated on the basis of nightside electron densities profiles obtained from the ISIS 2 topside ionogram. The magnetic field was calculated from the dipole field model SRIVASTAVA (1974) suggested that VLF emissions generated above the ionosphere suffered reflection

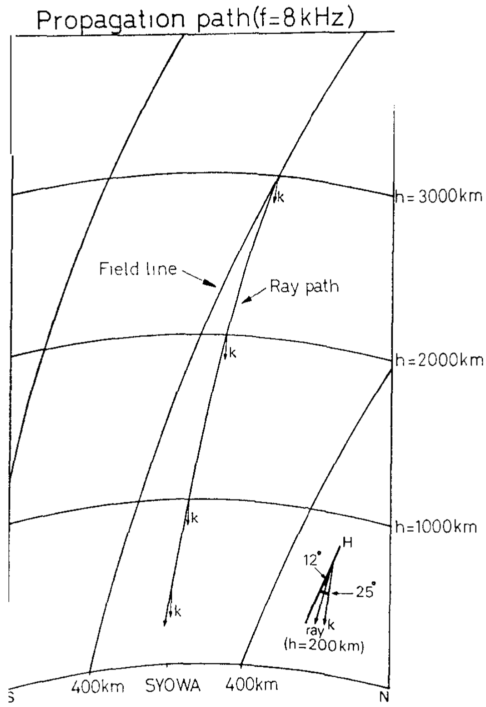

Fig 11 A calculated ray path of an 8 kHz whistler mode wave from 3000 km to 200 km altitude The wave normal angle from the vertical at the altitude of 200 km is assumed to be 0° Magnetic field lines illustrated in the figure are dipole-type field lines which approximate to the real geomagnetic field lines around Syowa Station by fitting the angle of the dipole field line to the dip angle calculated from the 1975 IGRF model

or absorption before reaching the ground. He showed that at a wave frequency of 8.0 kHz, the limit value of wave normal angle from the vertical, beyond which the signal would be reflected back to the ionosphere, is 2.0° for a disturbed ionospheric model. As the limited transmission angle from the vertical is very small, we assumed the wave normal angle from the vertical is 0° at 200 km altitude and calculated the reverse ray tracing from 200 km to 3000 km

A calculated result is shown in Fig. 11. The angle between the wave normal vector and geomagnetic field is estimated to be 19° at 3000 km altitude. If the angle between the geomagnetic vector (***B***) and wave normal vector (***K***) is larger than a few tens degrees, the wave reflects and can not reach the ground. A certain ristricted wave only can reach the ground. It was found that the wave propagates to the lower latitude side than the magnetic field line through the source, as the wave propagates toward the ionosphere. The calculated propagation path is also illustrated in Figs. 3, 5 and 7. As shown previously, VLF waves do not propagate along the geomagnetic field line From these calculations, it is concluded that very limited waves among VLF waves observed on the satellite can reach the ground through a non-ducted path.

GURNETT (1966) and SRIVASTAVA (1976) examined the relationships between VLF emissions observed at high altitude and on the ground They were unable to find a good correspondence between the ground and satellite VLF data. On the other hand, JØRGENSEN (1968) showed a similar spectrum of VLF emission observed at high altitude and on the ground. We examined 51 VLF emission data and could find three events whose spectra were similar between at the high altitude and on the ground. These results show that the similar auroral hiss emissions between ground-satellite were not so often obtained. When the narrow-band spectrum was observed at the high altitude near the zenith of ground station, there is a good correspondence between ground and satellite VLF spectra. However, there is a lack of correspondence among saucer and LHR emissions and VLF emissions observed on the ground.

Hiss emissions are not so frequently observed at the night side in summer. Electron density near the altitude of ISIS 2 satellite increases one or two orders of magnitude in summer (N. MATUURA, private communication). These background electron density variations may change a condition of the hiss excitation process. Therefore, it is necessary to study a seasonal variation of hiss emissions and its relationship to background plasma variations in the future.

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, Antarctica. We thank Prof. T. OGUTI, Dr. S. KOKUBUN and Dr K. HAYASHI for giving valuable suggestions. We wish to thank Prof. I. KIMURA and Mr. H. YAMAGISHI for kindly providing the ray tracing program. We also like to express our appreciation to Messrs. N. SATO, R. FUJII, T. OZAKI, M. IWASE and T. MATSUO for helping satellite and ground VLF data analysis. This research was supported by the 17th Japanese Antarctic Research Expedition members. We are grateful to them for a success of observations at Syowa and Mizuho Stations.

References

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

GURNETT, D A. and FRANK, L A (1972): VLF hiss and related plasma observations in the polar magnetosphere J. Geophys Res, **77**, 172–190.

JAMES, H. G. (1976): VLF saucers J Geophys. Res, **81**, 501–514

JIRICEK, F. and TRISKA, P (1976) Lower hybrid resonance associated phenomena observed with the Intercosmos 10 satellite. Space Res., **16**, 567–573.

JØRGENSEN, T S (1968): Interpretation of auroral hiss measured on OGO 2 and Byrd Station interms of incoherent Cerenkov radiation J. Geophys Res, **73**, 1055–1069.

KIMURA, I (1966): Effects of ions on whistler-mode ray tracing Radio Sci, **1**, 269–283

LAASPERE, T and JOHNSON, W C (1973): Additional results from an OGO 6 experiment concerning ionospheric electric and electromagnetic fields in the range 20 Hz to 540 Hz J Geophys Res, **78**, 2926–2944

LAASPERE, T and HOFFMAN, R A (1976): New results on the correlation between low-energy electrons and auroral hiss J. Geophys Res, **18**, 524–537.

McEWEN, D J and BARRINGTON, R. E (1967) Some characteristics of the lower hybrid resonance noise bands observed by the Alouette I satellite. Can J. Phys, **45**, 13–19

MENG, C-I. (1976). Simultaneous observations of low-energy electron precipitation and optical auroral arcs in the evening sector by the DMSP 32 satellite J Geophys Res , **81**, 2771–2785.

MENG, C-I and SYNDER, A L , Jr. and KREOEHL, H. W. (1978) Observations of auroral traveling surges and electron precipitations J. Geophys Res., **83**, 575–585.

MOSIER, S. R. (1971) Poynting flux studies of hiss with the Injun 5 satellite. J Geophys. Res., **76**, 1713–1728

MOSIER, S. R. and GURNETT, D A (1972). Observed correlations between auroral and VLF emissions. J. Geophys Res , **77**, 1137–1145

SRIVASTAVA, R. N (1974) Propagation of VLF emissions in the magnetosphere and the ionosphere. Planet Space Sci , **22**, 1545–1564

TAYLOR, W. W L and GURNETT, D A (1968). Morphology of VLF emissions observed with the Injun 3 satellite J Geophys Res , **73**, 5615–5626.

(*Received June 10, 1978*)

Appendix I

All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2. A faint auroral arc was observed on the northern horizon of Syowa Station. Hiss emissions were not observed on the ground. Multiple saucer emissions were observed at 23h39m45s UT and 23h41m00s UT. Auroras related to the saucer emissions at 23h39m45s UT were not observed in the all-sky photographs, while the intense saucer emissions at 23h41m00s UT were observed just after the satellite passed over the field lines through the faint auroral arc.

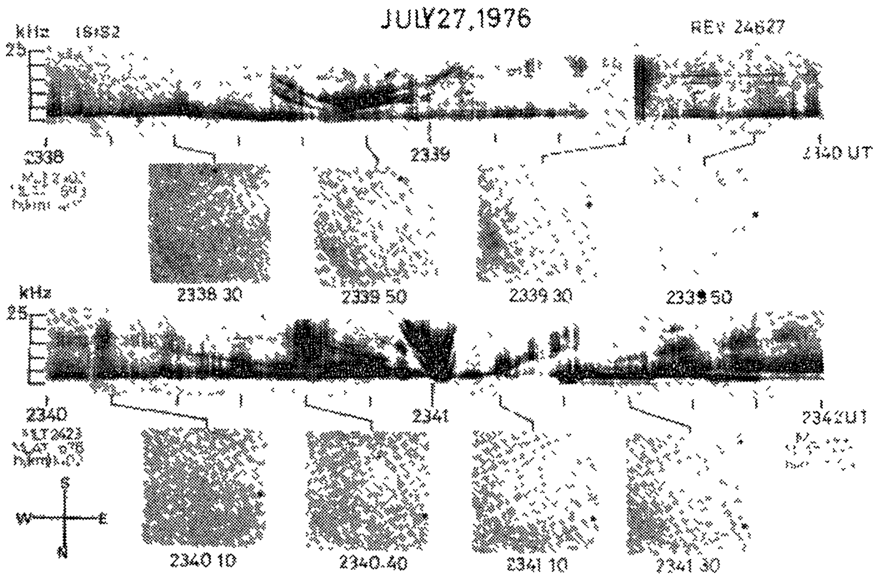

Fig A-1.

Appendix II

All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2. A faint auroral arc was observed on the southern horizon of Syowa Station. Hiss emissions were not observed on the ground Multiple saucer emissions were observed just after the satellite passed over near the faint arc at 23h01m00s UT. The latitudinal width of each saucer emission is about a few tens kilometers

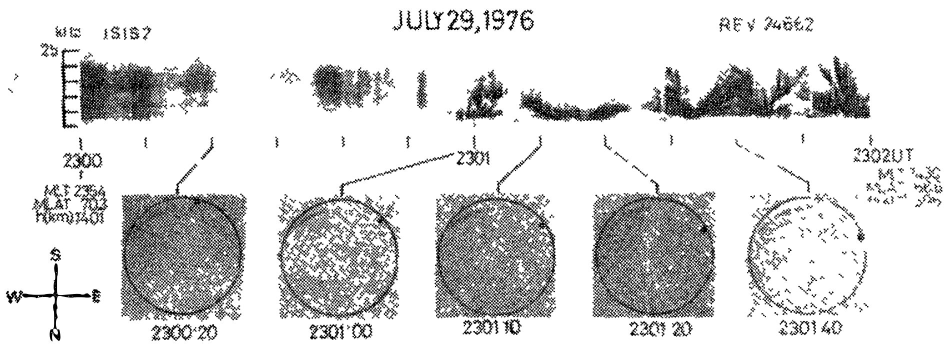

Fig A-2

Appendix III

All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2. An auroral arc was observed at the southern horizon of Syowa Station Moon was seen on the western horizon of Syowa Station Weak auroral hiss emissions were observed on the ground The lower cutoff frequency of emissions

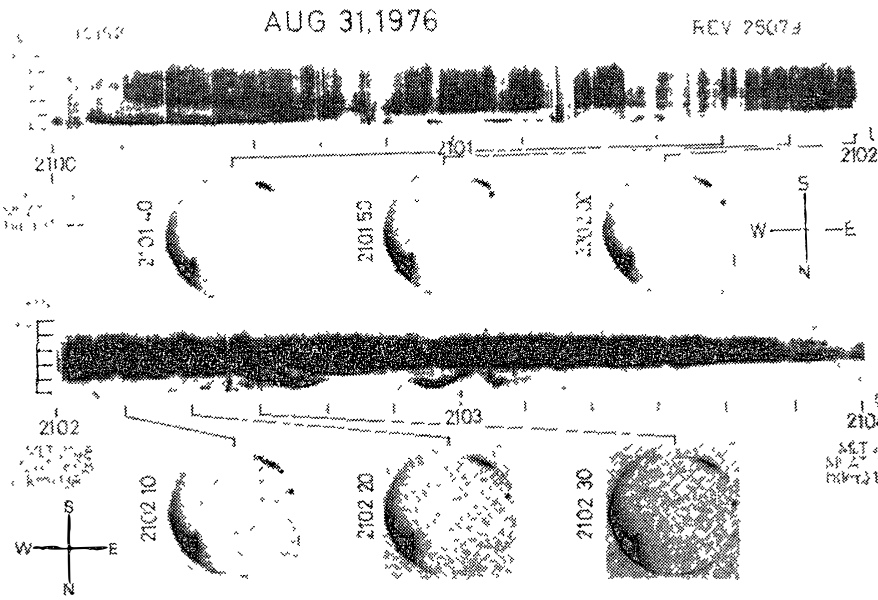

Fig A-3

changed from a few kHz to 10 kHz. Saucer emissions were observed just after the satellite passed over the field lines threading the weak auroral arc at 21h02m30s UT.

Appendix IV

All-sky camera photographs at Syowa Station and VLF dynamic spectrum observed on ISIS 2. A bright auroral arc was observed on the southern horizon of Syowa Station. Hiss emissions were not observed on the ground untill 19h08m00s UT. Wide-band VLF emissions were continuously observed on ISIS 2. The saucer emissions were observed just after the satellite passed over the field lines through the bright auroral arc at 19h05m30s UT.

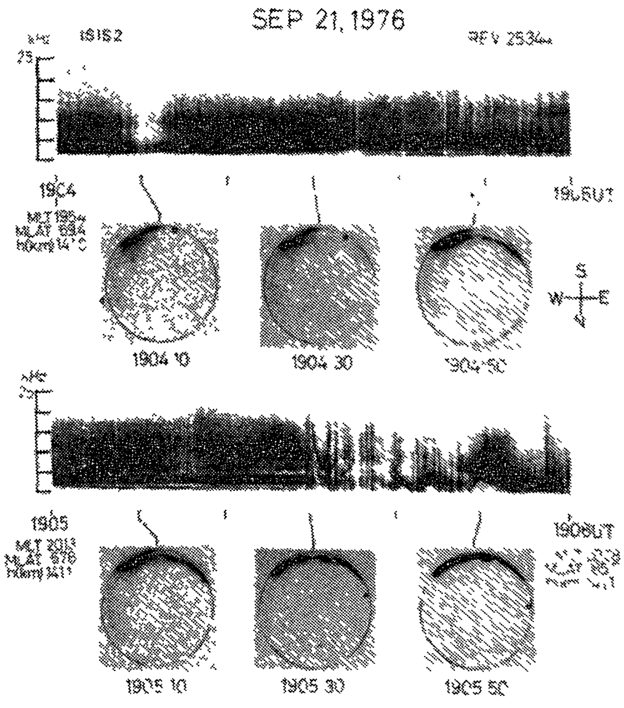

Fig. A-4