Comparisons of Auroral Hiss Spectra Observed at Syowa and Mizuho Stations

Kazuo MAKITA*

昭和・みずほ基地におけるヒス・スペクトラムの比較

巻田和男*

要旨: 昭和基地とみずほ基地とで同時に受信されたオーロラ・ヒス現象の比較を行ったところ多くの場合，ヒスの強度は現象により2地点でかなり異なっているが，ヒスのスペクトラムは比較的よく似ており，また発生時刻の時間差も2地点で1秒以上の差が認められなかった．これらの事実は，似たようなオーロラ・ヒスが地上で受信される範囲が，昭和基地とみずほ基地の距離（～270 km）よりも広いことを示している．他方，人工衛星により撮影されたオーロラと地上のヒスとの関係から，オーロラの発光領域から600 km ぐらい離れるとヒスが受信されないことがはっきりした．このことはヒスの受信される最大の広がりが600 km 以内であることを示している．ヒスの伝搬路を ray-tracing により計算したところ，地上へ伝搬可能な領域の広がりは，ほぼ300 km であることが示され，観測結果をほぼ説明できる．

Abstract: Simultaneous observations of auroral hiss emissions have been carried out at Syowa and Mizuho Stations. The intensity of auroral hiss emissions was different from case by case at the two stations. However, the spectral shapes of hiss emissions obtained at both stations were generally similar and the delay of the occurrence time of auroral hiss between the two stations can not be recognized within one second accuracy. These results show that the observable scale of the similar auroral hiss on the ground is wider than the distance between Syowa and Mizuho Stations (~270 km). From the examinations of the auroral photographs observed on the DMSP satellite and the auroral hiss emissions observed on the ground, when the aurora is located farther than 600 km from the station, hiss emissions are not observed at the station reducing the threshold level ($\sim 10^{-16}$ W/m^{2}Hz). These results suggest that the maximum observable region is within about 600 km. The ray-tracing result shows that 8 kHz hiss waves departed from the duct at altitude of 3000 km on the geomagnetic field line of $\lambda = 70.0°$ spread over the ground in scale of 300 km. This calculation result is consistent with our observation results.

1. Introduction

The statistical distributions of auroral hiss observed on the ground and satellite

* 拓殖大学. Takushoku University, 4–14, Kohinata 3-chome, Bunkyo-ku, Tokyo 112.

are investigated by many workers (JØRGENSEN, 1966; GURNETT, 1966; BARRINGTON *et al.* 1971; HUGHES *et al.*, 1971). JØRGENSEN (1968) examined the auroral hiss emission observed simultaneously at Narssarssuaq, Godhavn and Tromsö. He reported that the active hiss region moves to the high latitude side accompanying by the poleward movement of aurora. SRIVASTAVA (1976) observed hiss emissions at College and Barter Island which is about 600 km apart from College, and obtained that the similar spectra of hiss emission could not be found between these two stations. From these results, it is considered that the observable scale of the similar hiss emissions is within a few hundred km at the ground. We observed auroral hiss emissions at Syowa and Mizuho Stations (Mizuho Station is about 270 km apart from Syowa Station), using almost the similar VLF observation system and compared hiss spectra in detail.

2. Observations

Coordinated VLF observations have been carried out at the two ground stations Syowa and Mizuho since 1976. The locations of Syowa and Mizuho Stations are lat=−70.38°, long=79.39° and lat=−72.32°, long=80.62° in geomagnetic coordinations, respectively. Mizuho Station is about 270 km apart poleward from Syowa Station along the geomagnetic meridian. Both stations are situated in the auroral zone and suitable to study the auroral activities, related phenomena and their latitudinal dependence as well.

Almost the same observation system for measuring VLF emissions was adopted at both Syowa and Mizuho Stations. The block diagram of the VLF observation systems at these stations is shown in Fig. 1. A triangle loop antenna of 10 m in

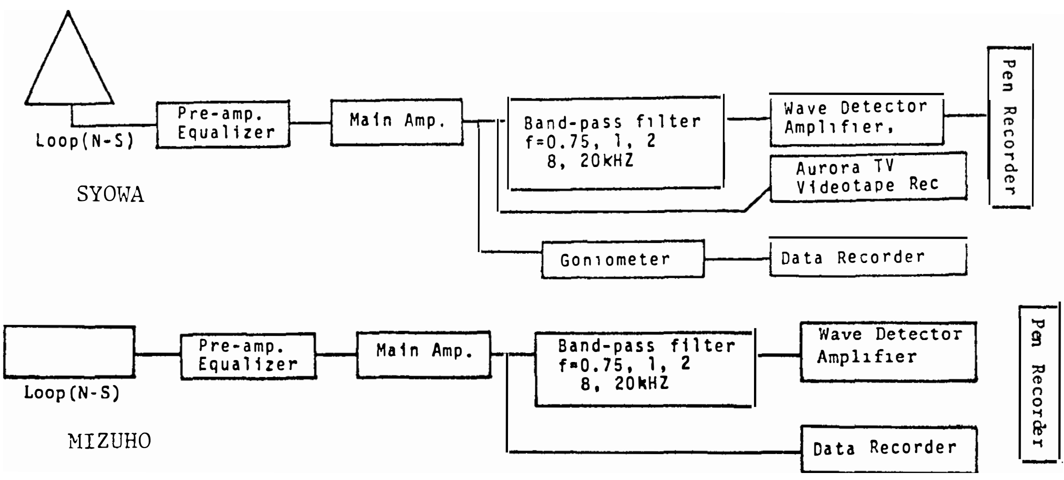

Fig 1 Block diagram of the VLF observation systems at Syowa and Mizuho Stations.

height and 20 m at base was used for receiving VLF emission at Syowa Station. A square loop antenna and its dimension is 2 m in height and 20 m in width with an effective area of 40 m is used at Mizuho Station. Both antennas were set in a vertical plane whose normals are oriented in the geomagnetic east-west direction. A specially designed circuit for equalizing the frequency characteristics of antenna is assembled in the preamplifier in order to make possible a quantitative comparison of the intensity in VLF emission between the two stations. The frequency-amplitude characteristics of both receivers (including equalizer and preamplifier) are shown in Fig. 2. Both receivers can detect the wave with intensity above 10^{-16} watt/m^2Hz in the frequency range from 300 Hz to 20 kHz. VLF emissions were recorded by several magnetic tape recorders (video tape recorder, audio tape recorder) and the band limitted intensities were recorded by pen writing recorders The center frequency of the narrow-band pass filters is 750 Hz, 1 kHz, 2 kHz, 8 kHz and 20 kHz and band-width of them is 300 Hz, 400 Hz, 800 Hz, 3.2 kHz and 1.6 kHz respectively. The most difficult problem in our observations was how to achieve the earthing of the electric circuits. Especially Mizuho Station is located on the thick continental ice (the thickness is about 2000 m), hence it was difficult to have a good earthing of the circuits. The low frequency range of VLF emissions (lower than 2 kHz) was seriously disturbed by the dynamo noise because of the poor earthing of the power system at Mizuho Station for the first part of the observation period. A radial counter poise (radius 30 m, number of radial lines 24) extended under the snow surface near the foot of the antenna, fairly reduced the noise level and the high S/N level of VLF emissions was obtained for the rest of the observation period.

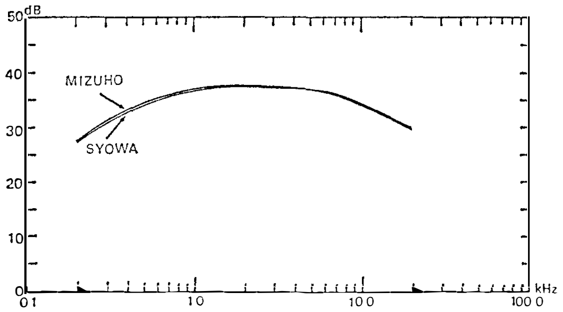

Fig 2 The frequency-amplitude characteristics of VLF receivers at Syowa and Mizuho Stations

The all-sky camera auroral photographs and the meridian auroral photographs were operated at Syowa Station and they were used to study the relations of the location, pattern and slow movement of aurora and hiss emissions. Since the coverange of all-sky camera photograph is limited within one thousand km and is not enough to study the relation between the auroral activities and the hiss emissions in a global scale. Hence, photographs of aurora obtained by a polar-orbiting U.S. Air Force satellite DMSP (in 99° inclination Sun-synchronous orbit with altitudes ranging between 815 km and 852 km, the orbital period is about 102 minutes) are also examined to study the relation between hiss emissions at Syowa Station and auroral activities in the pre-midnight sector.

3. Comparisons of Auroral Hiss Spectra Observed at the Two Stations

The diurnal and seasonal variations of the occurrence frequencies of hiss emissions observed at Syowa and Mizuho Stations are statistically examined. Fig. 3 represents

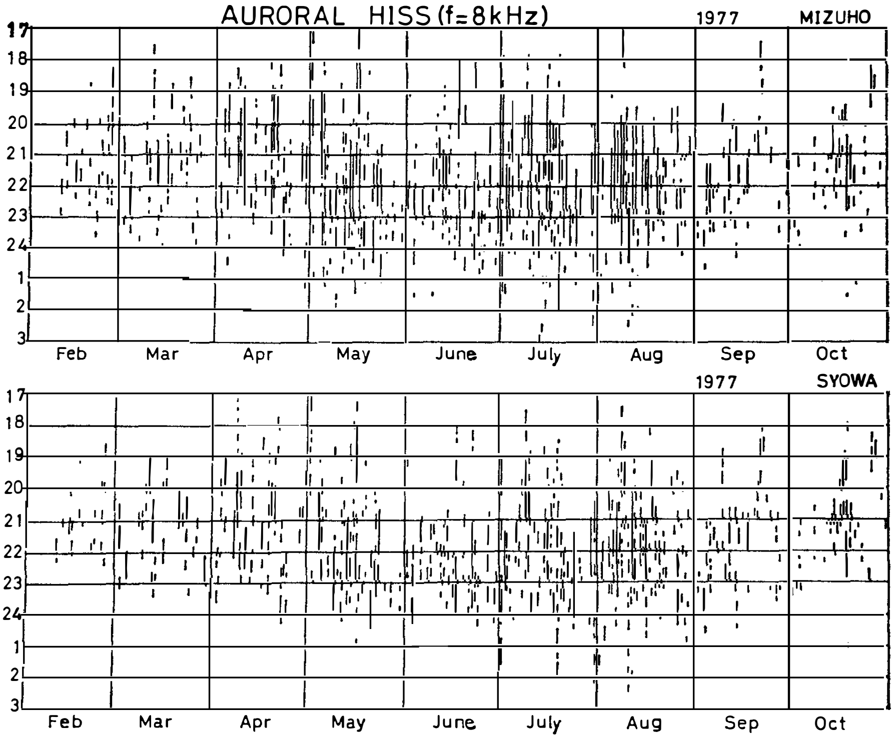

Fig 3. Diurnal and seasonal variations of the occurrence rate of auroral hiss at 8 kHz band observed at Syowa and Mizuho Stations The events with spectral densities above 1 0 $\times 10^{-15}$ watt/m²Hz were selected at Syowa Station and above 0.5 $\times 10^{-15}$ watt/m²Hz at Mizuho Station

all auroral hiss events with intensity higher than the threshold level at 8 kHz band, based on the records of both stations. The hiss emissions tend to appear at earlier magnetic local time in equinoxes in the similar fashion at the two stations. It is seen in this figure that the auroral hiss emissions occur more frequently at Mizuho Station than at Syowa Station. However, this is not real, and is due to the fact that we selected hiss emissions stronger than 0.5×10^{-15} watt/m^{2}Hz at Mizuho Station and hiss emissions stronger than 1.0×10^{-15} watt/m^{2}Hz at Syowa Station. Thus, there is no systematic differences of occurrence of hiss between Syowa and Mizuho Stations, although the difference of the geomagnetic latitude is about 3°. We next examine in detail two typical auroral hiss events observed at both stations.

—September 12, 1977 event—

The intensity of auroral hiss at 0.75, 1.0, 2.0, 8.0, and 20 kHz bands observed at Syowa and Mizuho Stations is shown in Fig. 4. From 2040 UT to 2130 UT, the similar auroral hiss is intermittently observed. According to the meridian auroral photograph, the steady auroral arc is seen near the poleward horizon of Syowa Station in this interval. After 2200 UT, the strong auroral hiss with wide frequency range began to occur associated with the initial brightening of aurora near the zenith of Syowa Station. The intensity of this emission observed at Mizuho Station was stronger than that at Syowa Station. Fig. 5 shows the frequency-time spectra of auroral hiss observed at both stations from 2050 UT to 2220 UT The spectral shape and the time variations of lower and upper cut-off frequency were especially similar between the two

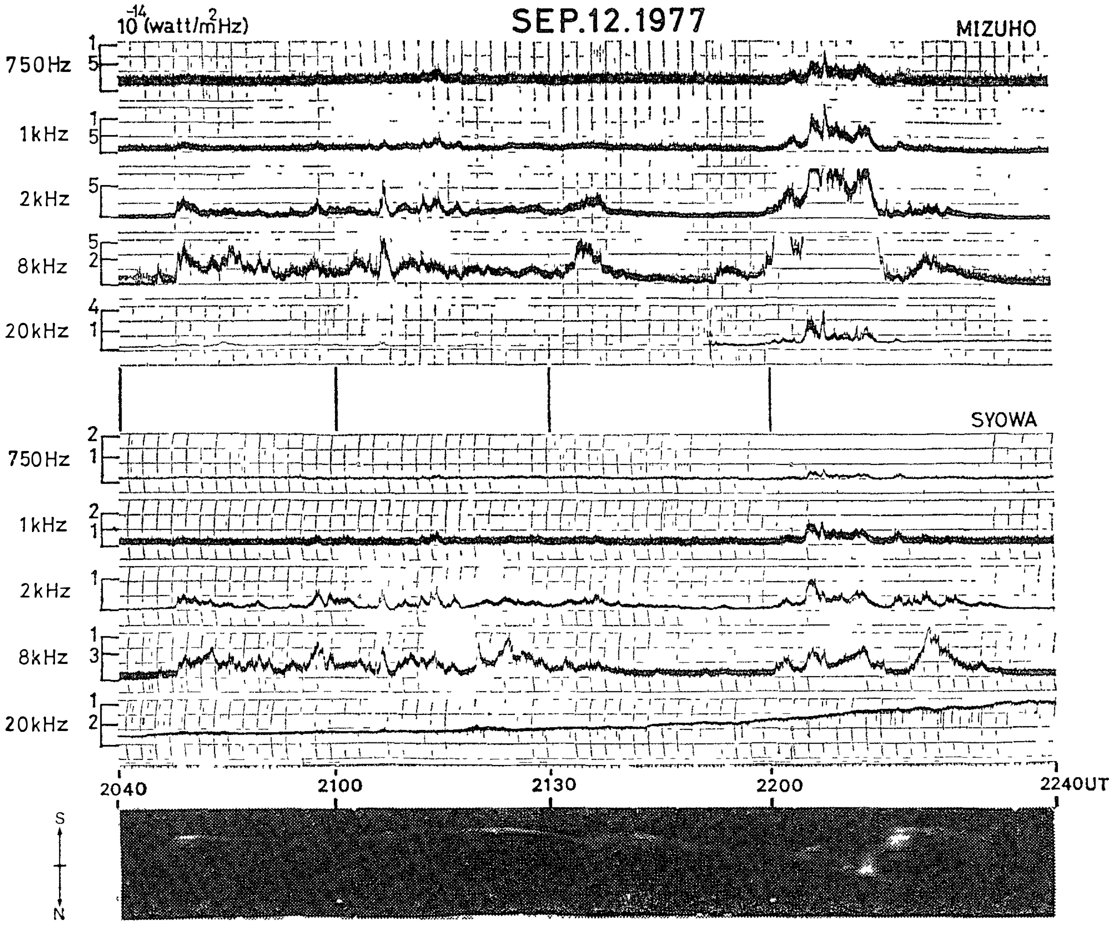

Fig 4 The auroral hiss intensity at 0 75, 1 0, 2 0, 8 0 and 20 0 kHz bands observed at Syowa and Mizuho Stations. The meridian auroral photographs observed at Syowa Station during this interval are also shown

stations from 2100 UT to 2120 UT. We examined several times expanded-frequency spectrograms of auroral hiss emission in order to study the characteristic of hiss in detail. Fig. 6 shows the expanded frequency-time spectra from 2105: 00 to 2105: 33 UT and the intensity of auroral hiss at 8.0 kHz band from 2103: 50 to 2107: 10 UT.

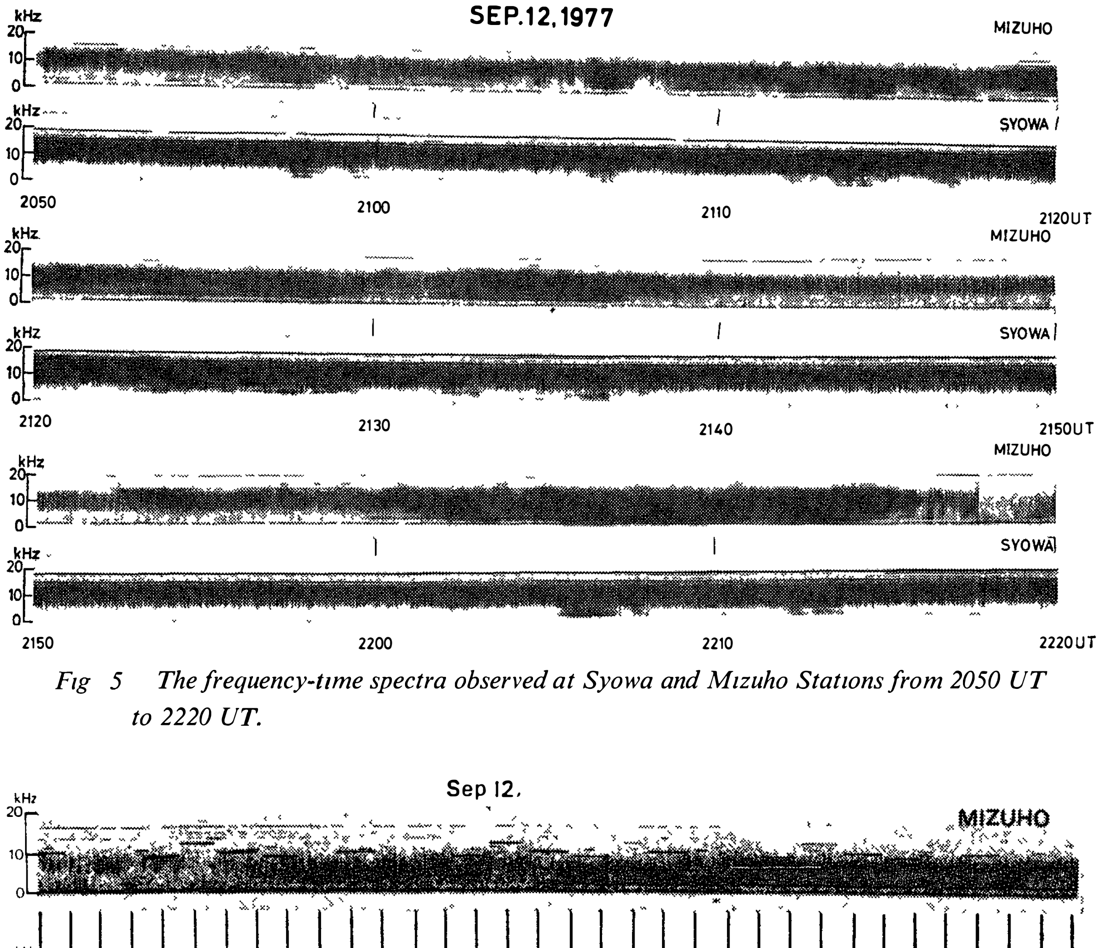

Fig 5 The frequency-time spectra observed at Syowa and Mizuho Stations from 2050 UT to 2220 UT.

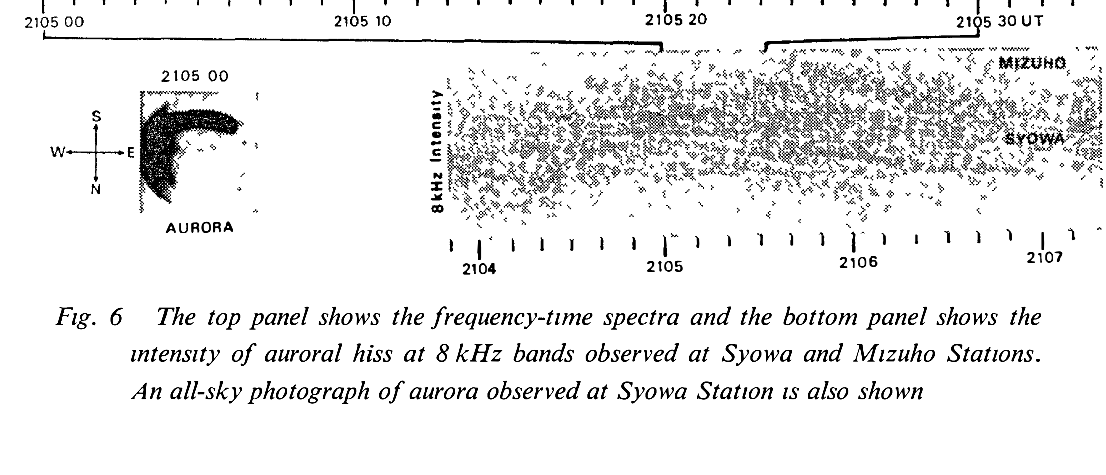

Fig. 6 The top panel shows the frequency-time spectra and the bottom panel shows the intensity of auroral hiss at 8 kHz bands observed at Syowa and Mizuho Stations. An all-sky photograph of aurora observed at Syowa Station is also shown

In the bottom panel, the fast variation of 8 kHz band intensity is atmospheric and the slow variation of the background level represents the occurrence of auroral hiss emissions. It shows the auroral hiss emissions began to occur after 2105: 00 UT. The upper panel shows the frequency-time spectra at both stations after 2105: 00 UT. The occurrence time of hiss between Syowa and Mizuho Stations was adjusted by the Omega-signal received at both stations. Since the hiss emissions have no clear dispersive spectra, it is not easy to compare the hiss spectra observed at both stations in detail. In this analysis, we found that the hiss spectra observed at both stations were very similar within an accuracy of one second. This result suggests that the observable distance of hiss emissions on the ground may be larger than 270 km in this case.

_August 27, 1977 event—

The intensity of auroral hiss at 0.75, 1.0, 2.0, 8.0 and 20.0 kHz bands observed at both stations is shown in Fig. 7. From 2200 to 0030 UT, the similar auroral hiss

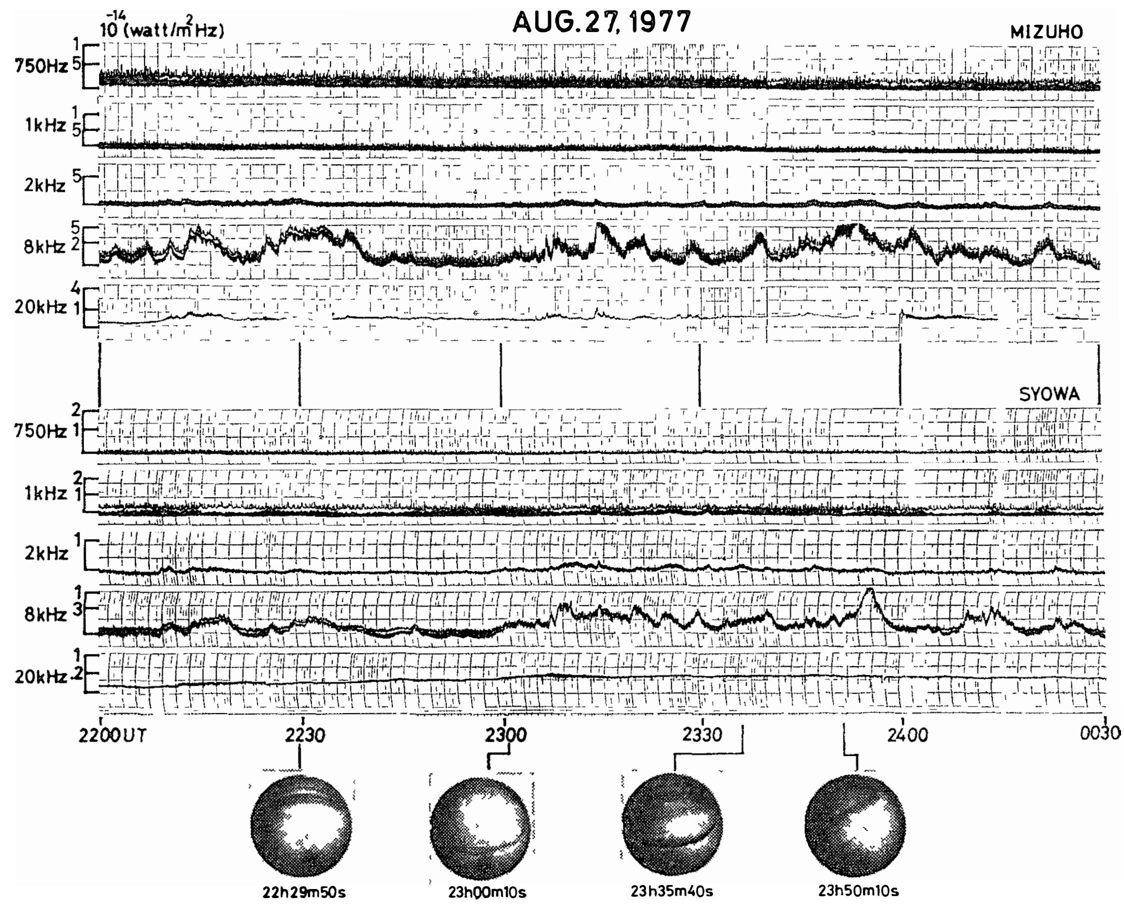

Fig. 7. The auroral hiss intensity at 0.75, 1.0, 2.0, 8.0 and 20.0 kHz bands observed at Syowa and Mizuho Stations. The all-sky auroral photographs of aurora observed at Syowa Station are also shown.

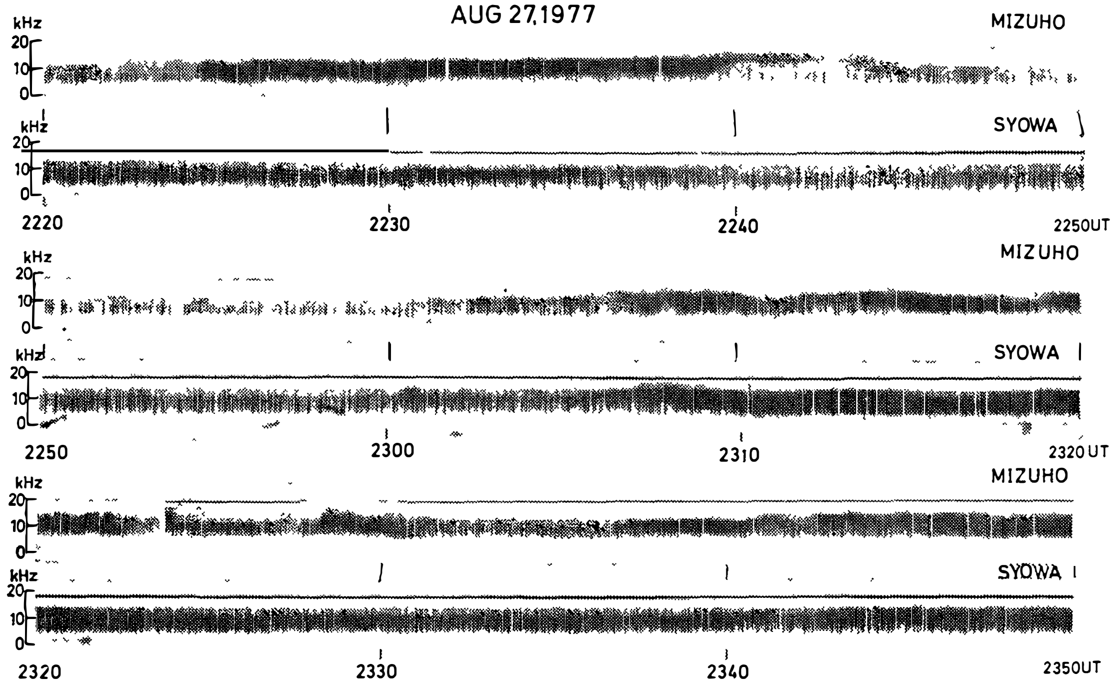

Fig 8 The frequency-time spectra observed at Syowa and Mizuho Stations from 2220 UT to 2350 UT

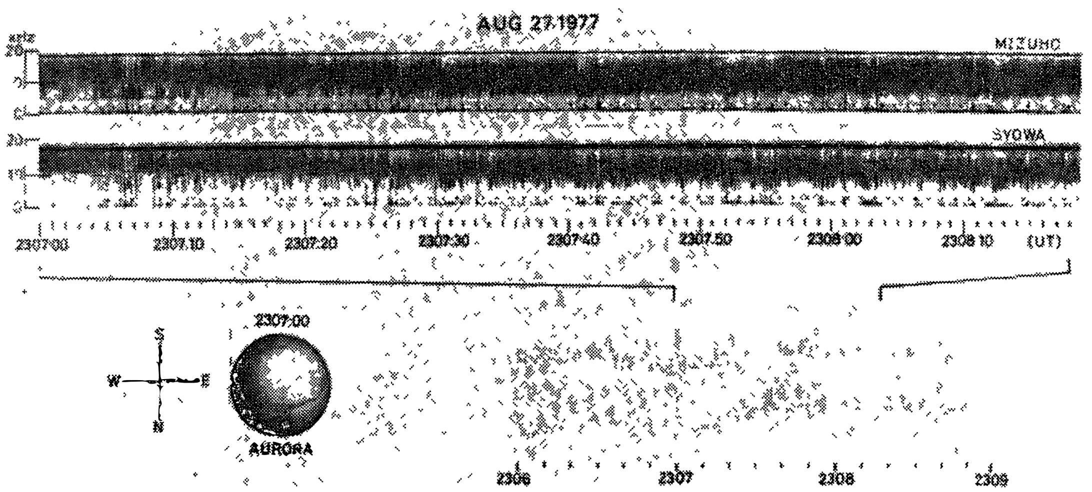

Fig 9 The top panel shows the frequency-time spectra and the bottom panel shows the intensity of auroral hiss at 8 kHz bands observed at Syowa and Mizuho Stations An all-sky photograph of aurora observed at Syowa Station is also shown

emissions are intermittently observed In this time interval, the steady auroral arc is seen near the poleward horizon of Syowa Station around 2230 UT and near the zenith after 2300 UT. Fig 8 shows the frequency-time spectra of auroral hiss observed at both stations from 2220 to 2350 UT. The intensity and the spectral shape were especially similar between the two stations around 2310 UT. The expanded frequency-time spectra of auroral hiss observed from 2307: 00 to 2308: 18 UT and the band limited intensity of auroral hiss at 8 kHz from 2306: 00 to 2309: 00 are shown in Fig. 9. The bottom panel shows the intensity of 8 kHz band of auroral hiss observed at both stations. It shows very similar variations of hiss intensities. The upper panel also shows the frequency-time spectra. The similar hiss spectra including the atmospherics are recognized at both stations

4. The Global Auroral Activity and Auroral Hiss

The intensity of hiss emission becomes generally weaker when the auroral activity is far away from the observation site of VLF emission. Since the coverage of all-sky camera photograph is limited within one thousand km and is not enough to study the relationship between the auroral activities and the hiss emissions, the photographs of aurora obtained by a polar-orbiting U S. Air Force satellite (DMSP) are examined to study the relationship between the hiss emissions at Syowa Station and the global

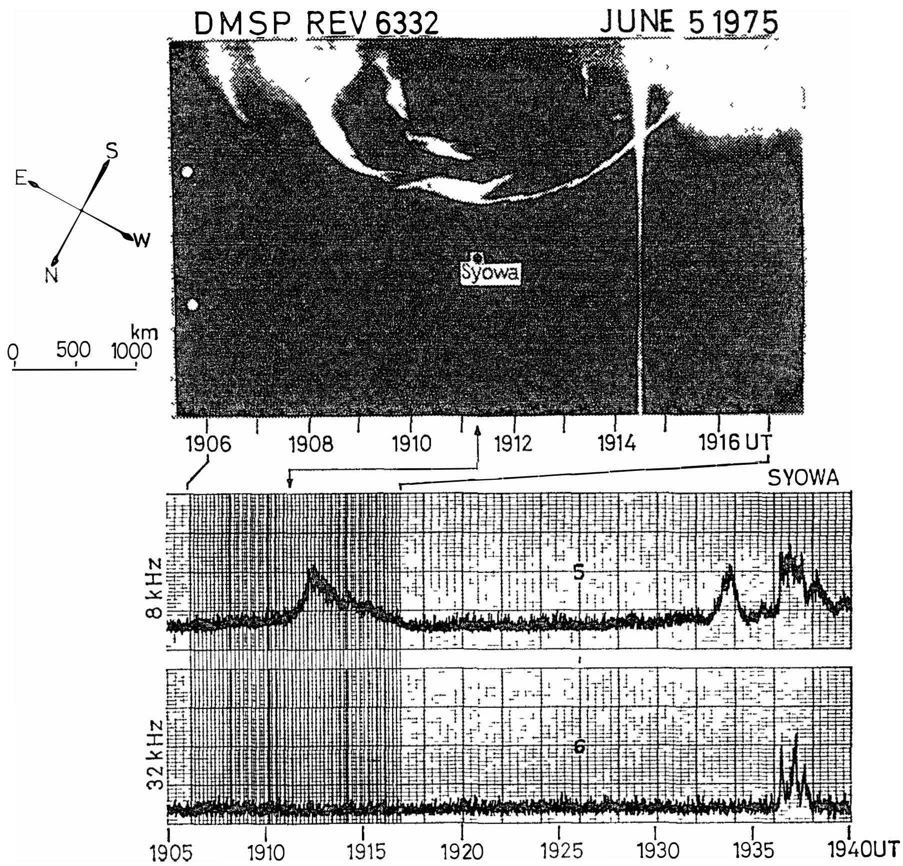

Fig. 10. The top panel shows the DMSP auroral photograph and the bottom panel shows the intensity of auroral hiss at 8 kHz and 32 kHz bands observed at Syowa Station

auroral activities. Fig. 10 shows the DMSP auroral photograph and the VLF emission at the 8 kHz and 32 kHz bands observed at Syowa Station. A bright auroral arc, with a westward traveling surge, was seen at about 300 km south of Syowa Station. The strong hiss emission at the 8 kHz band that was observed around 1913 UT would be related to the closest approach of the bright auroral arc at Syowa Station. A strong hiss with a high frequency component above 32 kHz was observed around 1936 UT. It may be an indication that the active aurora reached near the zenith of Syowa Station, but we had no auroral data at the moment.

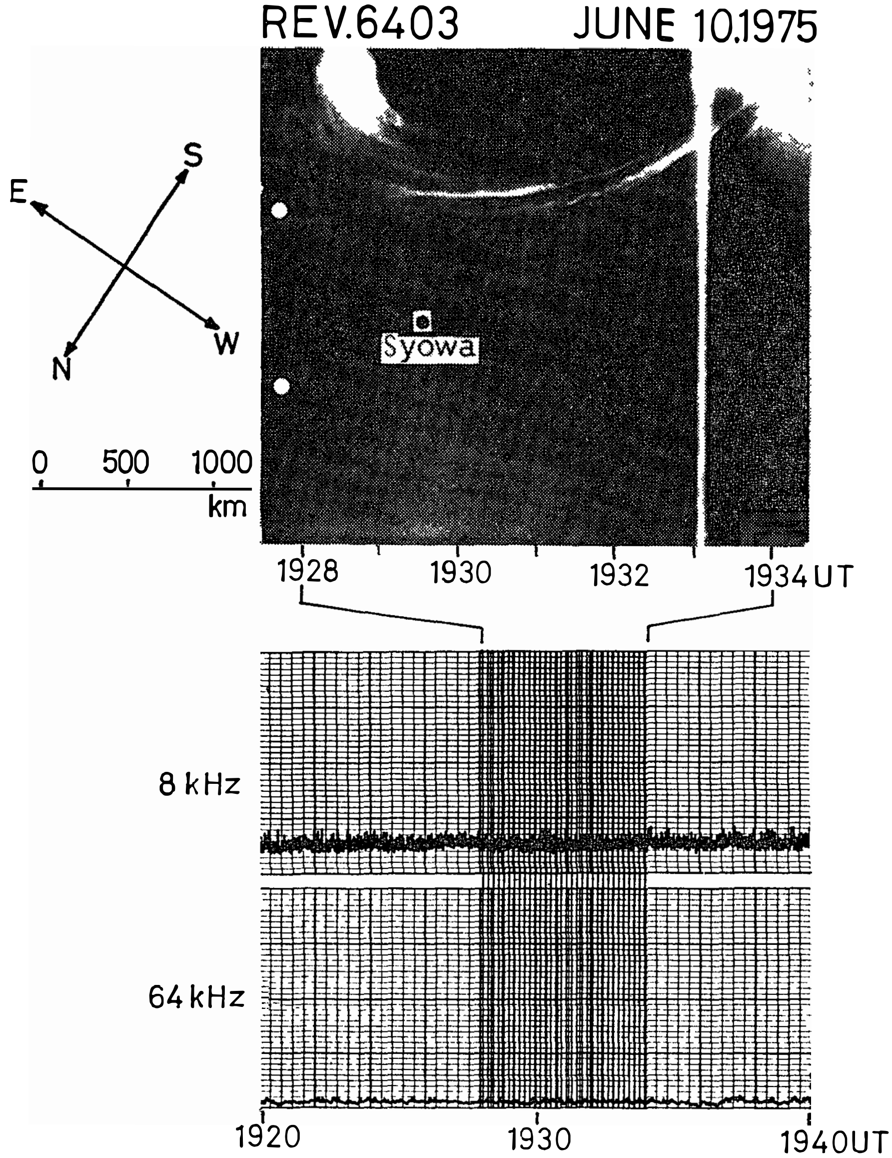

Fig. 11. The DMSP auroral photograph and the intensity of auroral hiss at 8 kHz and 64 kHz bands observed at Syowa Station are shown at the top and the bottom panel respectively

On the other hand, when the aurora is located around 500 km or more away from Syowa Station, the auroral hiss is not observed in relation with the bright aurora as shown in Fig. 11. The auroral photograph and the VLF emission at the 8 and 64 kHz bands are shown in this figure. The bright multiple auroral arcs were seen at about 600 km south of Syowa Station from the auroral photograph taken from 1928 UT to 1930 UT. In this interval, however, no auroral hiss emissions at the 8 kHz and 64 kHz bands were recognized at Syowa Station. These tendencies were seen in some other examples.

These relations suggest that auroral hiss emissions are not observed when the aurora is located farther than 600 km poleward of the station. The similar results are obtained by AYUKAWA (1978; private communication). According to his examinations of the relationship between the location of aurora and the hiss intensity, when the auroral location is 500 km away from the station, the associated hiss intensity becomes very weak SRIVASTAVA (1976) examined the simultaneous hiss observations between College and Barter Island about 600 km apart from each other and obtained that auroral hiss emissions were not identical at these two stations From these examinations, he suggested that the maximum propagation distance of hiss emission must be about 600 km

5. Discussions

It is clear that the similar auroral hiss emissions can be observed at both stations simultaneously. From the auroral photographs observed on DMSP satellite, the maximum correlation distance of hiss emissions observed on the ground may be less than 600 km. In order to explain these observed results, we computed the ray paths of 8 kHz waves from 3000 km altitude, where the duct would terminate (CERISIER, 1974), to the ionosphere Note that there are other possibilities that the waves depart from the duct at the altitude higher than 3000 km or the wave propagates down to the ionospheric level (=200 km) along the field line. We have examined these possibilities in detail and obtained that this model well explains the coordinated ground-satellite VLF observation results and the relationships between the arrival direction of hiss and the locations of aurora (MAKITA, 1979). First, we must examine the wave normal directions of the ray at the ionospheric level (h=200 km) carefully because the wave transmission through the lower ionosphere requires that the wave normal directions of the downgoing ray must be in a small transmission cone angle (MAEDA and OYA, 1963; HELLIWELL, 1965).

Fig 12 shows ray paths computed with different initial wave normal angles θ_i (angle measured from the field line) around the exit point from the duct It also

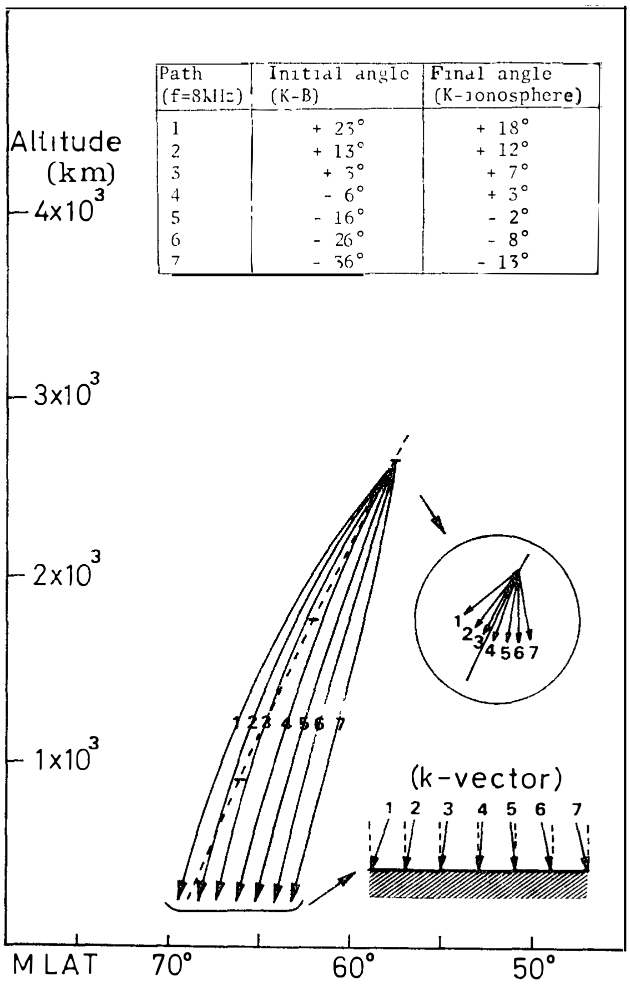

Fig 12. Ray paths for the waves of 8 0 kHz at various initial wave normal angles starting at 3000 km and coming down to the final altitude near 200 km. The initial wave normal angles are measured from the field line and the final wave normal angles are measured from the ionospheric vertical plane ($h \sim 200$ km) The magnetic latitude at the ground is 70.0°.

shows the wave normal angles of the ray path (measured from the ionospheric vertical plane at altitude of 200 km). Assuming the limited transmission cone angle is $\pm 5°$ at frequency of 8 kHz, the wave normal directions of the two ray paths indicated by "path 4 and 5" lie in the transmission cone. This result indicates that the transmission region of VLF waves departs from the duct and also shows that the transmission area at the ionospheric level (h=200 km) is about two hundreds of km or more. These calculated results well explain our observed results at Syowa and Mizuho Stations. The calculated ray paths also indicate that the distance between the exit of hiss and the aurora at the ionospheric level depends on the magnetic dip angle. Since the width of the transmission cone angle varies with the electron density at the ionospheric level, it is important to examine the electron density at the ionospheric altitude in detail in order to determine the transmission region of auroral hiss

Acknowledgments

The author thanks Prof T. OGUTI, Dr. S. KOKUBUN and Dr K. HAYASHI for their valuable suggestions He wishes to express his appreciation to the 17th and 18th Japanese Antarctic Research Expedition members, especially Prof T. YOSHINO, Dr. H. FUKUNISHI, Mr K. NIKKI and Mr. T. TOYA. His appreciation is also due to the computer programs developed by Prof I KIMURA and Mr. H. YAMAGISHI in calculating the ray path. DMSP data were provided by the USAF Air Weather Service, Global Weather Central, through the World Data Center A at Boulder. The author's thanks are also extended to the organization for supplying DMSP auroral photograph data. This research was supported in part by the Geophysics Research Laboratory, University of Tokyo and in part by the National Institute of Polar Research.

References

BARRINGTON, R E, HARTZ, T R and HARVEY, R W (1971): Diurnal distribution of ELF, VLF and LF noise at high latitudes as observed by Alouette 2 J Geophys Res, **76**, 5278–5291

CERISIER, J C. (1974). Ducted and partly ducted propagation of VLF waves through the magnetosphere J Atmos Terr Phys, **36**, 1443–1467

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

HELLIWELL, R A (1965) Whistlers and Related Ionospheric Phenomena Stanford, Stanford Press, 23–82

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

JØRGENSEN, T. S (1966) Morphology of VLF hiss zone and their correlation with particle precipitation events J Geophys Res, **71**, 1367–1375

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

MAEDA, K and OYA, H (1963). Penetration of VLF radio waves through the ionosphere. J Geomagn Geoelectr, **14**, 151–171

MAKITA, K (1979): VLF-LF hiss emissions associated with aurora JARE Sci. Rep, Ser. A (Aeron), **16**, 126p

SRIVASTAVA, R N (1976): VLF hiss, visual aurora and the geomagnetic activity Planet. Space Sci, **24**, 375–379

(*Received May 28, 1979*)