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RESEARCH REPORT

MID-LATITUDE WHISTLER ACTIVITIES DEDUCED FROM SIMULTANEOUS OBSERVATIONS OF CAUSATIVE ATMOSPHERICS AND CONJUGATE MEASUREMENTS OF VLF TRANSMITTER SIGNALS

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Abstract

Whistler activities at a middle latitude(L=1.93) are deduced from atmospherics activities around the geomagnetic conjugate point in the opposite hemisphere, and propagation characteristics determined by conjugate observation of the whistler-mode signals from the VLF transmitter. The whistler activities correlate strongly with atmospherics activities within the area 1500 km distant from the conjugate point, and correlate moderately with those within the area 3000 km distant from the conjugate point when one includes the propagation condition in the ionosphere and magnetosphere.

1. Introduction

It is generally understood that the whistler occurrence frequency depends on the field intensity and location of causative atmospherics in the opposite hemisphere as well as on the propagation characteristics in the ionosphere and magnetosphere (e.g. ionospheric transmission and duct trapping in the field-aligned columns of enhanced ionization). Concerning the relationship between the whistler occurrence and causative atmospherics, Ondoh(1979) reported that the relatively higher whistler occurrence at Okinawa (L=1.13) compared to the whistler occurrence at Varanasi(L=1.11) in the Indian Ocean, depended on the high thunderstorm activity around the conjugate point of Okinawa, east of Jawa Island, on the world map of the thunderstorm day. Yoshino(1976) found the high occurrence frequency of low-latitude whistlers at Sugadaira(L=1.3) when the cloud was within 500 km from the conjugate point(Northern Australia) and in its southwest sector, using the cloud pictures observed by meteorological satellites. Tanaka and Hayakawa(1980) interpreted the enhancement of whistler activity in winter late afternoons at low-latitude stations in Japan in terms of the high thunderstorm activity around the geomagnetic conjugate zone(Northern Australia) of the whistler stations. Ohta and Okada(1985) reported high whistler activity at Yamaoka(L=1.3) and Moshiri(L=1.6) due to the thunderstorm at the conjugate zone(Northern Australia) with the use of cloud pictures.

Thunderstorm occurs in clouds, but one cannot always identify clearly a thunderstorm region in the cloud with the use of cloud pictures. Thus, we examined more directly the dependency of the whistler occurrence frequency on causative atmospherics by using observation data of mid-latitude whistlers at Ceduna(L=1.93), South Australia, and atmospherics location data in East Asia. In addition, at Ceduna, we carried out simultaneous conjugate observation of whistler-mode signals from a VLF transmitter(11.905, 12.649 and 14.881 kHz, 500 KW), at the eastern station(Komsomolskamur, geographic lat. 50.6°N, long. 137.0°E) of the Soviet "Alpha" navigation system. This observation provided information on the propagation condition in the ionosphere and magnetosphere.

The present study aims to present mid-latitude whistler activities by means of correlative analyses between the whistler occurrence and the distribution of atmospherics sources, including the propagation condition determined by the observation of VLF whistler-mode signals.

2. Instrumentation

Figure 1 shows a block diagram of the measuring system installed at Ceduna. Wideband signals picked up by the crossed loop antennas(triangular type loops 10 m high with 16 m base oriented in the geomagnetic NS and EW directions) were fed through preamplifiers to main amplifiers, and natural VLF/ELF signals(1-8 kHz) were recorded directly; the two channel VLF transmitter signals(10-20 kHz) were recorded in forms of PCM(Pulse Code Modulation) in a VTR for one minute every 10 minutes from 16 h to 8 h JST(135°EMT). An output of

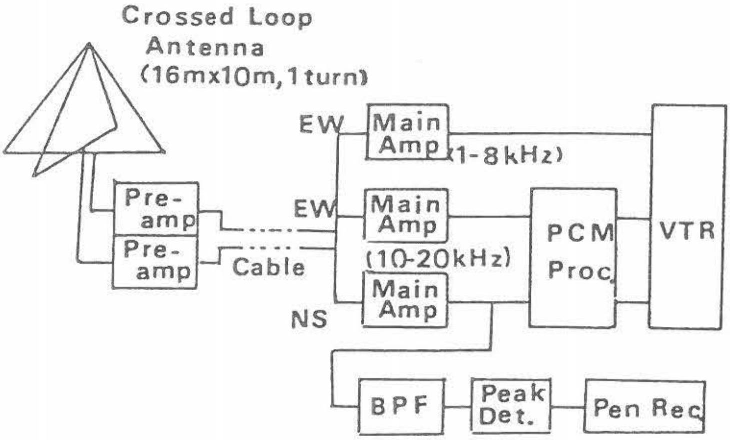


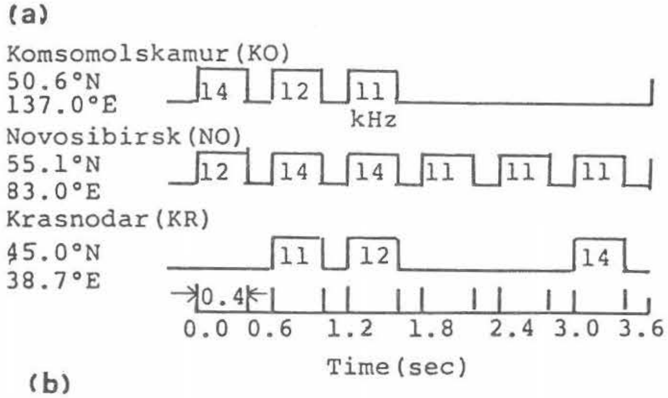
Fig. 1 Block diagram of the measurement system installed at Ceduna.

NS channel amplifier was also fed to a bandpass filter(bandwidth, ±5 Hz) with the tuning frequency of 14.881 kHz, and was continuously monitored by a pen-recorder after rectification by a peak detection circuit.

A location system of atmospherics sources is composed of three direction finders(DFs) installed at Moshiri, Sakushima and Kagoshima in Japan in order to identify atmospherics sources up to 4000-5000 km away from Japanese Islands(Iwai et al., 1969). DF observations were carried out during 18 h50-55 m and 4 h50-55 m JST.

3. Detection of whistler mode signals

Figure 2 shows (a) a transmission format of Soviet "Alpha" navigation system and distances between each of the three transmission stations and Ceduna,(b) arrival directions at Ceduna, clockwisely measured from geographic north. Figure 3 presents (a) a time sequence of 14.881 kHz transmission signals deduced from the format of Fig. 2 (a), and (b) an example of the amplitude variation in NS and EW components of received signals at 14.881 kHz, for which waveforms displayed were converted into a lower frequency(14.881 kHz x 1/8) by a frequency-converter with a function of the bandpass filter(±5 Hz). Whistler-mode signals propagating through the magnetosphere from KO station to its conjugate point, Ceduna, were observed with a delay time of 0.5-0.6 sec. from the preceding waveguide-mode(KO) in NS component, so the whistler-mode signals in NS and EW components were superimposed partially on the succeeding waveguide-mode(NO) of a relatively small amplitude.



(b)

Station	KO	NO	KR
Distance(km) from Ceduna	9,190	10,820	12,810
Direction(°) from North	-2.2	26.5	51.1

Fig. 2 (a)Transmission format of Soviet "Alpha" navigation system and (b)distances between each of three transmission stations and Ceduna, and arrival directions at Ceduna, clockwisely measured from the geographic north.

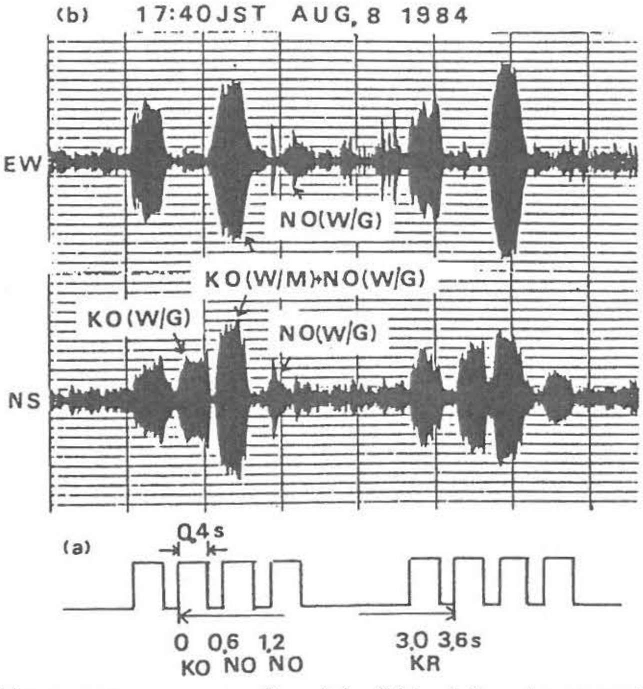


Fig. 3 (a)Time sequence of 14.881 kHz transmission signals derived from the format of Fig.2 (a), and (b) an example of the amplitude variations in NS and EW components of the received signals at 14.881 kHz. W/G and W/M indicate the waveguide-mode and the whistler-mode signals, respectively.

Figure 4 presents diurnal intensity variations of the NS component of the whistler-mode signals averaged over 8 active days and the waveguide-mode signals(NO) at 14.881 kHz. Intensity of the whistler-mode signals dominantly increases around sunset at both stations and moderately increases around sunrise at Ceduna over the intensity of the waveguide-mode signals(NO). The intensified whistler-mode signals around sunset indicate right-handed circular polarization with nearly equivalent amplitudes of NS and EW components by means of computer-aided FFT analyses(Nishino et al., 1987).

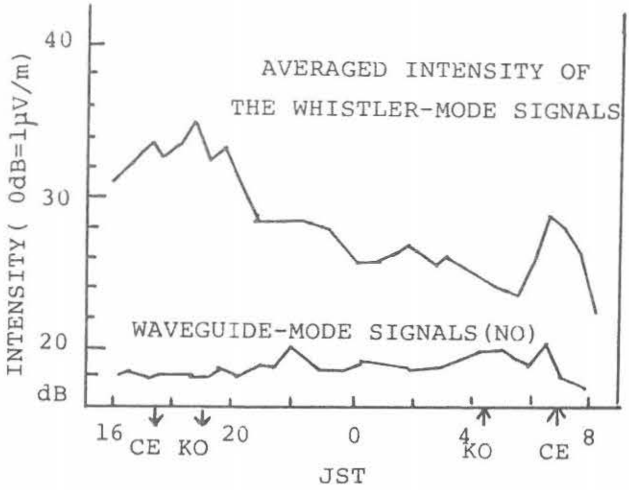


Fig. 4 Diurnal intensity variations of NS component of the whistler-mode signals averaged over 8 active days and the waveguide-mode signals(NO) at 14.881 kHz. Upward and downward arrows indicate sunrise and sunset times at Ceduna and KO station, respectively.

4. Observed results

Figure 5 shows the diurnal variations of whistler occurrence rate per minute and the occurrence probability of the 14.881 kHz whistler-mode signals averaged from July 25 to September 6, 1984 at Ceduna. The occurrence probability ranging from 1 to 0 is expressed as a rate of the duration of the received whistler-mode signals to the whole observation time from 16 h to 8 h JST. The whistler occurrence at the mid-latitude shows a dominant peak around sunset(17-19 h JST), a small peak before midnight, and thereafter a gradual decrease. According to the review paper by Hayakawa and Tanaka(1978), the whistler occurrence number at low-latitudes (L=1.2-1.6) indicates a sharp enhancement during 14-17 h MLT("daytime whistlers") and a broad maximum during 04-06 h MLT("nighttime whistlers"). Such characteristics are different from the whistler occurrence at the mid-latitude during one winter season at Ceduna. On the other hand, the occurrence probability of the whistler-mode signals shows a dominant peak around sunset, a broad peak around midnight, and a secondary peak around sunrise at Ceduna. Both variations are

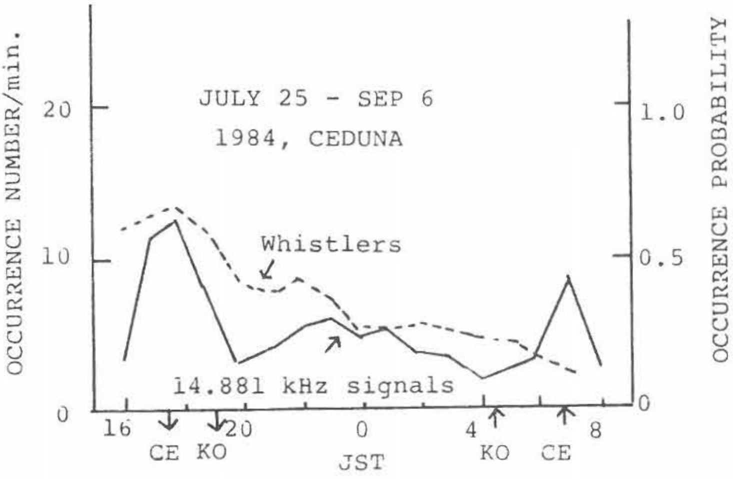


Fig. 5 Diurnal variations of the whistler occurrence rate per minute and the occurrence probability of 14.881 kHz whistler-mode signals averaged over the whole period of the observation(July 25-September 6, 1984) at Ceduna. Upward and downward arrows indicate the same as in Fig.4.

closely correlated, and the correlation coefficient is 0.57, and amounts to 0.75 for a period of 16-04 h JST. The high correlation for the period of 16-04h JST indicates that the diurnal variation of the mid-latitude whistlers is more controlled by propagation condition than by thunderstorm activity, which is consistent with the relationship between whistlers and the whistler-mode signals from NSS transmitter(geomagnetic lat. 51°N) obtained at a high latitude(Helliwell, 1965). However, as described above, whistler activities at low latitudes depend on the thunderstorm activities around the conjugate zone. Hence, in order to investigate the dependency of the whistler activity on causative atmospherics, we pay an attension to the whistler activity around sunset when both variations show a peak.

Figure 6 shows a daily variation of whistler occurrence number during 18 h50m-51 m. As a whole, numerous whistlers occurred from the latter half of July to the earlier half of August. The high occurrence seems to be caused by high thunderstorm activity around the conjugate zone, as illustrated in Fig. 10.

Figure 7 indicates the daily variation of whistler dispersions averaged over one-minute observations. Whistlers were mostly of multiflash type with a dispersion of about 50 $(\text{sec})^{1/2}$, except for some echo-type whistlers observed on Aug. 2, 13 and 14.

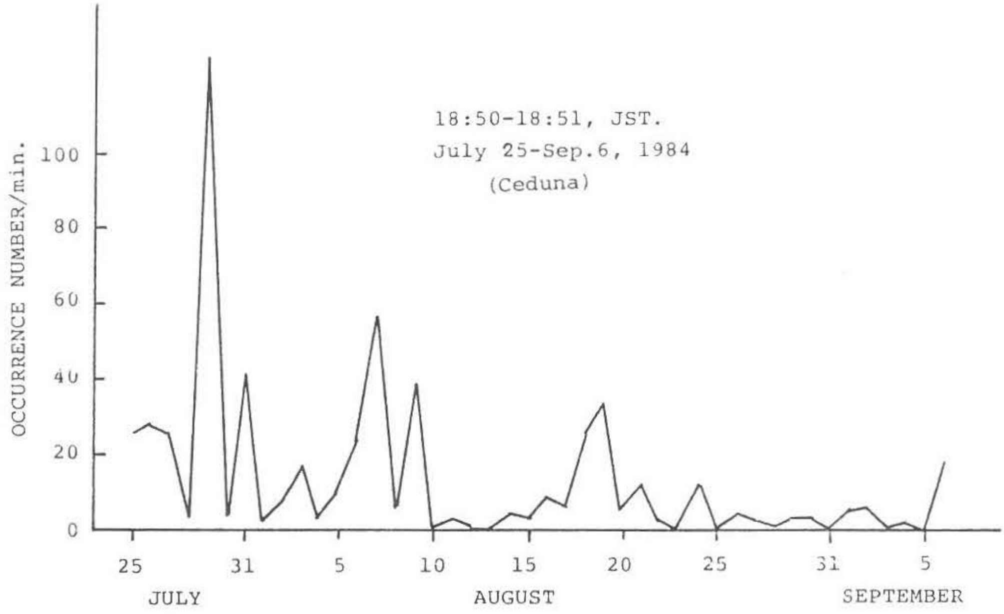


Fig. 6 Daily variation of whistler occurrence number during 18 h50m-51 m observed at Ceduna.

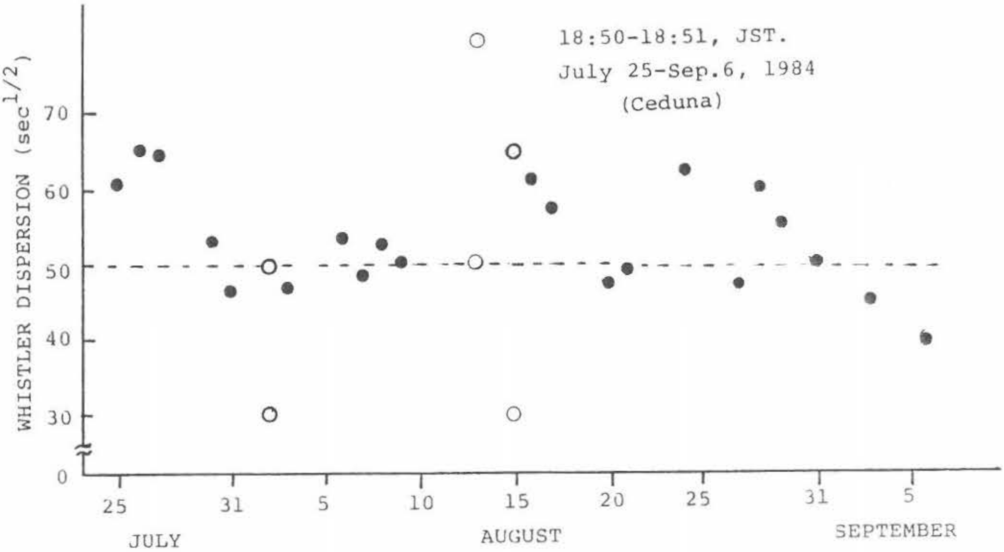


Fig. 7 Daily variation of whistler dispersions averaged over one minute observations. Solid and open dots indicate the dispersions for multiflash and echo types whistlers, respectively.

Figure 8 gives the distribution of atmospherics sources in East Asia observed during 18 h50-55 m on Aug. 7, for which the whistler occurrence in Fig. 6 shows the secondary peak. M, S and K indicate locations of the three DF stations, and KO the location of the VLF transmitter station. The distribution of atmospherics sources was obtained by the two DF data of Moshiri and Kagoshima. Atmospherics sources were widely scattered in a latitude range from 30 to 50 degrees in the China Continent, and were localized around the central region in Japan. Solid dots represent atmospheric sources identified during the whistler observation of 18 h50-51 m.

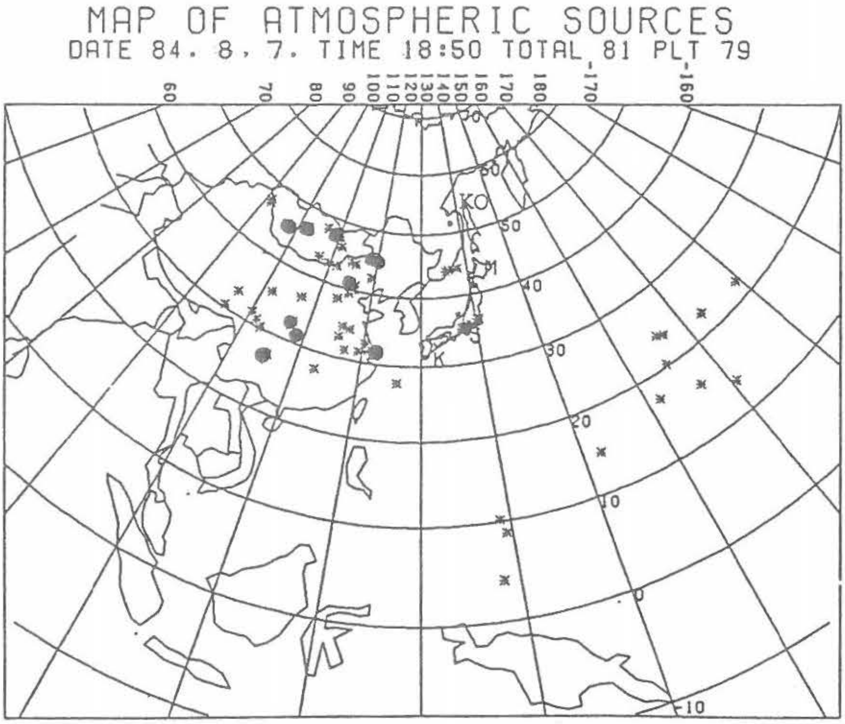


Fig. 8 Distribution of atmospherics sources in East Asia observed during 18 h50-55 m, August 7, 1984. M, S and K indicate the locations of the three DF stations, Moshiri, Sakushima and Kagoshima, respectively, and KO is the location of the VLF transmitter station. Solid dots represent the atmospherics sources identified during 18 h50-51 m of whistler observations.

Figure 9 shows the daily variation in geomagnetic latitude of the local center of the distribution of atmospherics sources. Atmospherics sources are seen mostly to distribute in the geomagnetic latitudes lower than the KO station. The average dispersion of daytime whistlers at Moshiri(L=1.59) lies in a range of 30-40 (sec)$^{1/2}$ (Hayakawa and Tanaka, 1978), while the average dispersion at Ceduna ranges around about 50 (sec)$^{1/2}$, as shown in Fig. 7. These results indicate that most whistlers observed at Ceduna propagate along the magnetospheric path between KO station and Ceduna. Thomson(1976) found that the preferred propagation path of the whistler-mode signals from NLK(18.6 kHz) transmitter in Seattle(L=3.0) lay along the geomagnetic field line near the receiving station, Wellinton(L=2.3), a result consistent with the propagation path of the mid-latitude whistlers.

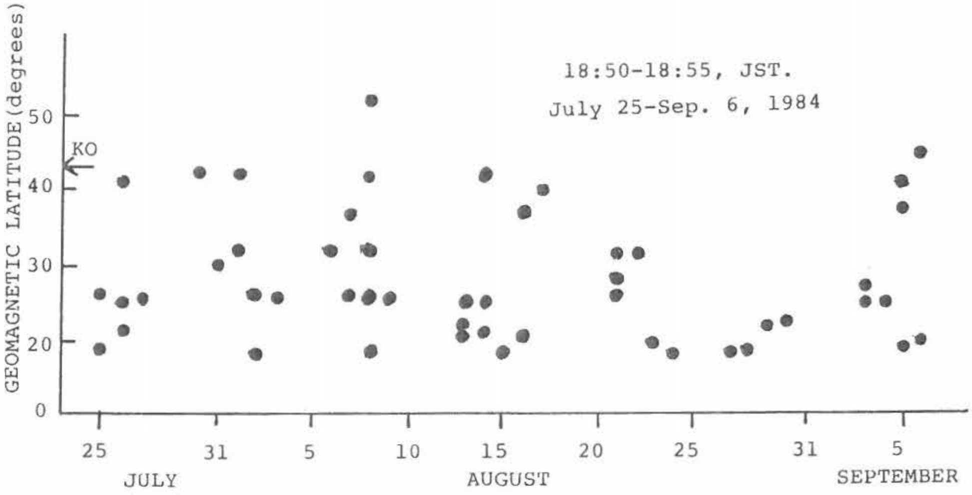


Fig. 9 Daily variation in geomagnetic latitude of the local centers of distribution of atmospherics sources.

Figure 10 shows a daily variation in the number of atmospherics sources whithin concentric circles of 1500, 2000, 2500, 3000 and 3500 km from the KO station. The number of atmospherics sources was determined by the two DF data, because the source number by triangulation of the three DF data decreased, particularly in the southwest sector of the Japanese Islands(Nishino and Kashiwagi, 1977). Except for a temporary increase on September 3-5, the atmospherics activity around KO station was high from the latter half of July to the earlier half of August, resulting in a good correspondence with the daily variation in whistler occurrence shown in Fig. 6. In order to elucidate the relationship between both activities, we calculate correlation coefficients between the occurrence number of whistlers and the source number of atmospherics for each concentric circle. Calculated coefficients were 0.73, 0.21, 0.17, 0.16 and 0.11 for the concentric circles of 1500, 2000, 2500, 3000 and 3500 km distances, respectively. A high coefficient within 1500 km distance indicates that the whistler occurrence at Ceduna correlates strongly with the atmospherics sources around the conjugate point.

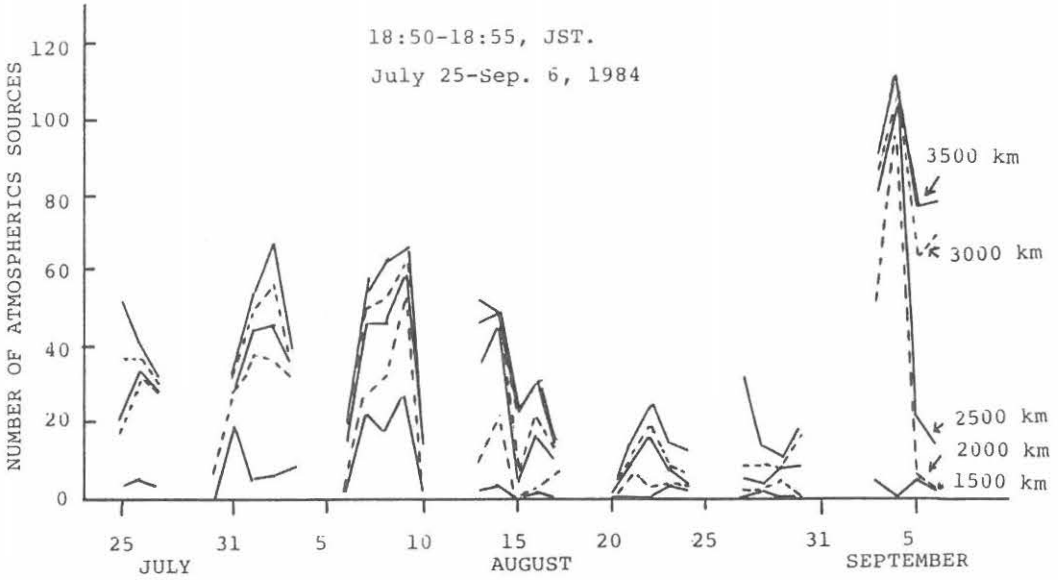


Fig. 10 Daily variation in the number of atmospherics sources within concentric circles of 1500, 2000, 2500, 3000 and 3500 km from KO station.

Figure 11 shows the daily variation in the occurrence probability of 14.881 kHz whistler-mode signals for the interval of 16-20 h JST around sunset, being a good(N=1) or a bad(N=0) propagation condition of the VLF whistler-mode signals in the ionosphere and magnetosphere. The correlation coefficent between the daily variations of the occurrence probability and whistler occurrence (Fig. 6) is rather low($\sim$0.23), which incicates a scarce dependency of the whistler occurrence on only the propagation condition. Therefore, we calculate correlation coefficients between the occurrence number of whistlers and the multiplier of the occurrence probability with the number of atmospherics sources within

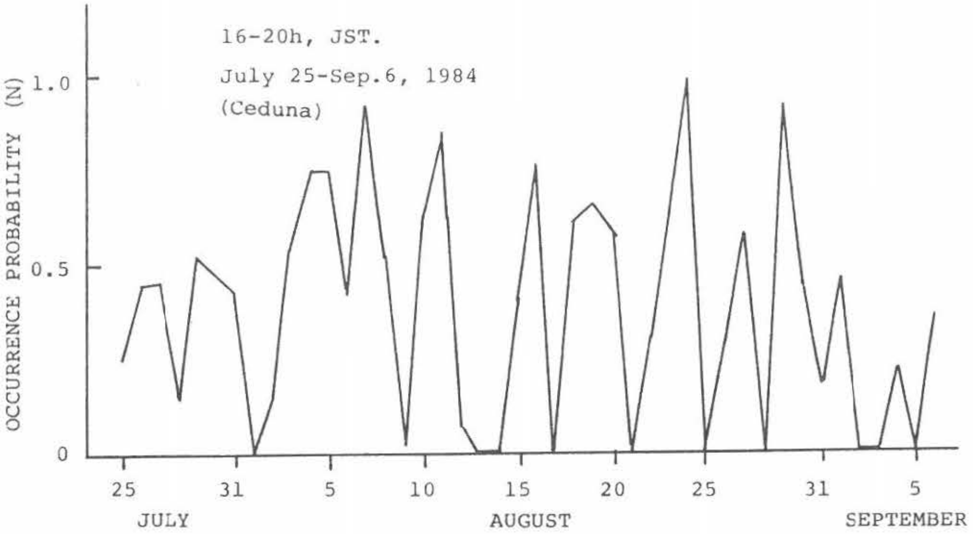


Fig. 11 Daily variation of the occurrence probability of the 14.881 kHz whistler-mode signals. The occurrence probability is given for the interval of 16-20h JST around sunset.

each concentric circle, in order to determine the joint effect of the causative atmospherics activity and the propagation condition. Calculated coefficients are represented by a dashed line in Fig. 12 along with the coefficents(solid line) in the case of only the atmospherics activity described above.

It is recognized that the coefficients for the distances more than 2000 km from KO station are larger than those in the case of only the atmospherics acivity. This suggests that the whistlers observed at Ceduna correlate with the atmospherics sources located at 1500 km or more away from the KO station in case that the propagation condition in the ionosphere and magnetosphere is included. Furthermore, in order to estimate the effective coverage distance, we calculate correlation coefficients between the occurrence number of whistlers and the multiplier of the occurrence probability with the number of atmospherics sources in the ranges of 1500-2000 km, 2000-2500 km, 2500-3000 km and 3000-3500 km distance from the KO station. Calculated coefficients are also depicted by a dot-dash line in Fig. 12, in which the coefficent becomes nearly zero in the 3000-3500 km range. Thus, the occurrence of the mid-latitude whistlers observed at Ceduna correlates with the atmospherics sources within 3000 km from KO the station, including the propagation condition.

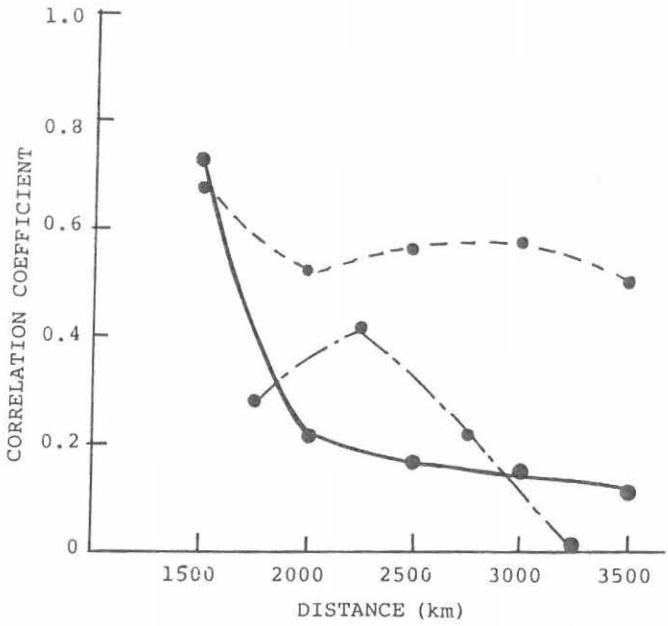


Fig. 12 Correlation coefficients between the occurrence number of whistlers and the number of atmospheric sources. Solid line indicates the coefficients for the case of only atmospherics sources within concentric circles of 1500, 2000, 2500, 3000 and 3500 km from KO station. Dashed and dot-dash lines represent the coefficients between the occurrence number of whistlers and the number of atmospherics within each concentric circle of the above distances and in the ranges of 1500-2000, 2000-2500, 2500-3000 and 3000-3500 km from KO station, respectively, where the propagation condition determined by the occurrence probability of the VLF whistler-mode signals is included.

5. Concluding remarks

The following conclusions are derived from simultaneous observations of whistlers and VLF whistler-mode signals at Ceduna and causative atmospherics sources in the opposite hemisphere: 1) The whistler activity correlates strongly with the atmospherics sources within 1500 km from the conjugate point. 2) The whistler activity correlates moderately with the atmospherics sources within 3000 km from the conjugate point, when the propagation condition in the ionosphere and magnetosphere is included.

Helliwell(1965) indicated that the total electromagnetic energy in a whistler-producing stroke was about ten times as great as in the average lightning fash. Tanaka and Hayakawa(1980) estimated the whistler intensity observed at low latitude stations, assuming that the intensity of whistler-producing atmospherics at 5 kHz was 16 dB greater than the average intensity at 10 kHz presented by world distribution of atmospheric radio noise. As a result, the whistler intensity in the winter late afternoon was 8-10 dB greater than the background atmospheric radio noise. The 8-10 dB intensity redundancy is likely to detect atmospherics within the area of 1500 km from the conjugate point, referring the attenuation factor of 6-8 dB/Mm at the 5 kHz waveguide-mode wave given by Chapman et al.(1966).

Carpenter(1966) defined a coverage area of about 20° latitude by 30° longitude in the opposite hemisphere for natural whistlers received at a mid-latitude station. The obtained coverage area within 3000 km distance from KO station seems to be rather large. However, most summer atmospherics in East Asia occur in mainland of China and the Japanese Islands (Watt, 1967, Nishino and Kashiwagi, 1977), which cover an area of 25° latitude by 30° longitude.

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