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OBSERVATIONS OF VLF HISS AT VERY LOW L VALUES*

by

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ABSTRACT

Observations of intense bursts of very-low-frequency (VLF) radio noise at low altitudes near the magnetic equator are reported using data from the Injun 3 satellite. The spectral characteristics of these radio noise events typically consist of hiss extending from about 1 kHz to above 8.8 kHz (the highest frequency measured). These equatorial VLF hiss events are very similar to VLF hiss commonly found near the auroral zone.

During the ten month lifetime of Injun 3, a total of ten VLF hiss events occurred below 35 degrees magnetic latitude with noise spectral densities exceeding 3×10^{-10} gamma^2 Hz^{-1}. All of these events occurred below 350 km altitude and at L values less than 1.2. Nine of the events occurred below 20 degrees magnetic latitude.

These equatorial VLF hiss events are noteworthy because of their unusual region of occurrence. Whereas auroral zone VLF hiss may be attributable to the precipitation of energetic ($E \leq$ 10 keV) charged particles, no comparable flux of charged particles is known to exist in the region where the equatorial VLF hiss occurs.

I. INTRODUCTION

In this paper we report the observation of intense bursts of very-low-frequency (VLF) radio noise at low altitudes (less than 350 km) near the magnetic equator (from 5° to 35° magnetic latitude) using VLF data from the Injun 3 satellite. The frequency-time spectra of these equatorial VLF radio noise events typically consist of broad-band (1-10 kHz) noise classified as VLF hiss, in accordance with the classifications given by Gallet [1959]. The spectral characteristics of these equatorial VLF hiss events, which we call equatorial VLF hiss, are very similar to a type of broad-band VLF hiss found near the auroral zone and variously called auroral hiss [Martin et al., 1960], VLF hiss [Morozumi, 1963; Jørgensen, 1966; Gurnett, 1966] or, as we shall call it, auroral zone VLF hiss.

The observation of VLF hiss at low altitudes near the magnetic equator is significant in several respects. (i) Ground-based studies of the occurrence of VLF emissions by Laaspere et al. [1964], Helliwell [1965], Jørgensen [1966], and others have shown that VLF emissions activity decreases rapidly for magnetic latitudes below about 50°. Thus, one would not expect to find intense VLF radio noise at low altitudes near the equator. Prior to the observations presented here the lowest latitude at which VLF hiss has been observed is, to our knowledge, at Moshiri, Japan, 34.3° magnetic latitude [Iwai, 1964]. (ii) Because the VLF wave energy is guided approximately along the geomagnetic field line the instability mechanism for generating equatorial VLF hiss must be operative at low altitudes in the ionosphere (probably below 500 km). (iii) The intense fluxes of charged particles with energies from a few hundred eV to several tens of keV which are believed to be responsible for VLF emissions at middle and high latitudes are not known to occur at the L values (less than 1.2) where these equatorial VLF hiss events occurred.

II. CRITERIA FOR IDENTIFYING VLF HISS EVENTS

The discovery of VLF hiss at low altitudes near the magnetic equator came about as the result of a previously published study of auroral zone VLF hiss [Gurnett, 1966]. VLF hiss events were selected for analysis by requiring that the magnetic spectral density at 5.5 kHz, 7.0 kHz, and 8.8 kHz, as determined from the satellite-borne spectrum analyzer, exceed 3×10^{-10} $\text{gamma}^2\ \text{Hz}^{-1}$ for a period of 8 seconds. This noise intensity threshold is approximately five times the VLF receiver noise level and corresponds to a VLF power flux on the order of 10^{-14} watts $(m^2\ \text{Hz})^{-1}$.

From the 4000 revolutions of Injun 3 VLF data available, a total of 171 revolutions occurred for which the above noise intensity threshold was exceeded. Of the 171 revolutions satisfying this noise intensity criteria, the majority (140 events) occurred at high magnetic latitudes (above 60° invariant latitude) and were classified as auroral zone VLF hiss. The frequency spectra of these auroral zone VLF hiss events typically consisted of a flat noise spectrum extending from a lower frequency limit of about 2-4 kHz to above the upper frequency limit of the VLF receiver (8.8 kHz) . The maximum magnetic spectral density of these auroral zone VLF hiss events was about 4×10^{-8} gamma^2 Hz^{-1} corresponding to a VLF power flux of about 10^{-12} watts $(m^2\ Hz)^{-1}$.

Of the remaining 31 revolutions satisfying the noise intensity criteria described earlier, ten events were found with spectral features very similar to auroral zone VLF hiss (wide-band noise with little temporal structure on a time scale less than 1 second) but which occurred at <u>magnetic latitudes less than 35°</u>. All of these events occurred below 350 km altitude and at L values less than 1.2. Nine of the ten events occurred below 20° magnetic latitude. We shall call these low latitude VLF hiss events <u>equatorial VLF hiss</u>.

III. CHARACTERISTICS OF EQUATORIAL VLF HISS

From the ten equatorial VLF hiss events found in the Injun 3 data, two events, occurring on 20 September and 6 October 1963, have been selected to illustrate the general features of equatorial VLF hiss. The magnetic noise spectral density at 5.5 and 8.8 kHz and the wide-band (200 cps to 7 kHz) magnetic field strength for these two events are shown as a function of magnetic latitude in Figures 1 and 2. (For details on the satellite instrumentation, see Gurnett and O'Brien [1964]). Frequency-time spectrograms of the wide-band VLF signals for these two events are shown in Figures 3 and 4, respectively.

In Figure 1 (the 20 September event) the 5.5 and 8.8 kHz spectrum analyzer channels show a strong noise burst (5×10^{-8} $gamma^2$ Hz^{-1}, peak) approximately 5 degrees wide in geomagnetic latitude and centered on -11.5° magnetic latitude. Although not shown, the spectrum analyzer channels at 7.0, 4.3, and 2.7 kHz also indicate a similar enhancement. Thus, we can conclude that the frequency spectrum of the noise burst is relatively flat, extending from less than 2.7 kHz to above 8.8 kHz. In Figure 1 the wide-band magnetic field strength shows a corresponding enhancement centered on approximately -11.5° geomagnetic latitude with a peak amplitude of about 7 milligammas. The frequency-time spectra of the 20 September event, shown in Figure 3, consists of a wide-band noise spectrum from about -9.5° to -14° magnetic latitude with little temporal structure on a time scale less than a few seconds. On the basis of the spectrogram in Figure 3 we have classified this radio noise as VLF hiss.

Also appearing on the spectrogram in Figure 3 is a tone with a frequency varying between about 5 to 6 kHz. This tone appears on all the equatorial hiss events investigated and is not found on higher latitude data. The duration of this tone is usually several minutes and is generally much longer than the duration of the equatorial VLF hiss events. Thus, we do not believe that this tone is associated with the VLF hiss. The origin of this quasi-constant frequency tone has not been established.

No energetic charged particle flux (electrons with energy > 40 keV or protons with energy > 500 keV) above the background level of the Injun 3 charged particle detectors was detectable during this VLF hiss event.

The noise intensity at 5.5 and 8.8 kHz for the 6 October event is shown in Figure 2. The noise enhancement for this event extends from approximately 25° to 35° geomagnetic latitude and has a peak intensity of about 3×10^{-8} $gamma^2$ Hz^{-1}. The peak wide-band magnetic field strength is very large, approximately 12.0 milligammas. The frequency-time spectrogram for this event is shown in Figure 4 and appears as a white noise spectrum above about 2 kHz with very little frequency-time structure. Since the automatic gain control (AGC) circuit in the satellite maintains the signal at constant amplitude it is very difficult to distinguish the VLF hiss in Figure 4 from the VLF preamplifier noise. Evidence that the AGC circuit is decreasing the gain during the event can be seen in Figure 4 from the fact that the number of whistlers and their amplitude decreased markedly during the period when the VLF hiss event occurred, from about 25° to 35° geomagnetic latitude.

The above two events were selected to illustrate the general characteristics of the equatorial VLF hiss events found in the Injun 3 data. These characteristics are: (i) a wide-band magnetic noise enhancement in the frequency range from about 2 kHz to above 8 kHz, (ii) peak intensities on the order of 10^{-8} $gamma^2$ Hz^{-1}, (iii) occurrence at low magnetic latitudes (less than 35°) and at low altitudes (below 350 km).

IV. REGION OF OCCURRENCE

In Table 1 we summarize the relevant coordinates at peak intensity for the ten equatorial VLF hiss events found in the Injun 3 data. The magnetic latitude of these events is very low, with nine of the ten events being below 20° magnetic latitude, and the lowest magnetic latitude being 7.2°. Nine of the ten events occurred at L values [McIlwain, 1961] less than 1.20. The altitude at which these events were observed is also very low, in all cases below 350 km, and near the perigee altitude for Injun 3 (237 km).

In Figure 5 we show the altitude and magnetic latitude coordinates for all the equatorial hiss events satisfying our previously discussed noise intensity criteria (magnetic spectral density exceeding 3×10^{-10} gamma^2 Hz^{-1} at 5.5, 7.0, and 8.8 kHz). Similarly, in Figure 6 we show the magnetic latitude and local time coordinates of the satellite at all points satisfying the above noise intensity criteria.

In the interpretation of Table 1 and Figures 5 and 6, it is important to consider how much data was obtained in different altutude, latitude, and local time regions. We shall consider these coordinates one at a time.

A. Altitude

Since the perigee altitude was 237 km we cannot determine whether equatorial VLF hiss occurs below this altitude. We can, however, be reasonably certain that equatorial VLF hiss does not generally occur from about 350 km up to the Injun 3 apogee altitude (2785 km) because there were approximately 1000 revolutions available in this altitude range for which no VLF hiss was observed near the magnetic equator. Thus, we can conclude that equatorial VLF hiss with intensity greater than about 3×10^{-8} $gamma^2\ Hz^{-1}$ generally occurs only below about 350 km altitude.

Because the region viewed by the ground telemetry station decreases rapidly with decreasing altitude, only 29 revolutions occurred with data below 350 km altitude and within ± 35° magnetic latitude. Of these 29 revolutions four occurred during May-June 1963, for which no VLF hiss was observed, and 25 revolutions occurred during September-October 1963, for which the ten events discussed above were observed. Thus, VLF hiss was observed on approximately one-third of the revolutions which passed through the region below 350 km and within ± 35° geomagnetic latitude.

B. Latitude

It can be noted from Table 1 that all except one of the equatorial VLF hiss events were observed in southern (negative) magnetic latitudes. This absence of northern latitude events is due to ground telemetry station locations. No data were available at low altitudes (less than 350 km) in the range of geomagnetic latitudes from approximately +10° to +25°. Thus, we cannot determine whether equatorial VLF hiss occurs at the conjugate point in the northern magnetic hemisphere.

C. Local Time

The revolutions with data below 350 km and within ± 35° of the magnetic equator occurred primarily during September and October. The local time sample is, therefore, very nonuniform and no conclusions can be drawn from Table 1 and Figure 6 concerning the diurnal variations in the occurrence of equatorial VLF hiss.

V. DISCUSSION

These observations of VLF hiss at low altitudes near the magnetic equator represent, to our knowledge, the lowest L value (1.09) at which VLF radio noise emissions have been observed. Since the wave energy for the whistler mode of propagation is guided approximately along the geomagnetic field line [Storey, 1953] it follows that the source region for these equatorial VLF hiss events must also be at very low L values, probably $L < 1.20$. (For frequencies below the lower hybrid resonance frequency the wave energy is not necessarily guided along the geomagnetic field line [Hines, 1957]. However, in the lower ionosphere the lower hybrid resonance frequency, about 3 kHz at 350 km altitude, is generally below the frequencies of equatorial VLF hiss.) Further evidence that the source region for these equatorial VLF hiss events is at very low L values (less than ~ 1.2) is provided by the fact that VLF hiss is generally not observed by Injun 3 at L values greater than 1.2, except at much higher L values in the outer radiation zone.

Whereas VLF hiss at auroral zone latitudes is believed to be associated with intense fluxes of electrons ($> 10^7$ electrons/cm^2 ster sec) with energies of a few keV or less [Gurnett, 1966] no comparable fluxes are known to exist at L values less than 1.20. Although no measurements of charged particle energy fluxes in the above energy range have been made for L less than 1.20, the closest data given by Frank and Swisher [1967] places an upper limit on the energy flux at L = 1.25, B = 0.20, of 0.2 erg $(cm^2 \text{ sec ster})^{-1}$. This upper limit is to be compared to typical charge particle energy fluxes in the auroral zone of several tens of ergs $(cm^2 \text{ sec ster})^{-1}$ occurring during auroral zone VLF hiss events. The absence of intense fluxes of energetic charged particles in the region where equatorial VLF hiss is observed would seem to eliminate some of the traditional mechanisms used to explain VLF hiss, such as Cherenkov radiation [Gallet, 1959; Ellis, 1957; and Jørgensen, 1967], or cyclotron resonance interactions [Kennel and Petschek, 1966].

TABLE 1

Universal Time (1963) Day	Hr:Min:Sec	Geomagnetic Latitude	Altitude km	Local Time Hours	Longitude	Latitude	B Gauss	L	Kp
Sept 9,	02:49:18	-16.7°	242	21.7	-77.6	-32.2	0.263	1.20	3
Sept 10,	01:41:25	+7.2°	303	20.8	-73.2	-8.6	0.254	1.10	4
Sept 12,	18:45:19	-17.2°	290	20.3	23.31	-8.07	0.291	1.17	0
Sept 14,	18:36:05	-19.0°	269	19.9	20.98	-10.12	0.293	1.20	0
Sept 15,	17:33:07	-16.5°	275	19.7	33.31	-7.92	0.298	1.15	1
Sept 16,	01:17:20	-12.4°	246	20.3	-75.37	-28.3	0.250	1.15	1
Sept 17,	17:23:10	-18.4°	260	19.3	31.0	-9.6	0.300	1.17	1
Sept 20,	23:53:03	-11.5°	260	19.4	-67.6	-28.5	0.236	1.16	1
Oct. 6,	14:25:04	-30.4	313	16.1	29.7	-23.1	0.292	1.51	3
Oct. 25,	10:28:05	-11.5	307	12.6	30.0	-2.6	0.290	1.09	1

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FIGURE CAPTIONS

Figure 1	Equatorial VLF hiss event on September 20, 1963
Figure 2	Equatorial VLF hiss event on October 6, 1963.
Figure 3	Frequency-time spectrogram for the September 20 event.
Figure 4	Frequency-time spectrogram for the October 6 event.
Figure 5	Altitude and geomagnetic latitude coordinates for the equatorial VLF hiss events.
Figure 6	Geomagnetic and local time coordinates for the equatorial VLF hiss events.

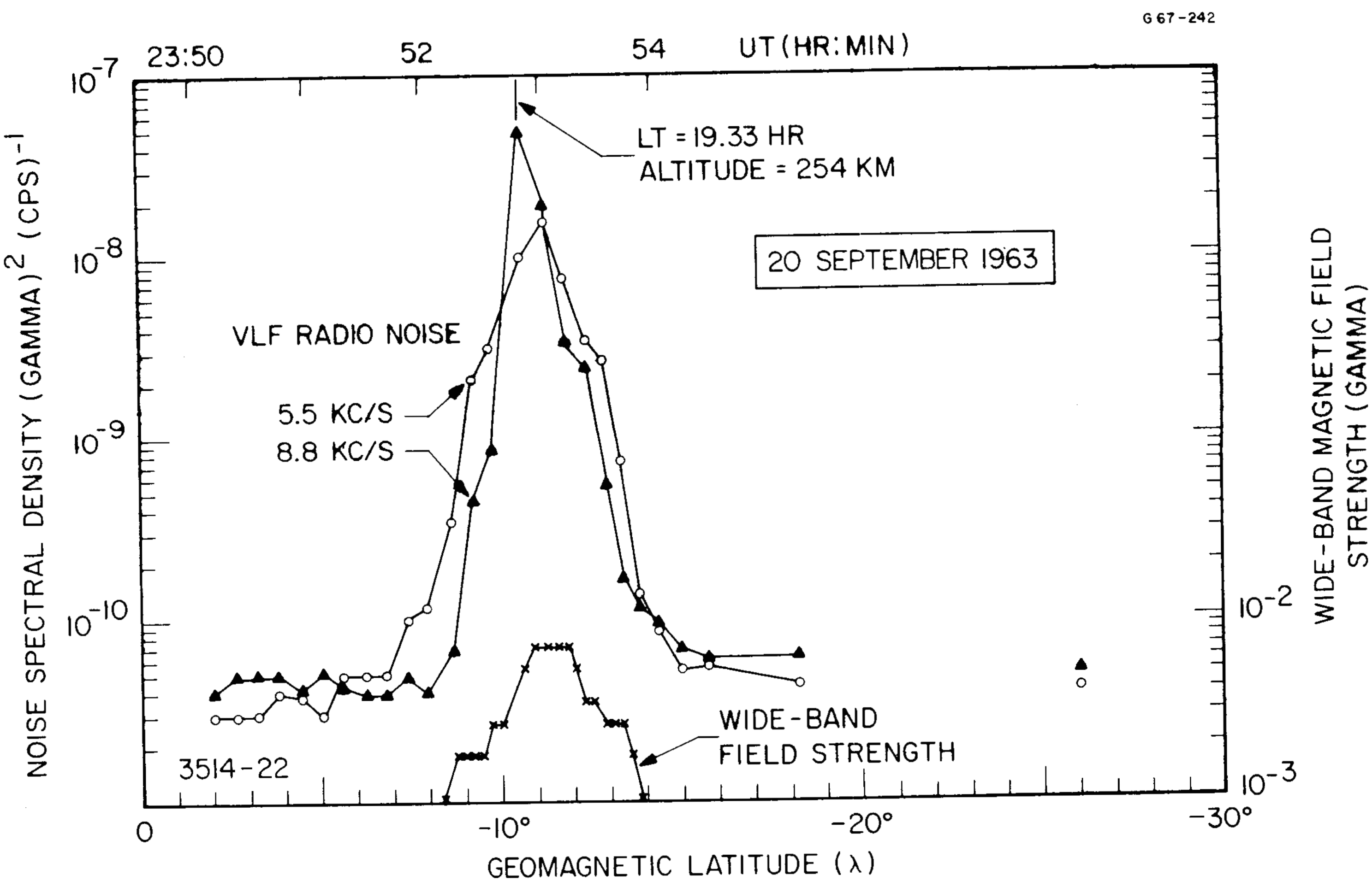

G 67-242
23:50
52
54
UT (HR: MIN)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
NOISE SPECTRAL DENSITY (GAMMA)^2 (CPS)$^{-1}$
LT = 19.33 HR
ALTITUDE = 254 KM
20 SEPTEMBER 1963
VLF RADIO NOISE
5.5 KC/S
8.8 KC/S
WIDE-BAND
FIELD STRENGTH
3514-22
0
-10°
-20°
-30°
GEOMAGNETIC LATITUDE (λ)
10^{-2}
10^{-3}
WIDE-BAND MAGNETIC FIELD
STRENGTH (GAMMA)

FIGURE 1

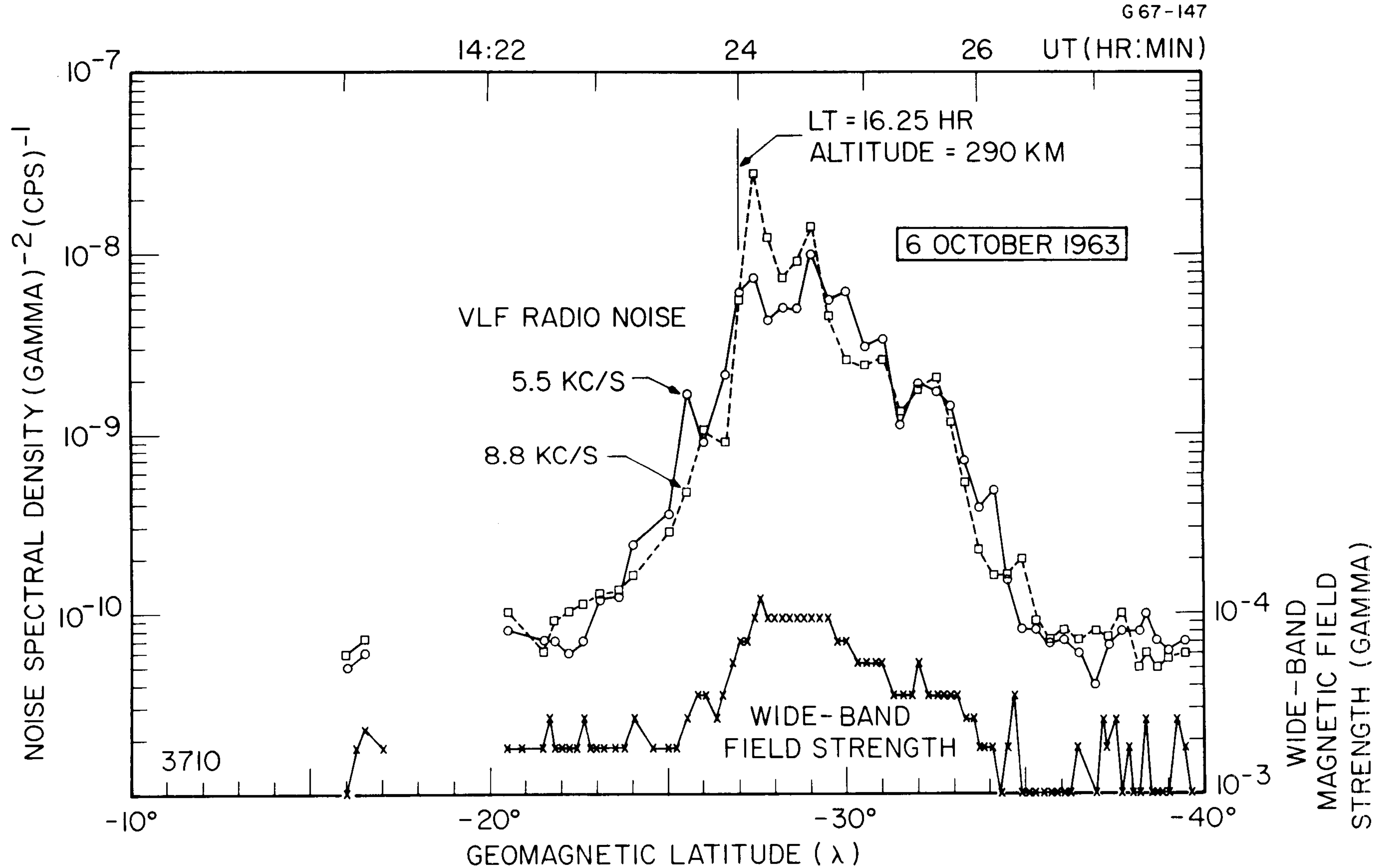
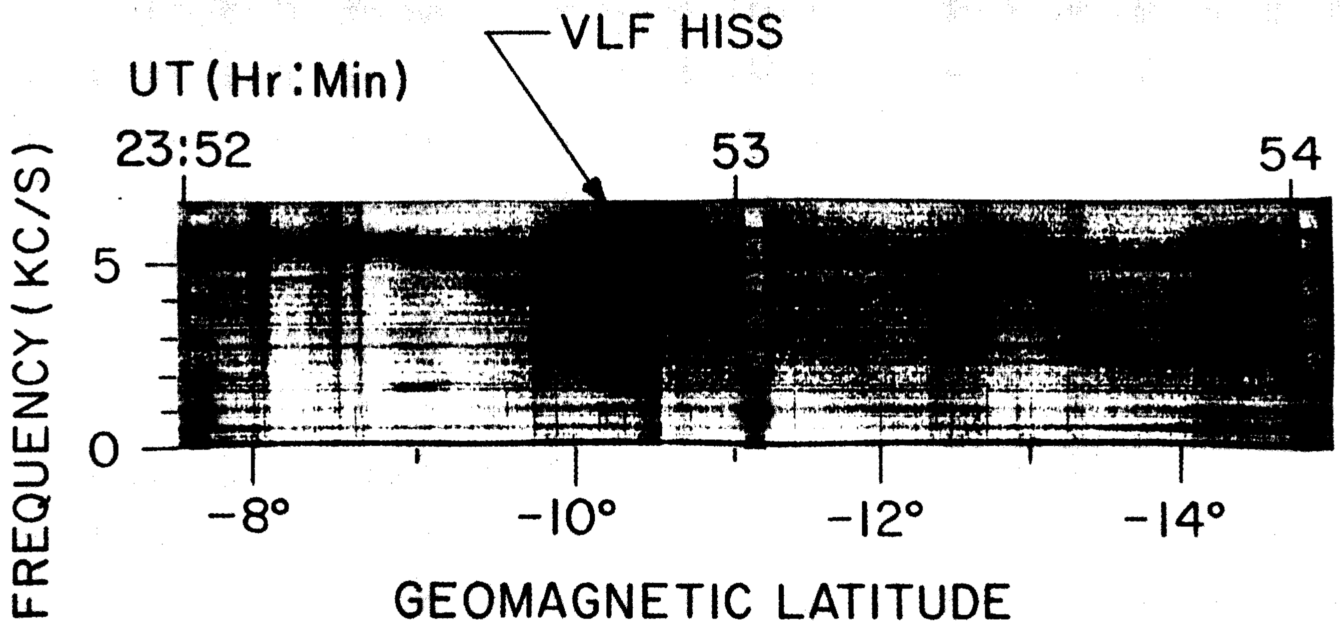

G 67-147
14:22
24
26
UT (HR:MIN)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
NOISE SPECTRAL DENSITY (GAMMA)$^{-2}$(CPS)$^{-1}$
LT = 16.25 HR
ALTITUDE = 290 KM
6 OCTOBER 1963
VLF RADIO NOISE
5.5 KC/S
8.8 KC/S
WIDE-BAND
FIELD STRENGTH
3710
10^{-4}
10^{-3}
WIDE-BAND
MAGNETIC FIELD
STRENGTH (GAMMA)
-10°
-20°
-30°
-40°
GEOMAGNETIC LATITUDE (λ)

FIGURE 2

G 67-736



3514-22

FIGURE 3

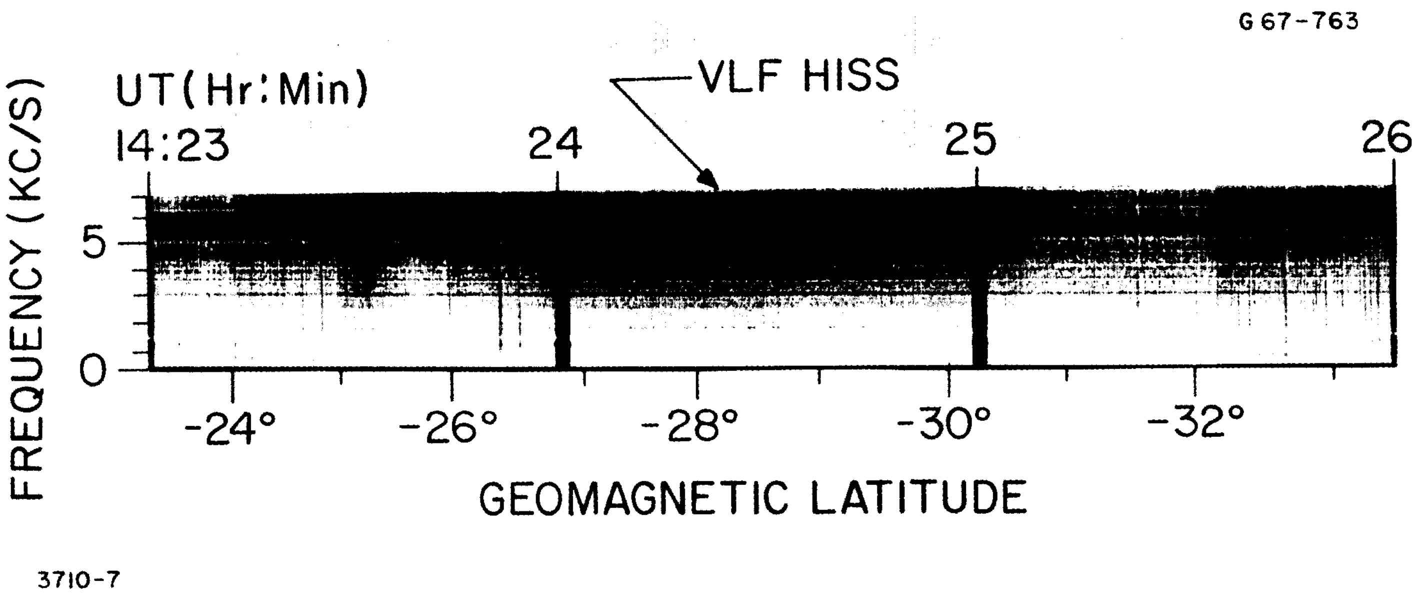

G 67-763
UT(Hr:Min)
14:23
24
25
26
VLF HISS
FREQUENCY (KC/S)
5
0
-24°
-26°
-28°
-30°
-32°
GEOMAGNETIC LATITUDE
3710-7

FIGURE 4

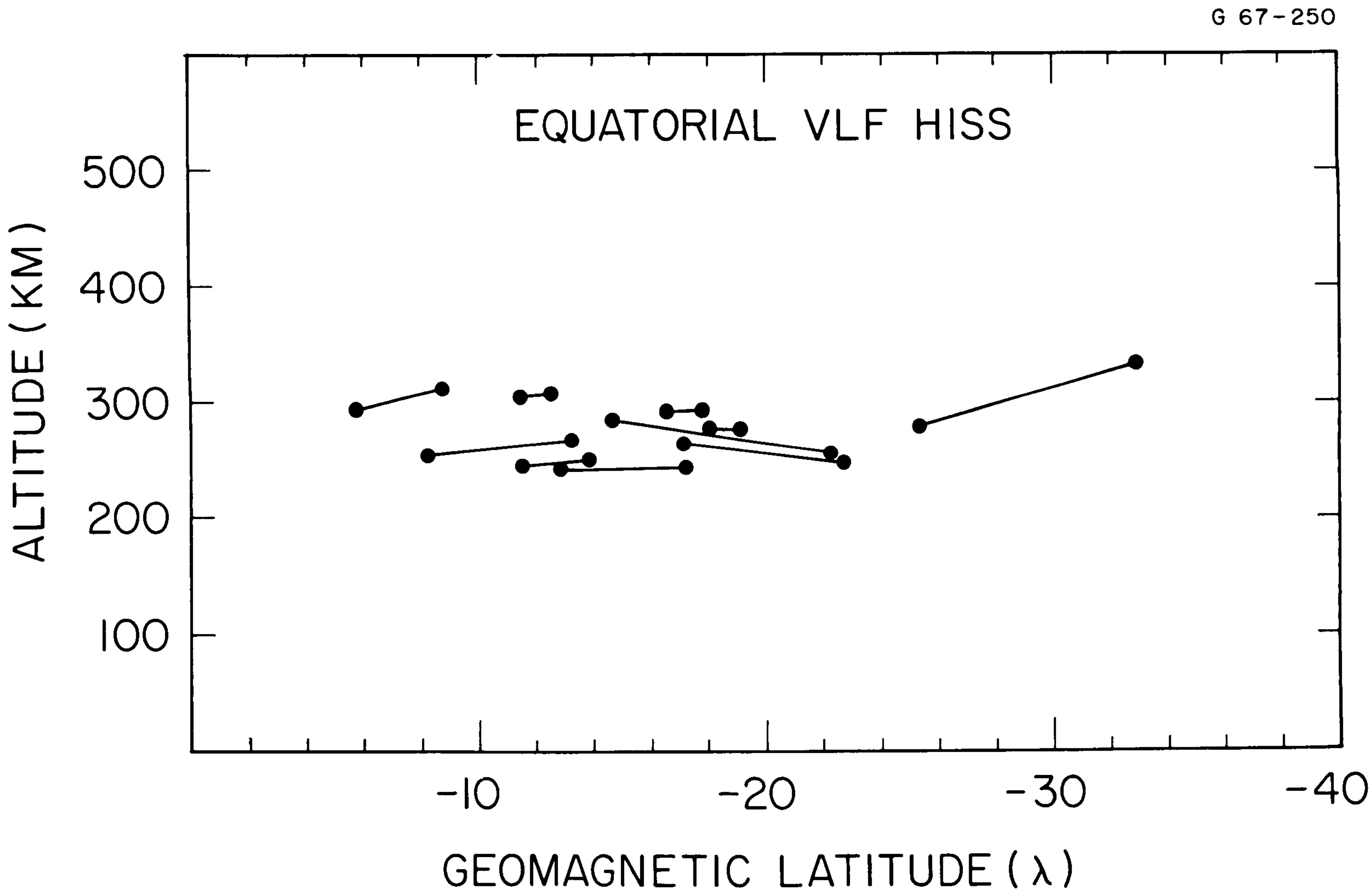

G 67-250
EQUATORIAL VLF HISS
ALTITUDE (KM)
500
400
300
200
100
-10
-20
-30
-40
GEOMAGNETIC LATITUDE (λ)

FIGURE 5

G67-252

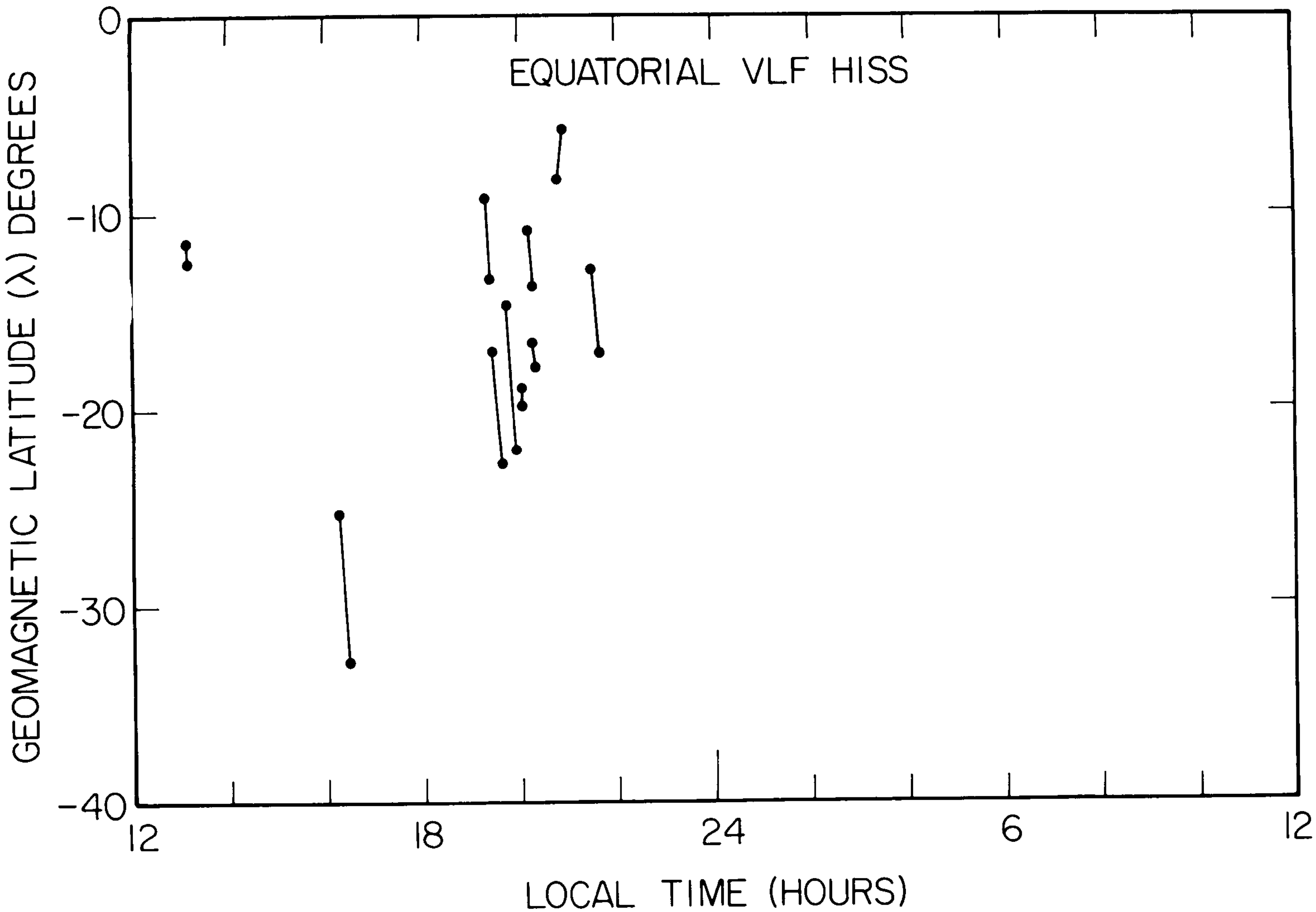


FIGURE 6

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