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SOME CHARACTERISTICS OF THE LOWER HYBRID RESONANCE NOISE BANDS OBSERVED BY THE ALOUETTE I SATELLITE

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An investigation has been made of the occurrence as a function of latitude and time of lower hybrid resonance (LHR) noise bands as recorded during 1963 and 1964 by the very-low-frequency receiver aboard the Alouette I satellite. Two different types of LHR noise are observed—polar and mid-latitude. Polar LHR noise bands, with the maximum frequency of occurrence at about 75° invariant latitude, are observed approximately one half of the time throughout the year and during both night and day. Mid-latitude LHR noise bands have a maximum frequency of occurrence at about 55° and are observed mainly during the months of June–October and primarily at night. The differences in appearance and occurrence of these two types of LHR noise suggest different excitation mechanisms.

1. INTRODUCTION

One of the new features of the signals observed by the very-low-frequency (v.l.f.) receiver of the Alouette I spacecraft (Barrington *et al.* 1963) was the frequent occurrence of noise bands with a sharp lower-frequency cutoff. Comparisons of satellite and ground-based observations have shown that this new type of v.l.f. noise has never been seen by a v.l.f. receiver on the ground (Brice and Smith 1964). As yet there is no adequate theory to explain the generation of the noise, but there is considerable evidence that its lower-frequency cutoff is the lower hybrid resonance (LHR) frequency of the ambient plasma (Brice and Smith 1965). The noise bands have accordingly been termed LHR noise bands. The present study of the occurrence pattern of these noise bands was undertaken for two reasons. First, the LHR frequency is a function of the positive-ion composition of the plasma, and hence information on its occurrence pattern is essential to proper planning of experiments designed to study composition by means of v.l.f. observations. Secondly, knowledge of the distribution in time and space of LHR noise might provide valuable clues as to its origin. While this paper is primarily concerned with the occurrence patterns of the noise, information on several of its characteristics is included.

2. OBSERVATIONS

The LHR noise recorded by the Alouette I v.l.f. receiver is variable in appearance. Its chief distinguishing characteristic is a sharp lower-frequency cutoff. At mid-latitudes this cutoff is normally constant or only slowly varying, while at high latitudes it is erratic and shows rapid fluctuations. The noise is often continuous, lasting for some minutes, but at times it appears as short bursts evidently triggered by whistlers. The bandwidth of the noise varies from one to several kilocycles/second.

Several examples of spectrograms of observed LHR noise bands are illustrated in Fig. 1. The first example, recorded at the Resolute Bay telemetry station

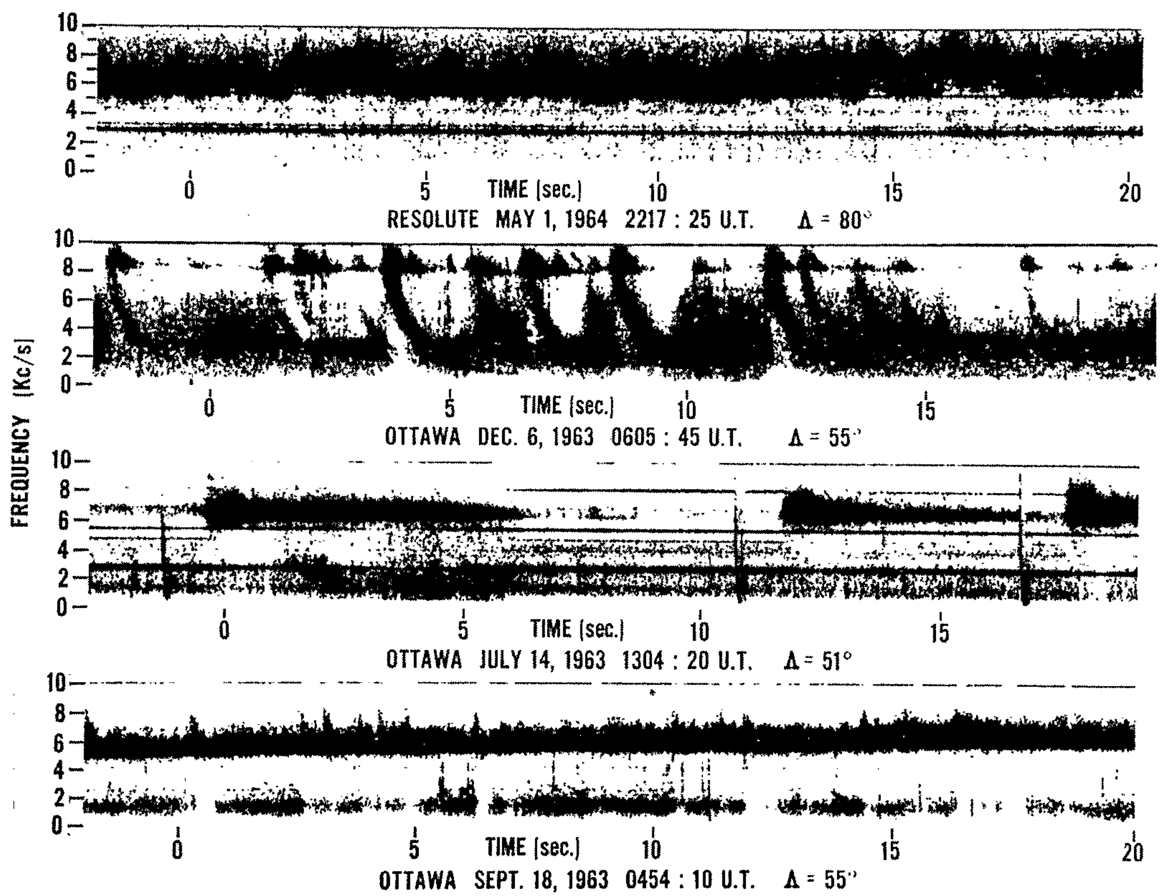

FIG. 1. Examples of lower hybrid resonance (LHR) noise bands recorded by the Alouette I v.l.f. receiver. The first was recorded at an invariant latitude of 80° N., while the last three were recorded at mid-latitudes.

while the satellite was at an invariant latitude of 80° N., is a noise band with a relatively large bandwidth and a cutoff frequency at about 5 kc/s. The fluctuations in the lower-frequency cutoff are characteristic of the LHR noise bands observed at high latitudes and are believed to be due to variations in the electron density of the medium. These fluctuations are, in fact, very useful in identifying LHR noise at high latitudes, for in this region other forms of v.l.f. noise are common.

The next three examples in Fig. 1 illustrate the form of the LHR noise bands observed at mid-latitudes. The second example was recorded at an invariant latitude of 55° N. and it can be seen that the noise between 8 and 10 kc/s has been triggered or enhanced both by short and by long fractional hop whistlers. There is also some v.l.f. noise in this example below 6 kc/s, but it does not appear to be triggered by the whistlers nor does it have a sharp lower-frequency cutoff. This noise is not LHR noise. The third example shows three triggered LHR noise bursts that persist for several seconds. Each noise burst is preceded by a fractional hop whistler, but the time delays of about one second indicate that it is the whistler mode energy reflected from the hemisphere opposite to that of the lightning discharge which is responsible for the triggering. The fourth example in Fig. 1 shows a fairly steady noise band with a lower-frequency cutoff that changes from about 5 kc/s at the beginning of the record to about 6 kc/s at the end. The latitude of the satellite changed by about 1° during this interval. There are a number of fractional hop whistlers appearing on this record, but their role in exciting the LHR noise band is uncertain.

The last three examples of Fig. 1 show the wide variation in appearance of LHR noise bands observed at mid-latitudes. They all show a fairly steady lower-frequency cutoff, but their duration varies from short bursts directly triggered by whistlers to more continuous emissions whose origin and cause is obscure. The continuous emissions account for about three quarters of the LHR noise observed at mid-latitudes. Whistlers are also observed on most of the records with steady noise bands and hence it is not possible to determine whether these bands are triggered by whistlers or not. The mid-latitude noise bands are all distinctly different in appearance from the LHR noise bands observed at northern latitudes, where the cutoff frequency is somewhat erratic and no triggering is observed. In further discussion, these two types of noise bands will be referred to as mid-latitude and polar LHR noise.

A study of occurrence of LHR noise bands was undertaken using v.l.f. data obtained from satellite passes recorded at three ground telemetry stations—Resolute Bay ($\Lambda = 84°$ N.), Ottawa ($\Lambda = 61°$ N.), and South Atlantic ($\Lambda = 43°$ S.). Each pass was of 10–15 minutes duration and, in general, included data recorded by the satellite over a latitude range of about 40° centered on the telemetry station. The data from the Ottawa and Resolute Bay stations thus provided a latitude coverage from about 40 to 90° N. invariant latitude, while the data from the South Atlantic station provided observations from the southern hemisphere over a latitude range of 25 to 65° S. invariant latitude. The study included all v.l.f. data recorded at Ottawa (250 passes) during 1963 and all v.l.f. data recorded at Resolute Bay (300 passes) and South Atlantic

(125 passes) during 1963 and 1964. These samples were considered sufficient to provide meaningful information on the time and spatial variations in occurrence of LHR noise bands.

The fraction of observing time during which LHR noise bands were recorded by the satellite receiver is shown as a function of invariant latitude in Fig. 2. The data were divided into three-month intervals to delineate possible seasonal variations in occurrence. A number of interesting features are apparent. There

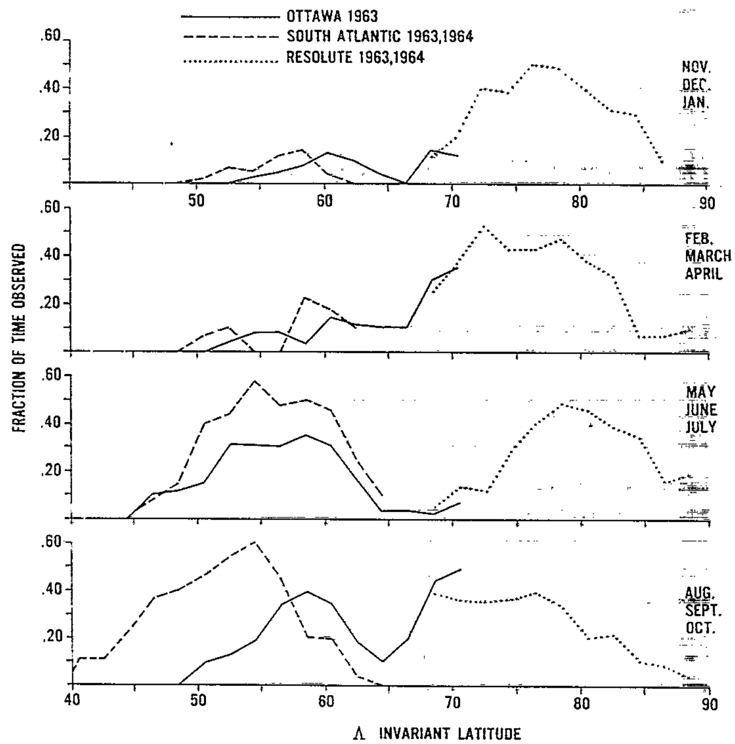

FIG. 2. Plots of the fraction of the total observing time during which LHR noise bands were observed as a function of invariant latitude. Data were taken from Ottawa, South Atlantic, and Resolute Bay Alouette I passes and are divided into 3-month periods.

are two regions where LHR noise bands occur most frequently and these regions are clearly separated in latitude. The lower-latitude region has a maximum occurrence of LHR noise at 50–60° invariant latitude, while a second maximum occurs in the region 70–80°. At these latitudes noise bands are observed as much as one half of the time. There is a marked decrease in frequency of occurrence of LHR noise bands in the vicinity of 65° invariant latitude. Inspection of the characteristics of the noise bands shows that the transition between noise bands with a fairly steady cutoff frequency and those with a rapidly changing cutoff frequency occurs at this same latitude. LHR noise bands occurring above 70° invariably have an irregular lower-cutoff frequency, while those below 60° consistently have a smooth lower-frequency cutoff.

The mid-latitude noise bands occur mainly during the months of May–October, both in the southern hemisphere and in the northern hemisphere and were seldom observed below about 45° invariant latitude. The polar LHR noise bands on the other hand are observed throughout the year, mainly in the region 70–85° invariant latitude.

The LHR noise-band occurrence pattern as a function of time of year is shown in more detail in Fig. 3. The fraction of time in which noise bands were observed during all Ottawa, South Atlantic, and Resolute Bay passes is plotted for each month of the year. Ottawa and South Atlantic data show a broad maximum for the months of June–October, while Resolute data show very little variation, with perhaps a slight minimum during these months.

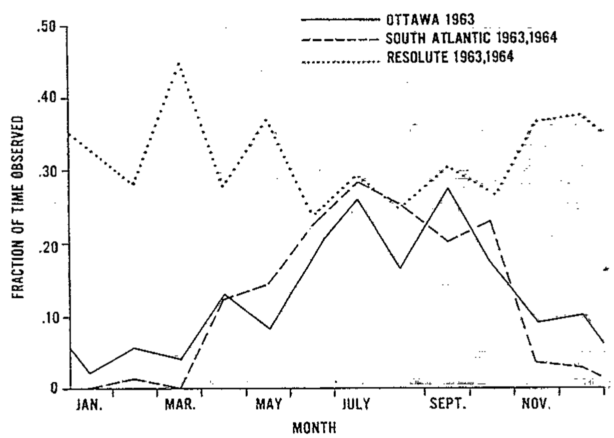

FIG. 3. Frequency of occurrence of LHR noise bands as a function of time of year, for observations made at Ottawa, Resolute Bay, and South Atlantic telemetry sites.

An attempt was made to determine the frequency of occurrence of both mid-latitude and polar LHR noise bands as a function of local time by choosing latitude regions and time intervals as long as possible without bringing in possible latitudinal and seasonal variations. The orbital parameters of the Alouette satellite are such that 3 months of recording both northbound and southbound passes are required to obtain observations at all times of day. Two suitable blocks of data were selected—all data from Ottawa passes between 54 and 63° invariant latitude from August to October, 1963, and all data from Resolute passes between 70 and 80° from October to March, 1963–64. The results are shown in Fig. 4. The fraction of the total observing time during which LHR noise bands were recorded is plotted against local time for both Ottawa and Resolute data. Both categories of noise bands show a peak in occurrence slightly before midnight and a secondary peak in the morning hours about 0600–0800 hours. The polar LHR noise bands were observed throughout the day as well, but the mid-latitude LHR noise was rarely observed from 1000 to 1800 hours.

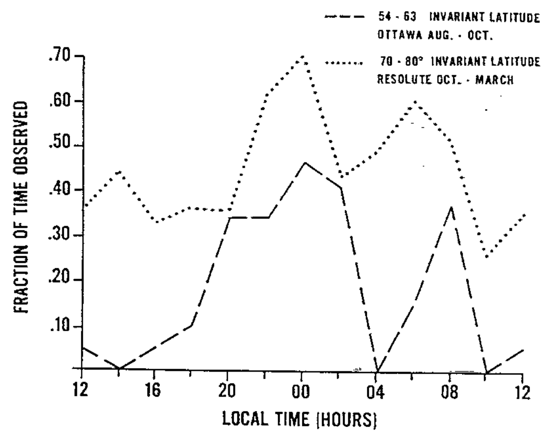

FIG. 4. Diurnal variation in the occurrence of LHR noise bands observed in the invariant latitude ranges 54–63° N. and 70–80° N.

3. DISCUSSION

It is clear from this survey of LHR noise band occurrence as a function of time and latitude that the polar and mid-latitude LHR noise bands are distinctly different, not only in appearance as illustrated in Fig. 1, but in occurrence patterns as well. These different types of noise bands occur most frequently in two well-separated latitude regions and on the few occasions when noise bands do occur throughout the entire latitude range between the regions, there is a sharp transition from one type of noise to the other at an intermediate latitude. A possible explanation of these features is that the two noise types are produced by different excitation mechanisms.

The polar LHR noise bands are seen to be present a large fraction of the time over a broad range of latitudes from about 70 to 85°. The only significant variation in time of occurrence is a diurnal one. While they do occur at all times of the day and night, they show two maxima, one somewhat before midnight and a second about 0600–0800 hours local time. These diurnal maxima are similar to those of a number of other auroral-zone geophysical phenomena (Hartz and Brice 1966) and suggest a possible relation between polar LHR noise bands, auroral activity, and particle precipitation. The noise bands are often observed simultaneously with pronounced spread F in the vicinity of the satellite (Petrie 1964) recorded by the topside sounder. Further detailed study of observations of polar LHR noise in relation to energetic particle measurements are required to establish whether energetic particles are, in fact, the source responsible for its generation.

Preliminary studies of the rapid fluctuations in the lower-frequency cutoff show that significant changes occur in less than 1/10 of a second. On the assumption that these fluctuations represent spatial rather than temporal variations within the medium, changes occurring within 1/10 of a second represent a scale size of the order of a kilometer. This suggests that the observed lower-frequency cutoff is determined by a relatively small volume of the medium.

The cutoff frequency, f_{hyb}, is related to the electron gyrofrequency, f_H, and the plasma density and composition in the following way:

$$\frac{1}{f^2_{\text{hyb}}} = \left(\frac{1}{f_H^2} + \frac{1}{f_N^2}\right) \frac{m_p}{m_e} \bar{m}_i(\text{eff}),$$

where f_N is the electron plasma frequency, m_p/m_e is the ratio of proton to electron mass and $\bar{m}_i$(eff) is the harmonic mean mass number for all the positive ions in the medium. The observed fluctuations in f_{hyb} could be due to variations in electron density and/or ion constituents, but it seems probable that the major cause is irregularities in electron density. These fluctuations in cutoff frequency may thus provide a means for studying inhomogeneities in electron density in the ionosphere at high latitudes.

The mid-latitude LHR noise bands exhibit marked latitudinal and time variations. They are observed most commonly in the region 45–60° invariant latitude and occur mainly in the months of May–October. They occur primarily during the night hours, with maxima at approximately the same times as polar LHR noise. In many cases they appear to be generated or triggered by whistlers, and it is therefore not surprising that whistlers recorded on the ground (Laaspere *et al.* 1963) and the mid-latitude LHR noise have the same general pattern of occurrence.

One possible mechanism for LHR noise-band generation (Smith *et al.* 1966) is a resonance effect of trapped whistler energy. This mechanism would permit generation of LHR noise bands over a well-defined height region only. The observations of LHR noise presented here are from a height of 1 000 km only, since Alouette I is in a circular orbit. A preliminary study of Alouette II v.l.f. data shows that LHR noise bands are observed over the full range of heights of the Alouette II orbit, from 500 km to 3 000 km. It is not possible to reconcile these observations with the trapped whistler energy source suggested by Smith (Smith *et al.* 1966).

4. SUMMARY

This study of occurrence and characteristics of LHR noise bands observed by the Alouette I v.l.f. receiver has shown that there are two types of LHR noise which can be aptly designated as polar and mid-latitude. The polar LHR noise is observed throughout the year both day and night and is present about one half of the time at high latitudes. There is as yet no theory that adequately explains its origin, but it appears to be related to particle precipitation. The mid-latitude LHR noise is observed primarily at night and mainly during the months of June–October. On many occasions there is a clear relationship between whistlers and LHR noise. It may well be that the whistler mode energy radiated from lightning discharges is the sole source of the mid-latitude noise bands.

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