Proc. NIPR Symp. Upper Atmos. Phys., 5, 70–76, 1992

FURTHER EXPERIMENTAL STUDY OF THE ROLE OF WAVELETS IN THE HISS BAND FOR TRIGGERING CHORUS EMISSIONS

Katsumi HATTORI[1], Masashi HAYAKAWA[1]*, Dominique LAGOUTTE[2], Michel PARROT[2] and François LEFEUVRE[2]

[1] *Solar-Terrestrial Environmental Laboratory, Nagoya University, 13, Honohara 3-chome, Toyokawa 442*
[2] *Laboratoire de Physique et Chimie de l'Environnement, CNRS, Orleans Cedex 2, France*

Abstract: The results of detailed spectral analyses and direction finding for ELF data containing simultaneous hiss and chorus have been reported on the basis of the data observed onboard GEOS1 satellite in the outer magnetosphere at a high geomagnetic latitude ($\Lambda \simeq 25°$). A combination of the present results with those from our previous equatorial studies, has yielded the following findings: (1) Each chorus element has a tendency to be originated from the hiss band and is asymptotic to the hiss band. (2) The intensity and occurrence of chorus are closely correlated with the intensity of the underlying hiss. (3) The hiss band exhibits some structures or wavelets (*i.e.* monochromatic wave components with significant duration), and we notice the existence of the causative wavelet at the foot of each chorus element. (4) There is a tendency that the intensity of wavelet increases with decreasing its duration. Furthermore, when we expect triggering chorus from a wavelet near the upper edge of the hiss band, the duration of the wavelet increases with decreasing its intenisty. (5) Very similar ϕ (azimuthal angle) values are noticed for both the hiss and chorus, suggesting that both phenomena come from the same source region. These observational facts might lead us to conclude that a wavelet existing near the upper edge of the hiss band is able to generate a chorus emission through coherent wave-particle interaction in the outer magnetosphere as in the case of active VLF wave injection experiments.

1. Introduction

It is known that there are two different types of magnetospheric VLF/ELF emissions; (1) unstructured hiss and (2) structured and discrete emissions (*e.g.*, HELLIWELL, 1965; SAZHIN, 1982; HAYAKAWA *et al.*, 1984, 1986a–c, 1990). However, the fundamental problems including whether these two types of emissions are essentially different or not and the link between the two, are still unsolved and they require further investigation. The generation mechanism of spontaneous chorus emissions has been studied experimentally by BURTON and HOLZER (1974), GOLDSTEIN and TSURUTANI (1984) and HAYAKAWA *et al.* (1984), and theoretically by NUNN (1974), BESPALOV and TRAKHTENGERTS (1974) and CURTIS (1978). These studies have indicated that chorus is generated in terms of the Cyclotron

* Present address: The University of Electro-Communications, 1–5–1 Chofugaoka, Chofu 182

instability by substorm-associated energetic electrons. In order to interpret banded chorus, NUNN (1974, 1986) has made a computational study of nonlinear resonant particle trajectories in the wave fields consisting of an array of closely spaced frequencies and wavenumbers, and he found that most of the energy goes into the mode at one edge of the array and the nonlinear resonant particle excitation of broad band signal causes spectral structuring to develop. His results might be relevant to the discussion of the present paper. Then, being closely associated with the generation of spontaneous chorus, there have been proposed two candidates as the stimulus to trigger a chorus which seem to contradict with each other. The first one is hiss which has so far been considered to be very incoherent and turbulent, because the ground and satellite VLF/ELF measurements have indicated that chorus is often accompanied by a background of hiss (BURTIS and HELLIWELL, 1976; CORNILLEAU-WEHRLIN *et al.*, 1978; KOONS, 1981). The second possibility is power line harmonics radiation (LUETTE *et al.*, 1977, 1979) which is monochromatic and coherent in nature. In order to investigate whether these two hypotheses are contradictory to each other, HATTORI *et al.* (1989, 1991a) have carried out extensive study for VLF emission data indicating both chorus and hiss observed on GEOS1 satellite with sophisticated signal analyses and direction finding, and have shown that there exist wavelets which are monochromatic with sufficient duration even in the hiss band, and such wavelets are responsible for triggering a chorus through a coherent wave-particle interaction just like the second possibility of the power line harmonic radiation. In this paper we will present further evidence of triggering chorus emissions from the wavelets in the hiss band on the basis of the GEOS1 ELF observation in the off-equatorial region.

2. Review of Our Previous Observation

HATTORI *et al.* (1991a) carried out some detailed analyses (including the fine structure analysis and direction finding) for VLF/ELF waveform data observed on GEOS1 satellite. They dealt with two events; one is on 21 July 1977 (near equatorial observation at the geomagnetic latitude of 6.8°–8.5°) and the other, 2 December 1977 at a higher geomagnetic latitude of 24°–23°. Important observational findings were summarized in HATTORI *et al.* (1991a), and we ask the readers to refer to their paper.

3. Further Evidence of Triggering Chorus from the Hiss Band

In order to obtain further evidence of the important implications summarized in HATTORI *et al.* (1991a), we have also carried out similar kinds of analyses for other events. In this paper we deal with the ELF data obtained by GEOS1 satellite in the outer magnetosphere at a high geomagnetic latitude (20°). In the papers of HATTORI *et al.* (1989, 1991a), the hiss band was in the frequency ragne of 0.5 to 1.0 kHz, but the present hiss event lies at a frequency lower than our previous events; the frequency range for this ELF event is from 200 Hz to 500 Hz. We have analysed two events; one on 20 June 1977, U.T. ≃ 17:00 and another, 19

November 1977, U.T. ≃ 6 h. For the first event we have observed only the hiss band, while for the second event on 19 November 1977 we have found that chorus seems to be triggered from the hiss band. Figure 1 shows the spectrogram of the hiss event and Fig. 2 illustrates an example of the fine structure analysis for the magnetic field observation of the hiss band with the resolution of 23 Hz in frequency and 43 ms in time. This figure indicates apparently the existence of many structures or wavelets (monochromatic wave components) within the hiss band, which has so far been considered to be quite incoherent and turbulent.

An example of the spectrogram on 19 November 1977 is illustrated in Fig. 3, which shows that both hiss and chorus are present simultaneously. The high resolution spectral analysis is carried out for some parts of Fig. 3 and the corresponding contour maps are shown in Fig. 4. We see from this contour map that a chorus

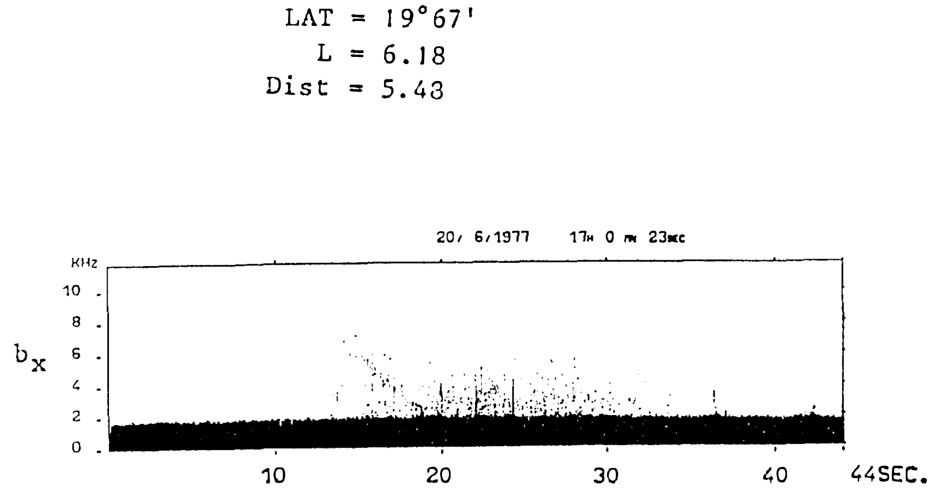

Fig. 1. The spectrogram of hiss observed onboard GEOS1 satellite in the outer magnetosphere. (after LEFEUVRE, *F. et al. (1981): Fig. 3. J. Geophys. Res.,* ***86****, 2359–2375.)*

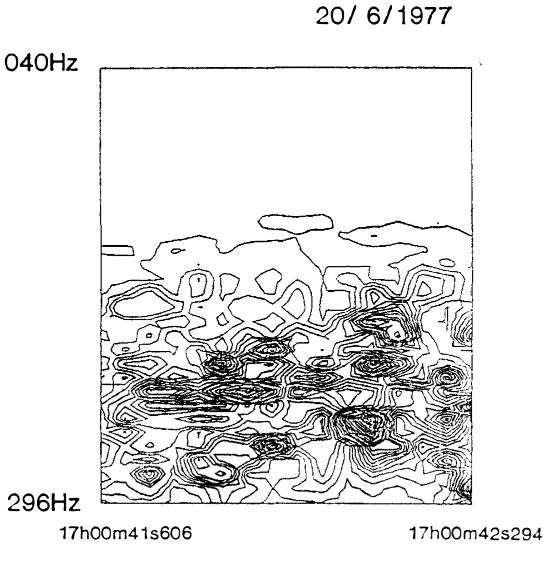

Fig. 2. *The intensity contour map of a part of Fig. 1.*

element is probably triggered by a wavelet existing just at the foot of the corresponding chorus. Although we show only one example, there are several other examples which indicate similar phenomena. Hence, the example presented in this paper seems to be rather universal though the frequency range is considerably lower than the previous ones (HATTORI *et al.*, 1989, 1991a). Figure 5 is the summary plot on the relationship between the magnetic field intensity ($\sqrt{B_w}$) and the duration (T) of wavelets in the hiss band including the previous results of the VLF event (HATTORI *et al.*, 1991a). This figure shows the observed intensity versus duration of the wavelets existing in the hiss band, and white circles are for wavelets in the hiss band from the previous VLF event. The average duration of wavelets in the hiss band on 21 July 1977 (VLF event) ranges from 50 to 150 ms, and the average value is 70 ms.

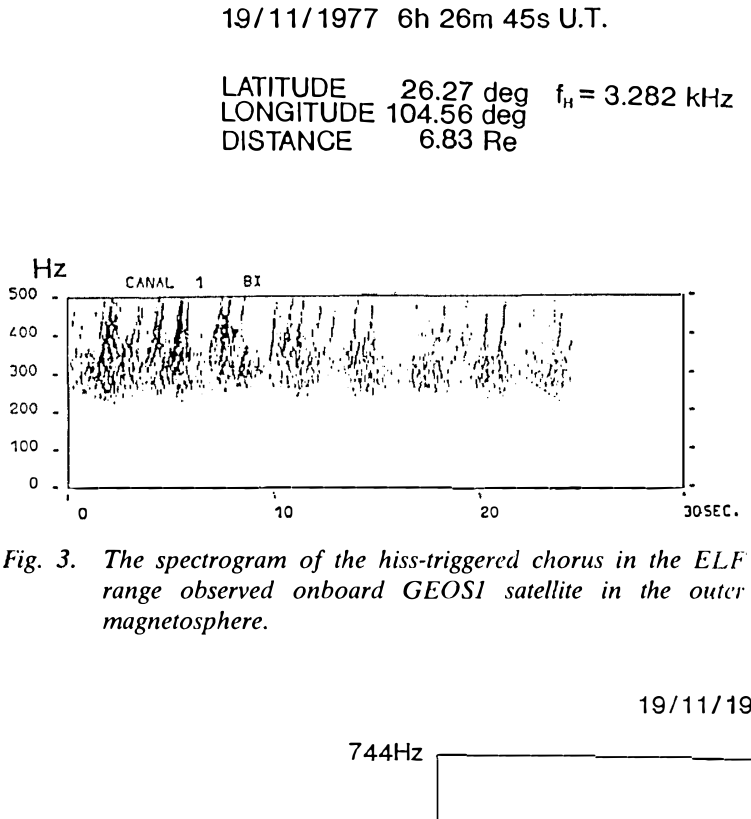

Fig. 3. The spectrogram of the hiss-triggered chorus in the ELF range observed onboard GEOS1 satellite in the outer magnetosphere.

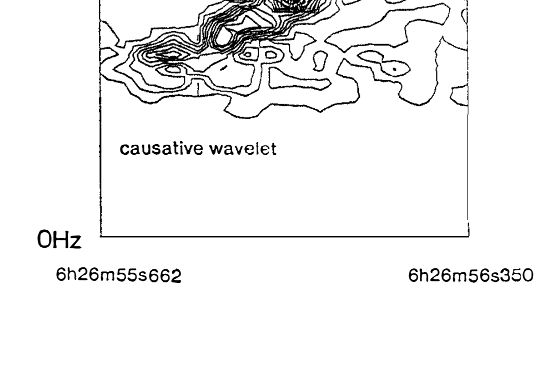

Fig. 4. An example of contour map of fine structure analyses of the ELF events. We can identify the causative wavelet in the hiss band and the corresponding chorus element.

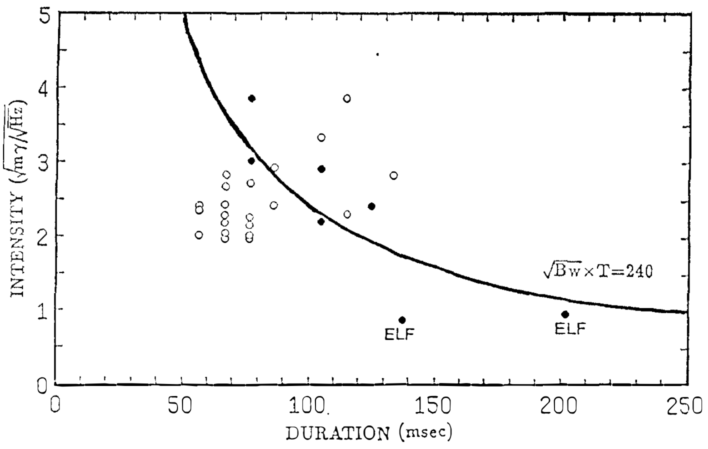

Fig. 5. The relationship between the intensity ($\sqrt{B_w}$) of wavelets and their duration (T). Full circles are the original wavelets which have triggered chorus emissions, while hole circles indicate wavelets which have not triggered chorus emissions, including wavelets from the previous VLF analysis. Two wavelets marked by ELF are also shown in this figure. The thick full line in this diagram indicates the threshold for triggering chorus.

Among these plots, those of full circles indicate that the wavelet is found to have triggered a chorus. In Fig. 5, we have also plotted two examples (including the one in Fig. 4) of wavelets which have obviously triggered or excited chorus emissions. They are plotted in Fig. 5 with full circles marked by ELF. As seen from Fig. 5, the duration of wavelets is considerably longer than in the previous event on 21 July (Fig. 5), but the intensity of wavelets is considerably smaller than in the previous event on 21 July 1977.

Figure 5 strongly suggests that only the wavelet with a sufficient amount of the product of intensity and duration is able to trigger a chorus. At first sight, there is a tendency that the intensity of wavelet increases with decreasing its duration. But the product of the intensity of the wavelet times its duration exceeds a threshold value, and then it is expected that a chorus emission is triggered by such a wavelet near the upper edge of the hiss band. The curve in Fig. 5 is the best fitted hyperbola for the full circles indicating the events on 21 July 1977 and ELF events. When this principle is applied to Fig. 5, there are some wavelets which seem to be able to trigger a chorus emission. But they are found not to be near the upper edge of hiss band, although they are within the hiss band.

Also, we have performed direction finding measurement for the ELF event as well as for the VLF events. The results show again that the same ϕ values are confirmed for both hiss and chorus, and this is again indicative that both hiss and chorus come from the same source region.

4. Discussion

We have presented further data indicating the possibility that a chorus is generated by a wavelet (monochromatic wave component) near the upper edge of the hiss band. First of all, the magnetospheric ELF hiss in the frequency range (200–500 Hz) lower than the previous events (HATTORI *et al.*, 1989, 1991a), is found again to include many structures or monochromatic wave components (we call them "wavelets") within the hiss band, which seems to be a universal phenomenon for the hiss and leads a further support to our previous finding. Extensive spectral analyses such as done in this paper, have reconfirmed that a chorus element is highly likely to be originated from a causative wavelet existing just at the foot of the chorus element. Also, the chorus element is asymptotic to the hiss band; that is, the initial df/dt of the chorus is nearly zero. The direction finding for the ELF hiss-triggered chorus event in this paper has also yielded that the same ϕ (azimuthal angle) values are obtained for both hiss and chorus, suggesting that both phenomena come from the same region. From these considerations, it may be concluded that a chorus is triggered from a wavelet existing near the upper edge of the hiss band through a coherent wave-particle interaction just like in the case of active VLF injection experiment (HELLIWELL *et al.*, 1986). Another important new finding in this paper is found from Fig. 5, which indicates the presence of a threshold of generating a chorus from a wavelet in the hiss band in the coordinates of the intensity and duration of wavelets. The curve best fitted to all the full circles which have triggered a chorus, is a hyperbola function given by the relationship $\sqrt{B_w}=240/T$, where B_w is the magnetic field intensity in $m\gamma/\sqrt{H_z}$ and T is the duration in msec of the wavelet in the hiss band. The wavelets with the $\sqrt{B_w}$ value above this experimental threshold are able to excite a chorus, and this kind of empirical formula has been derived for the first time. The two ELF points in Fig. 5 are observed at high geomagnetic latitude and as the equatorial intensity must be increased considerably so that these two points should be located at a little higher value than the plotted values because other full circle dots are derived from the near-equatorial observation. The mechanism of triggering a chorus from the wavelet in the hiss band, is already proposed and discussed in HATTORI *et al.* (1989, 1991a).

The important observational results are presented in the present paper, and further detailed discussion on the mechanism of hiss-triggered chorus will be published elsewhere (HATTORI *et al.*, 1991b).

References

BESPALOV, P. A. and TRAKHTENGERTS, V. Y. (1974): Nonstationary particle distribution in the magnetosphere and generation of periodic emissions in the VLF and SPP range. Geomag. Aeron., **14**, 266–271 (English translation).

BURTIS, W. J. and HELLIWELL, R. A. (1976): Magnetospheric chorus; Occurrence patterns and normalized frequency. Planet. Space Sci., **24**, 1007–1024.

BURTON, R. K. and HOLZER, R. E. (1974): The origin and propagation of chorus in the outer magnetospehre. J. Geophys. Res., **79**, 1014–1023.

CORNILLEAU-WEHRLIN, N., GENDRIN, R., LEFEUVRE, F., PARROT, M., GRARD, R., JONES, D., BAHNSEN, A., UNGSTRUP, E. and GIBBONS, W. G. (1978): VLF waves observed onboard GEOS-1. Space Sci. Rev., **22**, 371–382.

CURTIS, S. A. (1978): A theory for chorus generation by energetic electrons during substorm. J. Geophys. Res., **83**, 3841–3848.

GOLDSTEIN, B. E. and TSURUTANI, B. T. (1984): Wave normal direction of chorus near the equatorial source region. J. Geophys. Res., **89**, 2789–2805.

HATTORI, K., HAYAKAWA, M., SHIMAKURA, S., PARROT, M. and LEFEUVRE, F. (1989): GEOS-1 observation of hiss-triggered chorus emissions in the outer magnetosphere and their generation model. Proc. Natl. Inst. Polar Res. Symp. Upper Atmos. Phys., **2**, 84–95.

HATTORI, K., HAYAKAWA, M., LAGOUTTE, D., PARROT, M. and LEFEUVRE, F. (1991a): An experimental study of the role of hiss in generation of chorus in the outer magnetosphere, as based on detailed spectral analyses and direction finding measurements onboard GEOS-1. Natl Inst. Polar Res. Symp. Upper Atmos. Phys., **4**, 20–41.

HATTORI, K., HAYAKAWA, M., LAGOUTTE, D., PARROT, M. and LEFEUVRE, F. (1991b): Further evidence of triggering chorus emissions from wavelets in the hiss band. Planet. Space Sci., **39**, 1465–1472.

HAYAKAWA, M., YAMANAKA, Y., PARROT, M. and LEFEUVRE, F. (1984): The wave normals of magnetospheric chorus emissions observed onboard GEOS-2. J. Geophys. Res., **89**, 2811–2821.

HAYAKAWA, M., OHMI, N., PARROT, M. and LEFEUVRE, F. (1986a): Direction finding of ELF hiss in a detached plasma region of the magnetosphere. J. Geophys. Res., **91**, 135–141.

HAYAKAWA, M., TANAKA, Y., SAZHIN, S. S., OKADA, T. and KURITA, K. (1986b): Characteristics of dawnside mid-latitude VLF emissions associated with substorms as deduced from the two-stationed direction finding measurement. Planet. Space Sci., **34**, 225–243.

HAYAKAWA, M., TANAKA, Y., SHIMAKURA, S. and IIZUKA, A. (1986c): Statistical characteristics of mid-latitude VLF emissions (unstructured and structure); The local time dependence and the association with geomagnetic disturbances. Planet. Space Sci., **34**, 1361–1372.

HAYAKAWA, M., HATTORI, K., SHIMAKURA, S., PARROT, M. and LEFEUVRE, F. (1990): Direction finding of chorus emissions in the outer magnetosphere and their generation and propagation. Planet. Space Sci., **38**, 135–143.

HELLIWELL, R. A. (1965): Whistlers and Related Ionospheric Phenomena, Stanford, CA., Stanford Univ. Press, 248.

HELLIWELL, R. A., CARPENTER, D. L., INAN, U. S. and KATSUFRAKIS, J. P. (1986): Generation of band-limited VLF noise using the Siple transmitter; A model for magnetospheric hiss. J. Geophys. Res., **91**, 4381–4392.

KOONS, H. C. (1981): The role of hiss in magnetospheric chorus emissions. J. Geophys. Res., **86**, 6745–6754.

LUETTE, J. P., PARK, C. G. and HELLIWELL, R. A. (1977): Longitudinal variations of very low frequency chorus activity in the magnetosphere; Evidence of excitation by electrical power transmission lines. Geophys. Res. Lett., **4**, 275–278.

LUETTE, J. P., PARK, C. G. and HELLIWELL, R. A. (1979): The control of the magnetosphere by power line radiation. J. Geophys. Res., **84**, 2657–2660.

NUNN, D. (1974): A theoretical investigation of banded chorus. J. Plasma Phys., **11**, 189–212.

NUNN, D. (1986): A nonlinear theory of sideband stability in ducted whistler mode waves. Planet. Space Sci., **34**, 429–451.

SAZHIN, S. S. (1982): Natural radio emissions in the earth's magnetosphere, Nauka, Moscow, 77.

(Received May 27, 1991; Revised manuscript received July 8, 1991)