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CONJUGACY OF CNA PULSATIONS AND THEIR SOURCE MOVEMENT IN THE AURORAL ZONES

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Abstract: A statistical character of seasonal variation for the conjugacy of quasi periodic cosmic radio noise absorption (called CNA pulsation) is studied with the chart paper measured at Syowa Station in Antarctica and its magnetically conjugate Husafell Station in Iceland.

On the basis of the analyses of relative phase difference of the CNA pulsation for two cases among three stations in Iceland, the direction of source movement is also studied. The results indicate that the sources of CNA pulsation of Pc 3 and Pc 5 range in the prenoon sector moved generally from north (or high latitude) to south (or low latitude) direction, and from east to west direction, while the source of CNA pulsation at Pc 5 range in the morning sector moved primarily from south to north direction, and from east to west direction.

1. Introduction

A systematic and continuous observation system for cosmic radio noise absorption (CNA) has been installed at Syowa (SY) Station in Antarctica and Husafell (HU), Isafjördur (IS), and Tjörnes (TJ) in Iceland. The Syowa-Iceland pair stations (at $L\simeq 6$) are located in the auroral zone, and the two sites form the best pair stations at present for observing the conjugate CNA by a fast-response 30 MHz riometer.

Cosmic radio noise data sometimes show quasi-periodic variations, called CNA pulsation. The CNA pulsations sometimes accompany magnetic pulsations (ROSENBERG *et al.*, 1979; OLSON *et al.*, 1980; HIGUCHI *et al.*, 1988), pulsating auroras (HOLT and OMHOLT, 1962; ARNOLDY *et al.*, 1982), and quasi-periodic (QP) VLF emissions (SATO *et al.*, 1985).

The diurnal variation of CNA pulsation phenomena at Syowa Station has been reported by SATO *et al.* (1985). However the seasonal variation for the conjugacy of CNA pulsations is still not well understood, we examined the seasonal dependence of the CNA pulsations statistically with the correlation-chart paper for four months at the conjugate pair stations, Syowa and Husafell.

The observation of CNA provides important information for investigating auroral particle precipitation in the daytime. CNA pulsations are caused by an extra ionization in the lower ionosphere produced by energetic particle precipitation. A source movement of CNA pulsations must be connected to a movement of high energy particle precipitation, and this will offer important information on particle acceleration process.

OLSON and ROSTOKER (1978) estimated that the apparent phase velocity of Pc 4–5 geomagnetic pulsations will be approximately 14 km/s everywhere on the ground. OLSON *et al.* (1980) showed that CNA pulsations propagated in the same direction as Pc 5 geomagnetic pulsations; the propagation was westward in the morning and eastward in the afternoon. KIKUCHI *et al.* (1988) observed a new type of CNA pulsations without accompanying magnetic pulsations by a scanning beam riometer with a spatial resolution of 10 km, at Syowa Station, and they reported the CNA pulsation with a period of 1 to 10 min propagate eastward at a speed of 200 m/s to 3 km/s in the morning hours (5–10 MLT).

However, the source movement of CNA pulsations accompanying magnetic pulsations is poorly understood at present, especially along a north-south direction. Hence we analyzed two cases of the relative phase difference of CNA pulsations at HU-IS, HU-TJ, and IS-TJ when the relative coherency values are larger than 0.5, and we could estimate the direction of source movement of CNA pulsations over Iceland. In this calculation process, we adopted a maximum relative time difference longer than a sampling time to exclude a giant source which precipitated all over Iceland simultaneously.

Further, in order to reaffirm a previous result reported by HIGUCHI *et al.* (1988) we investigated the conjugacy of CNA pulsations ($0<f<50$ mHz) between Syowa Station and the three stations in Iceland.

The power spectrum, relative phase and coherency analyses in the present study were carried out using the conversational spectral analysis progarm (CSAP) system developed by IWABUCHI *et al.* (1978).

2. Seasonal Variations for Conjugacy of CNA Pulsations

So far few reports have been published on seasonal variations for the conjugacy of CNA pulsations, because there have been few conjugate pair stations which can observe CNA pulsations in the auroral zone, and the statistical examination was difficult for the conjugacy of CNA pulsations because of the lack of an acceptable data form for computer.

Table 1. Seasonal variations in the conjugacy of CNA pulsations between Syowa and Husafell from September to December 1983.

1983	Total event number	Conjugacy				Appearance			
		Good		Bad		Syowa		Husafell	
		Number	%	Number	%	Number	%	Number	%
9/13～30	26	5	19.2	7	26.9	7	26.9	0	0
10/ 1～31	50	20	40.0	6	12.0	3	6.0	4	8.0
11/ 1～30	86	22	25.5	47	54.6	14	16.3	17	19.8
12/ 1～13	16	4	25.0	9	56.2	1	6.3	7	43.8

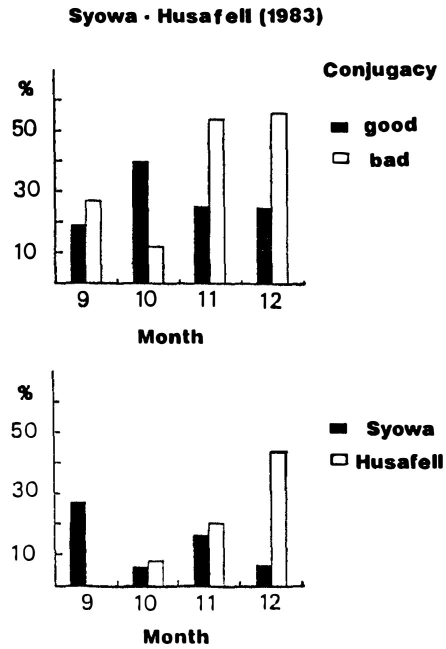

Fig. 1. CNA pulsations observed at Syowa and Husafell are classified into good and bad conjugacy groups (upper panel) and the bad conjugacy groups are further subdivided according to the station of dominant appearance (bottom panel), using the data from September to December 1983.

We picked up the occurrences of CNA pulsations at Syowa and Husafell conjugate pair stations (except for a substorm type) using the correlation-chart paper from 13 September to 6 December 1983. Comparing the shape and amplitude of the CNA pulsations, all the selected CNA pulsations are classified into three groups, *i.e.*, good and bad conjugacy groups and the intermediate one. The bad conjugacy events were further subdivided into the cases of clear CNA at Syowa, clear CNA at Husafell, and the remainning case (see Table 1).

The occurrence numbers of these classified CNA pulsation events are displayed graphically in Fig. 1, which shows that the conjugacy of CNA pulsations is best in October, *i.e.*, in equinox and seems to fall to worst conjugacy in December, *i.e.*, in winter in the northern hemisphere. This suggests that CNA pulsations do not take place always in the ionospheric region of an enhanced photoionization produced by the sunlight. So it can be interpreted that the conjugacy of CNA pulsations depends basically on the seasonal variation of the plasma density in the lower polar ionosphere.

3. Conjugacy between Syowa and Three Stations in Iceland

To show what kind of data of CNA pulsations were analyzed at first, some examples of CNA pulsations at Syowa Station and Husafell Station are shown in Fig. 2 along with the H components of magnetic variation picked from the correlation chart records. This figure shows the intensity of CNA at 30 MHz, and the direction of increasing absorption is downward. We notice here long-period CNA pulsation with the period of 3–8 min superimposing on short-period (30–100 s) pulsation.

In order to see an outline of the mutual phase relationship, an example of CNA pulsation chart at Syowa (SY), Husafell (HU), Isafjördur (IS), and Tjörnes (TJ) is shown in Fig. 3, where the time axis and amplitude are enlarged. It is seen from this figure that the mutual phase of CNA pulsations at four stations is approximately in

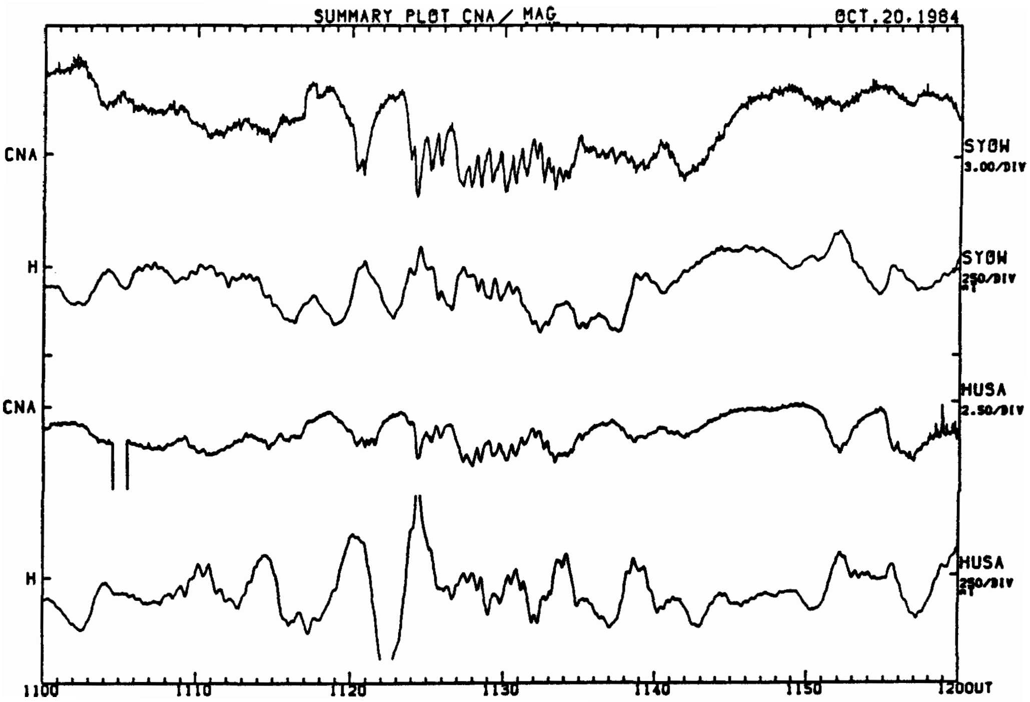

Fig. 2. Intensity of cosmic noise absorption (CNA) at 30 MHz and the H components of magnetic variation in the time interval of 1100–1200 UT on October 25, 1983.

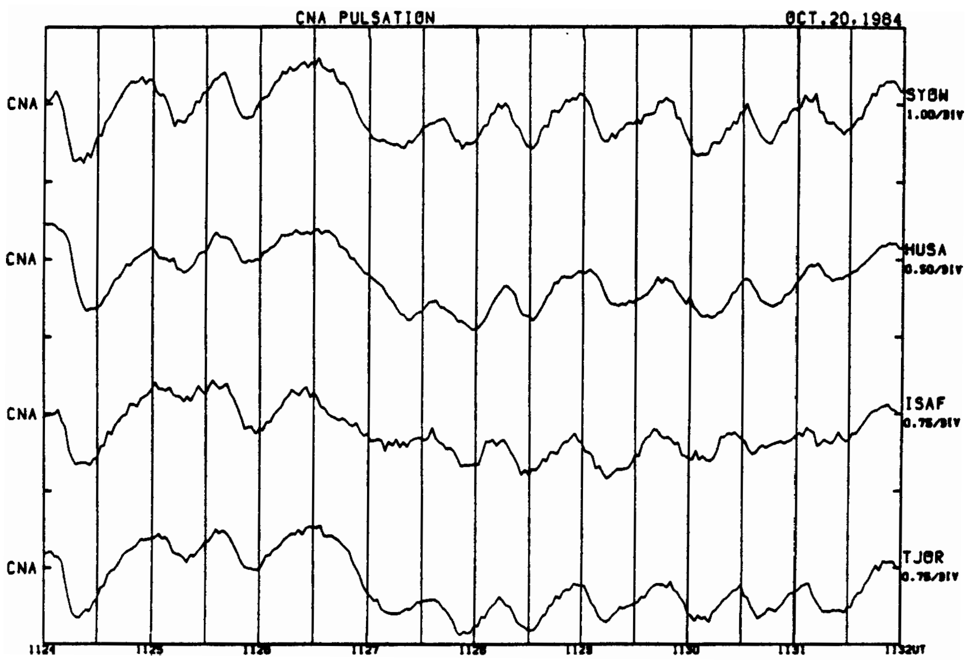

Fig. 3. An example of CNA pulsation chart at SY, HU, TJ, and IS where the time axis and amplitude are enlarged to inspect the mutual phase relation.

phase with one another as a whole at Pc 3 and Pc 5 range. The phase at HU, however, is apt to lag behind that of TJ and IS at first time and become in phase with TJ and IS at later time in the Pc 3 range.

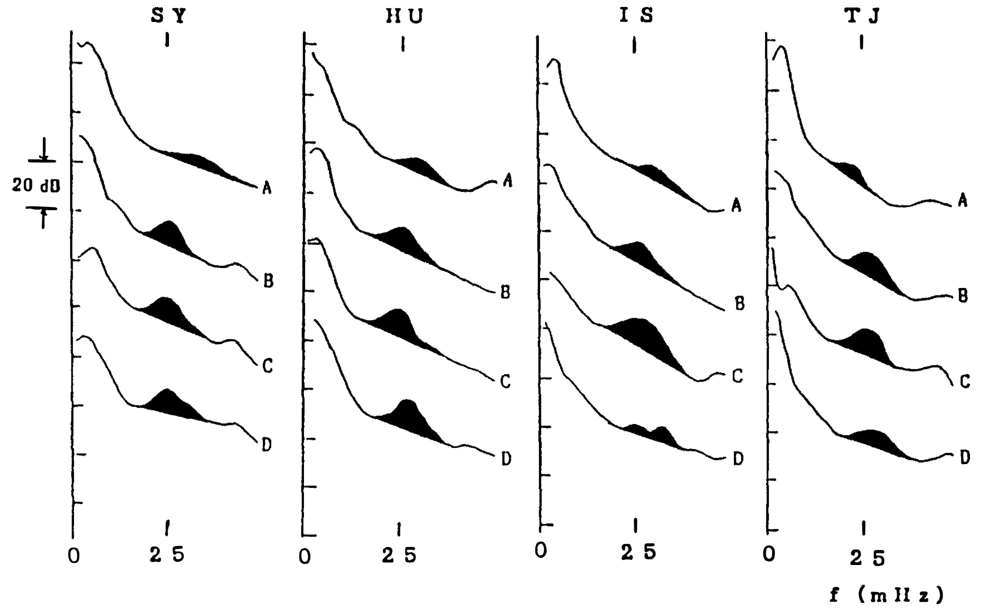

Fig. 4. Relative power spectra of the CNA pulsations as a function of the pulsation frequency observed at Syowa (SY), Husafell (HU), Isafjördur (IS), and Tjörnes (TJ) in the time interval 1103–1133 UT on 20 October 1984.

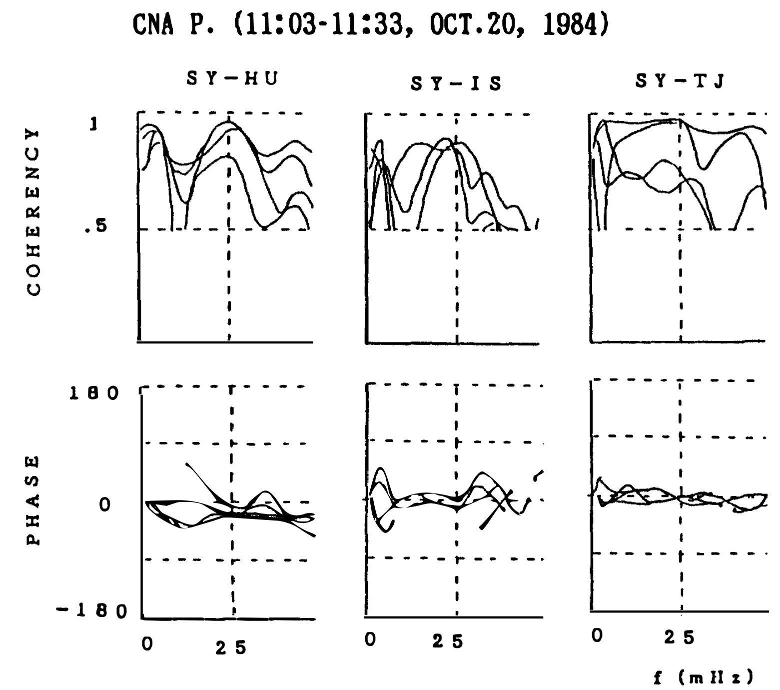

Fig. 5. Relative phase differences of the CNA pulsations at SY-HU, SY-IS, and SY-TJ, in the domain of the coherency greater than 0.5.

Figure 4 shows the relative power spectra of CNA pulsations observed at SY, HU, IS, and TJ in the time interval 1103–1133 UT on 20 October 1984. Each spectrum is analyzed over 15 min intervals and the separation between successive spectra is 7.5 min. It is seen in the relative power spectra of the CNA pulsations that there were well defined spectral peaks around 25 mHz throughout the successive spectra at the four stations.

In the domain of relative coherency larger than 0.5, the coherency and relative phase difference of CNA pulsations between Syowa Station and three stations in Iceland are superimposed over the four spectra (A to D in Fig. 4) at the top and bottom panels in Fig. 5. The analyzed results show that the coherency of SY-HU was relatively very good, and the relative phase difference of SY-TJ at 25 mHz range was least in comparison with that of SY-HU and SY-IS, and the phase difference of SY-HU is concentrated on a slightly negative value. For SY-IS, the coherency and the relative phase difference were worst relatively. These two tendencies, that is, the two characteristics of coherency and relative phase between Syowa Station and three stations of Iceland support the analysis of CNA pulsations published by HIGUCHI *et al.* (1988).

4. Source Movement of CNA Pulsations over Iceland

The geomagnetic latitudinal and longitudinal distances of HU-IS, HU-TJ, and IS-TJ are shown in Fig. 6. The relative phase difference (HU-IS, HU-TJ, and IS-TJ) of CNA pulsations over Iceland in the time interval 1103–1133 UT on 20 October 1984 are analyzed by the same way. When the values of relative coherency are larger than 0.5, the coherency and the relative phase difference for A to D spectra in Fig. 4 are superimposed in Fig. 7. The relative phase difference $\Delta\theta(^\circ)$ is converted into the relative time difference Δt(s) by a conversion formula $\Delta t = \Delta\theta/360f$, where f is a peak frequency of the relative power spectra.

The top panel of Fig. 7 shows that there are two frequency bands near 5 mHz and 25 mHz where the value of the relative coherency is greater than 0.8. Since the values of $\Delta\theta$ near 25 mHz except for a few analytical curves take positive values at HU-IS, HU-TJ, and IS-TJ, the source of CNA pulsations for Pc 3 range moves from IS to HU, TJ to HU, and TJ to IS, respectively. This suggests that the prenoon source of CNA

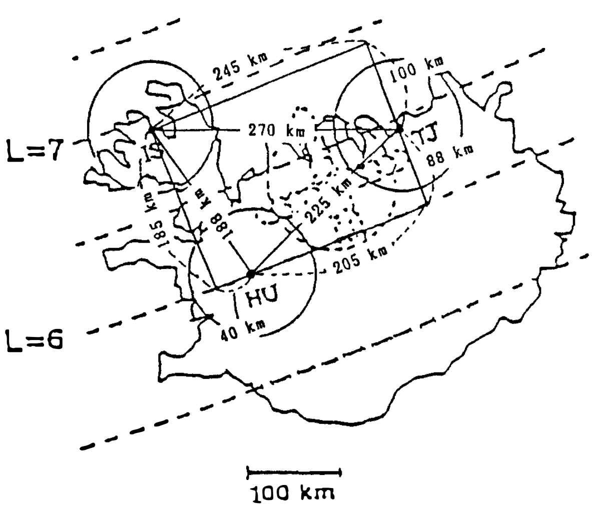

Fig. 6. The geomagnetic latitudinal and longitudinal distances of HU-IS, HU-TJ, and IS-TJ.

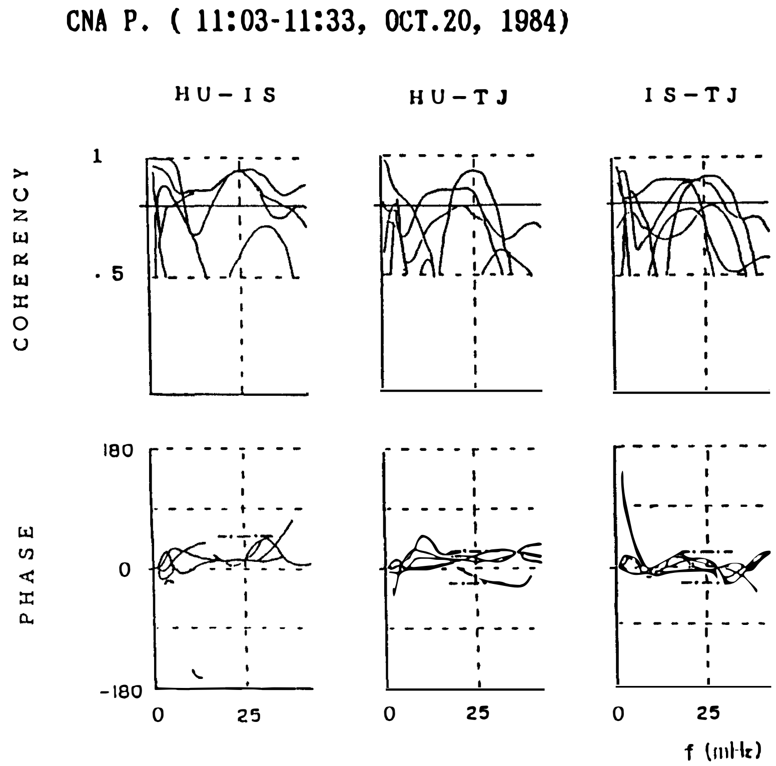

Fig. 7. Relative phase difference of the CNA pulsations at HU-IS, HU-TJ, and IS-TJ, in the domain of the coherency greater than 0.5. Solid straight lines in upper panel show the level of relative coherency 0.8.

pulsations for Pc 3 range moves from high latitude to low latitude, and generally from east to west.

We can also see some analytical curves of relative phase for HU-TJ and IS-TJ in Fig. 7 are reversed. But the reversed curves of relative phase are the result of the first analytical section (1103–1110.5, Oct. 20, 1984) which was not included in the noticed CNA pulsation chart (1124–1132, Oct. 20, 1984), Fig. 3. So we have neglected some exceptional analytical curves in Fig. 7.

However, when $\Delta\theta$ is relatively small, that is, Δt is nearly equal to or sometimes smaller than the sampling time of 2 s, an estimated speed becomes abnormally large. In this special condition the speed could not be interpreted as a source speed, but it can be interpreted that a giant source with energetic particle precipitation covers all over Iceland simultaneously and its source intensity is probably pulsating.

The maximum relative phase difference $\Delta\theta(°)$ in Fig. 7 is read the frequency range from 21.5 to 28.5 mHz centered at spectral peaks around 25 mHz (see a chain line in the figure). For HU-IS, the relative maximum time difference $\Delta t(\mathrm{s})=5.0$ s for the maximum $\Delta\theta=45°$ at $f=28$ mHz shows that a source reaches IS faster than HU, and the minimum source velocity have southward and westward components. For HU-TJ and IS-TJ, the extreme values $\Delta t=\pm 2.9(\mathrm{s})$ correspond to the maximum and minimum values $\Delta\theta=\pm 26°$ at $f=28$ mHz (see Fig. 7). Considering these three extreme relations of relative phase difference, that is, the relative maximum time differences Δt, we could estimate the minimum speed of the mean source movement: a southward

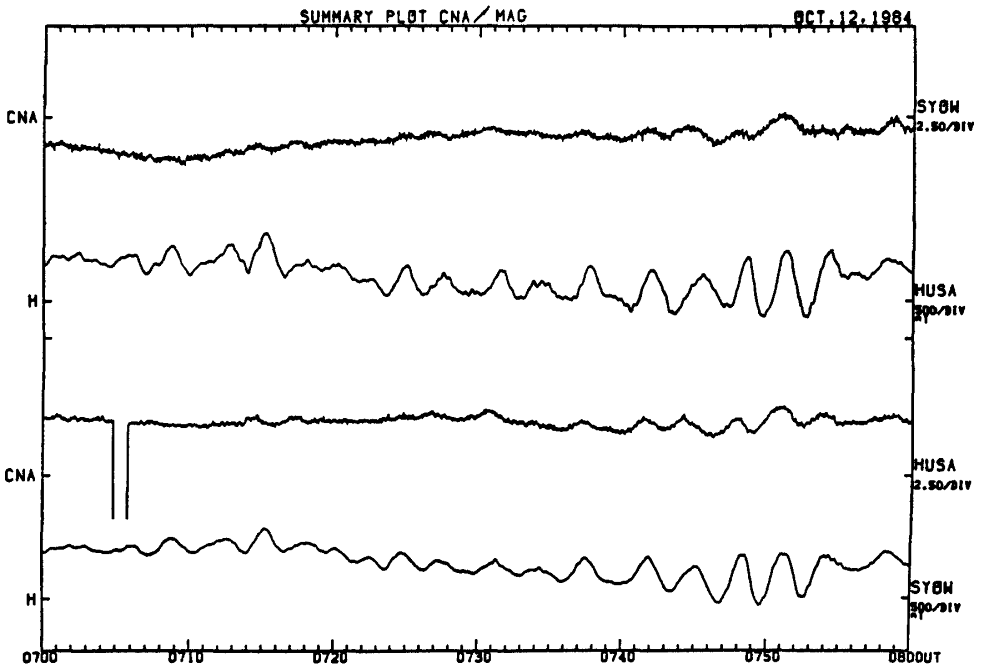

Fig. 8. Intensity of CNA at 30 MHz and the H components of magnetic variation in the time interval of 0700–0800 UT on October 12, 1984.

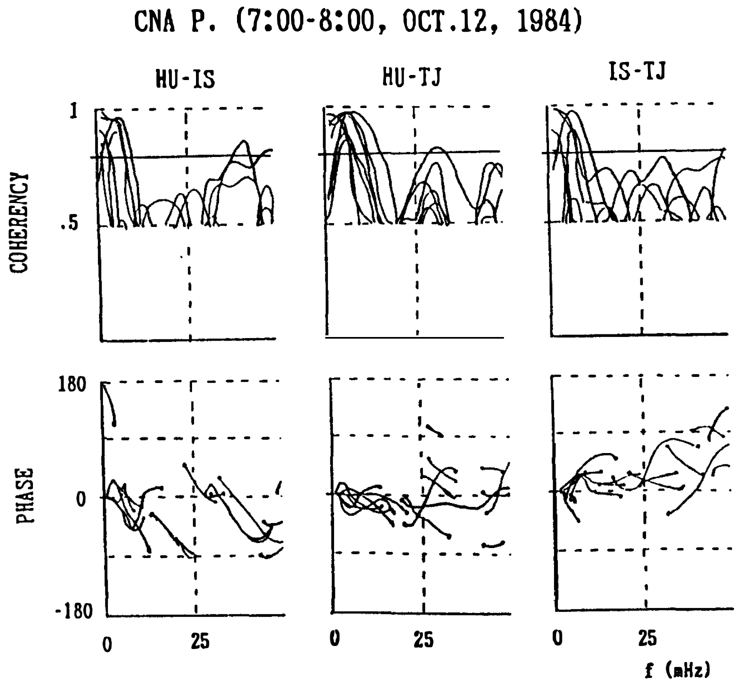

Fig. 9. Relative phase difference of the CNA pulsations at HU-IS, HU-TJ, and IS-TJ, in the domain of the coherency greater than 0.5. Solid straight lines in upper panel show the level of relative coherency 0.8.

speed V_s is about 30 km/s and a westward speed range is 8–80 km/s.

We can also find the frequency band near 5 mHz where the value of relative coherency is larger than 0.8 in Fig. 7. Since the values of $\Delta\theta$ at 5 mHz for HU-IS,

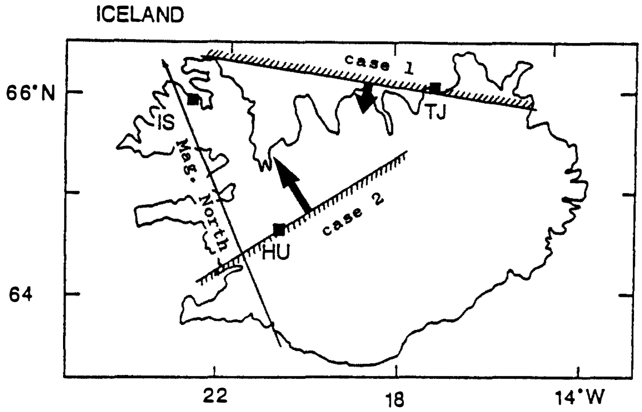

Fig. 10. A schematic diagram of phase progress to show the direction of the source movement of CNA pulsations for case 1 (1103–1133, Oct. 20, 1984) and case 2 (0700–0800, Oct. 12, 1984).

HU-TJ, and IS-TJ show positive values, the source movement seems to have the velocity components form IS to HU, TJ to HU, and TJ to IS respectively. These indicate that a prenoon source (1103–1140 MLT) of CNA pulsations at Pc 5 range moves from high latitudes to low latitudes, and generally westward direction.

Another example of CNA pulsation data in a time interval 0700–0800 on 12 October 1984 shown in Fig. 8 was analyzed in the same way, and the analyzed results are shown in Fig. 9. In this case, the frequency band where the value of relative coherency is larger than 0.8 exists centered at 5 mHz range in Fig. 9. For HU-IS and HU-TJ, the values of $\Delta\theta$ at 5 mHz range have mainly negative values, and the source movement is from HU to IS, and HU to TJ respectively. On the other hand, for IS-TJ the value of $\Delta\theta$ at 5 mHz range has a positive value, and the source of CNA pulsation in Pc 5 range moved probably from TJ to IS. These analyzed facts suggest that a morning source (7–8 MLT) of CNA pulsations at Pc 5 range moved from high latitudes to low latitudes, and generally from west to east direction.

In order to show the direction of source movement, we arrange the analyzed data of each analytical section and draw schematically the equal phase lines on a chart in Fig. 10 for case 1 and case 2.

5. Summary and Discussion

CNA pulsations observed at Syowa Station and Husafell from September to December 1983 were examined statistically to study the seasonal characteristics of the conjugacy at the geomagnetically conjugate-pair stations. The south-north conjugacy of CNA pulsations is best in October, *i.e.*, in equinox, and falls to worst in December, *i.e.*, in the winter in the northern hemisphere. It is interpreted that an effect of photoionization produced by the sunlight mainly controls the occurrence for conjugacy of CNA pulsations at the magnetically conjugate station.

To determine the source movement of CNA pulsations by analyzing the relative phase differences among the three stations in Iceland is a new attempt, and has a merit to estimate a source movement of north-south direction. We inferred the direction of source movement of CNA pulsation and investigated the minimum source speed limited by the sampling time.

On the basis of the analyses for two cases of the relative phase and coherency differences of the CNA pulsation among three stations in Iceland, a prenoon source of CNA pulsation at Pc 3 and Pc 5 ranges moved generally from high latitude (or north) to low latitude (or south), and from east to west direction. However, a morning source of CNA pulsation with Pc 5 range moved generally from low latitude to high latitude, and east to west direction.

Although our study of source movement of CNA pulsations in the auroral zones is a case study for two cases, the results are consistent with the previous discussion on generation mechanisms for Pc 3 and Pc 5 geomagnetic pulsations in the magnetosphere. It is suggested according to the analyzed results for two cases that the prenoon source movement of CNA pulsations with Pc 3 range is closely related to the propagation direction of Pc 3 geomagnetic pulsations which are originated from the direct compressional interaction between the solar wind and the magnetosphere. Further, we can infer that the morning source movement of CNA pulsation with Pc 5 range corresponds to the movement of Pc 5 geomagnetic pulsation which is generated by the Kelvin-Helmholtz instability on the low-latitude magnetopause in the morning sector.

It is also assumed that the source speed of CNA pulsations is about 30 km/s along north-south direction and an average source speed is about 44 km/s along an east-west direction.

The conjugacy of CNA pulsations between Syowa and Husafell Stations is the best among the existing pairs of observing points, and the relative phase differences between Syowa and Tjörnes Stations are the minimum in general. The coherency and the relative phase difference between Syowa and Isafjördur Stations are worse than those with the other two stations in Iceland. These tendencies obtained through this case study are almost the same as discussed by HIGUCHI *et al.* (1988).

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