STUDIES OF THE ENERGY SOURCE FOR HYDROMAGNETIC WAVES AT AURORAL LATITUDES

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Abstract: A preliminary report is given of a study of hydromagnetic waves observed on the ground at a high latitude (South Pole) location and at a station in the auroral zone (Syowa Station) during a day with considerable magnetic activity at $f \sim 30$ mHz. South Pole Station was located on closed field lines throughout the local day time interval of interest. Through cross-correlation spectral analyses, it is concluded that an external wave energy source can be observed over a wider azimuthal extent at an auroral zone location than at a location close to the magnetopause. The observations on this day at the two locations are studied for possible harmonic structure in the excited wave bands. It is suggested that such harmonic structure exists at the auroral zone station, but it is not clear at the South Pole Station.

1. Introduction

The advent of more sensitive magnetometer instruments and the use of digital data processing techniques have provided evidence that while longer period (~150–500 s) geomagnetic pulsations known as the Pc 5 band are certainly the most evident in data acquired at auroral zone stations (*e.g.*, SAITO, 1969; JACOBS, 1970), shorter period pulsations, in the Pc 3 range (~10–45 s), are also frequent occurrences at these latitudes (*e.g.*, TONEGAWA and FUKUNISHI, 1984). The recent investigations also reveal the wave characteristics of Pc 3–5 pulsations observed in the high latitudes. Nevertheless, the morphology of occurrence of such pulsations at auroral latitudes, produced by hydromagnetic waves in the Earth's magnetosphere, is poorly known at this time, as is (are) their energy source(s). It is likely that the source(s) are external to the magnetosphere, as are the sources of many of the lower frequency waves, although regarding the latter, many can occur as the result of internal plasma instabilities during magnetic storm conditions.

Magnetic field measurements were made in an observatory mode at the South Pole for a number of years during and following the International Geophysical Year (SAITO, 1965). Following a hiatus of no measurements in much of the 1970's, a considerably more sensitive instrument and sophisticated data acquisition system was installed in the austral summer 1981–82 for purposes of investigating the hydromagnetic wave activity at this high latitude station in the context of modern views of the magnetosphere (LANZEROTTI *et al.*, 1982). The South Pole location was of particular interest because of its geomagnetic latitude: depending upon geomagnetic activity, and thus, of course, on interplanetary conditions, the station can be under the auroral zone or in the polar cap during local night and can be on closed or open field lines or in the magnetospheric cusp region during local day. The criteria for determining which of these local day situations holds at any given time is not at all agreed upon as yet and is under active investigation in the scientific community.

This paper is a short progress report on an ongoing investigation of the source of energy for Pc 3-frequency hydromagnetic waves observed in the auroral zone, using data from the higher latitude South Pole Station as a measure of external energy input to the magnetosphere. The paper concentrates in particular on a specific interval around local magnetic noon (~1530 UT) on a day when strong Pc 3 activity and simultaneous modulation of VLF activity were observed at South Pole (LANZEROTTI *et al.*, 1985). Simple modeling considerations indicate that South Pole was likely located on closed magnetospheric field lines at the time (LANZEROTTI *et al.*, 1985). The auroral zone data for the same interval were recorded at Syowa Station, an Antarctic location with a magnetic local noon at ~1213 UT.

Illustrated in Fig. 1 is a map of the Antarctic region showing, in geomagnetic

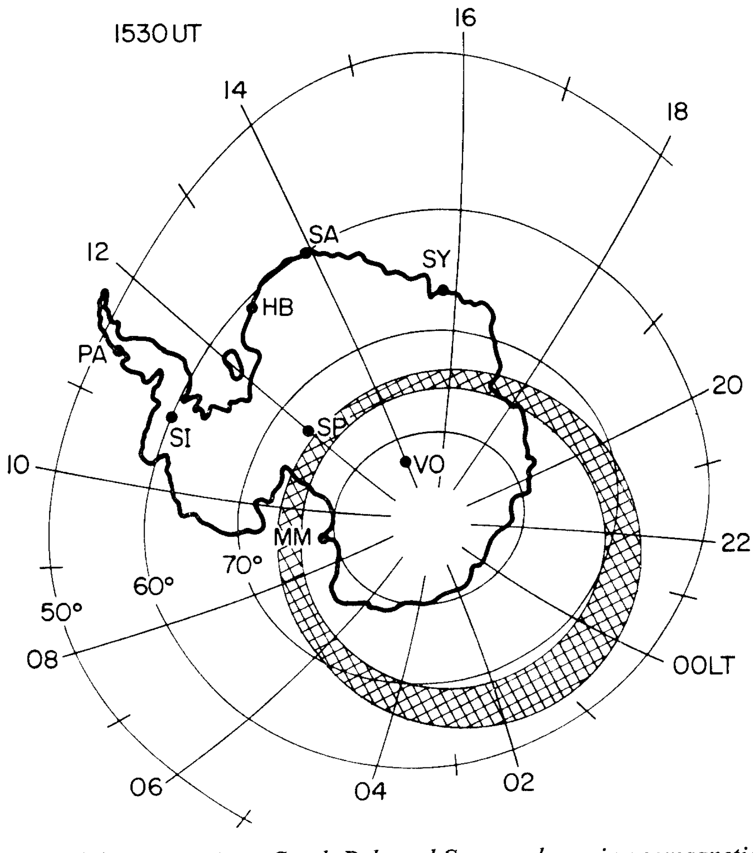

Fig. 1. Locations of the two stations, South Pole and Syowa, shown in geomagnetic coordinates at South Pole local noon. Also shown is the nominal auroral zone mapped to the top of the ionosphere.

coordinates, the relative locations of South Pole and Syowa Stations at local noon at South Pole. The nominal auroral zone mapped to the top of the ionosphere is also indicated. Given nominal auroral (geomagnetic) conditions, South Pole Station would be expected to be in the cusp and/or polar cap region of the magnetosphere. Syowa Station is approximately 3+hours advanced in magnetic time from South Pole.

The magnetic field data at South Pole Station were acquired with a fluxgate magnetometer with a noise level of ~0.2 nT (LANZEROTTI *et al.*, 1982). The analog outputs of the geomagnetic north/south (*H*-component), east/west (*D*-component) and vertical (*Z*-component) were digitized at one-second intervals with a digitization quantization of ~0.06 nT. The data were written in computer compatible format on magnetic tape, together with performance parameters of the instrument and the data acquisition system. The VLF signal level was measured with a dipole antenna with the output followed by narrow band filters at several frequencies ranging from ~0.5–40 kHz (GAIL, 1982). These data were also digitized at one-second intervals and written on the magnetic tape.

At Syowa Station, magnetic field fluctuations indicative of hydromagnetic waves are measured with a three axis search coil magnetometer. The system has a sensitivity of 0.001–5 nT/s in each axis over the frequency range 0.001–3 Hz. ELF-VLF electromagnetic waves are detected with a three-turn loop antenna, using nine narrow band filters over the range 0.35–95 kHz. The outputs of each sensor system are recorded on digital magnetic tape with a sampling frequency of 2 Hz for the magnetic pulsations and 0.5 Hz for the ELF-VLF filtered data. Details of the Syowa instrumentation are contained in SATO *et al.* (1984).

2. Results

Figures 2a and 2b contain dynamic power spectra of the *H*- and *D*-component magnetic field data and two frequency bands of VLF data from South Pole and Syowa Stations, respectively, on January 5, 1982 UT. Note that there is a data gap at Syowa in the interval from 18 to 19 UT on this day. The South Pole *H*- and *D*-component data are designated X and Y, respectively, in Fig. 2a for convenience. The dynamic spectra were calculated by the autoregressive (AR) method with order 15 (see TONEGAWA and FUKUNISHI, 1984). A time window of 20 min is shifted by 8 min for successive calculations of the power spectra. The background power is subtracted by fitting a second-order polynomial to the shape of the power spectrum. This emphasizes the spectral peaks. An eight level gray scale, in dB, is then used.

The features of the South Pole magnetic and VLF spectra from ~12–21 UT in the frequency band ~10–50 mHz have already been described in LANZEROTTI *et al.* (1985). In that report this South Pole event was described as a typical quasi-periodic (QP) VLF event with accompanying geomagnetic pulsations (GP)—a GP/QP event similar to that seen many times in geomagnetic and VLF records at auroral and/or sub-auroral regions (*e.g.*, SATO *et al.*, 1974; SATO and KOKUBUN, 1980; KIMURA, 1974; TROITSKAYA and KLEIMENOVA, 1972; KOROTOVA *et al.*, 1975). It was also concluded that the interval of enhanced Pc 3 activity occurred when the station was connected to closed geomagnetic field lines. This conclusion was reached primarily from using

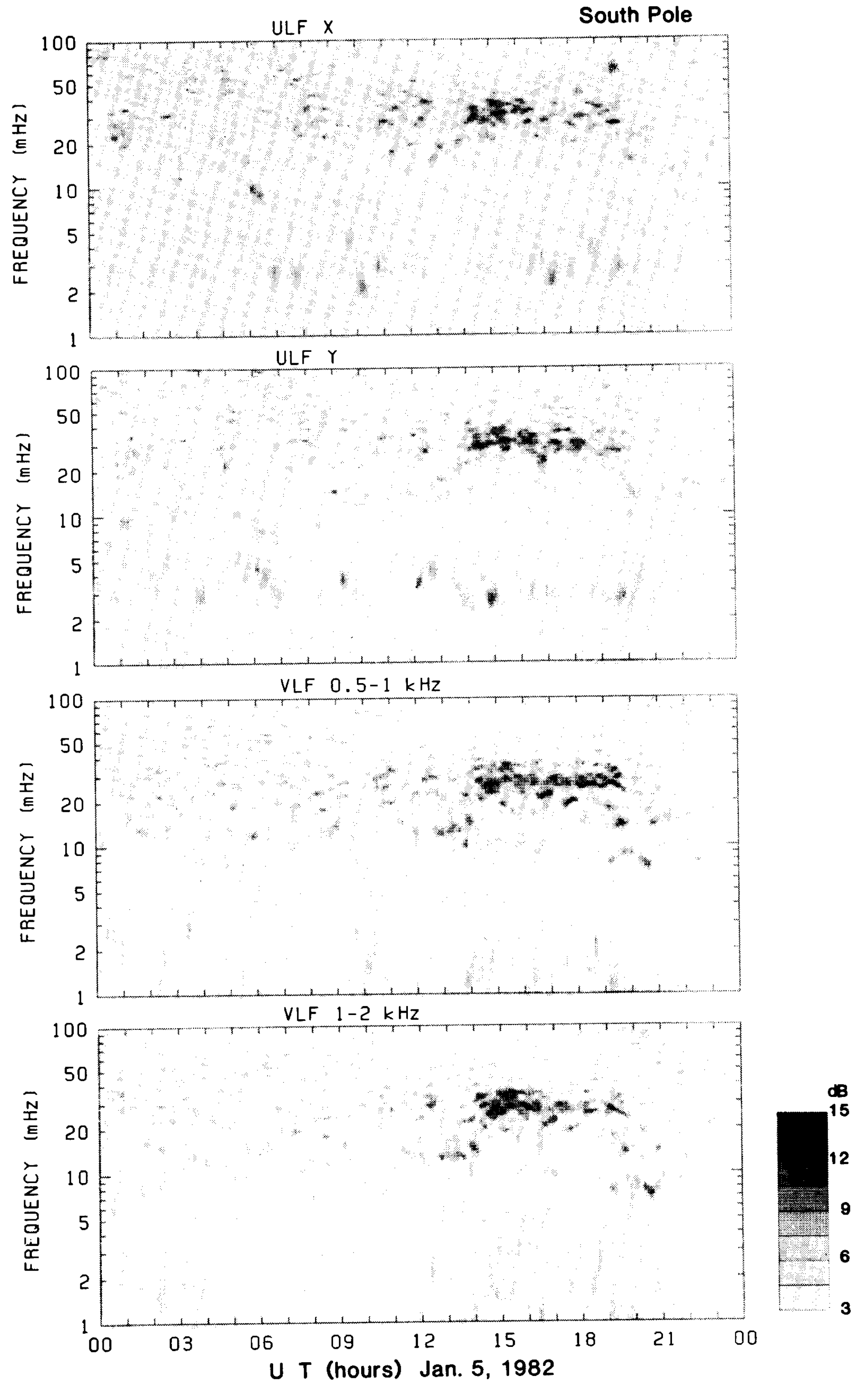

Fig. 2a. Dynamic specta of magnetic field and VLF data recorded at South Pole Station on January 5, 1982 UT.

the Olson-Pfitzer model of the magnetosphere and superimposing an interplanetary magnetic field similar to that actually existing at the time (see LANZEROTTI *et al.*, 1985).

The spectra of Figs. 2a and 2b clearly show that the most intense part of the QP/GP event occurred in the east/west component of the records measured at both

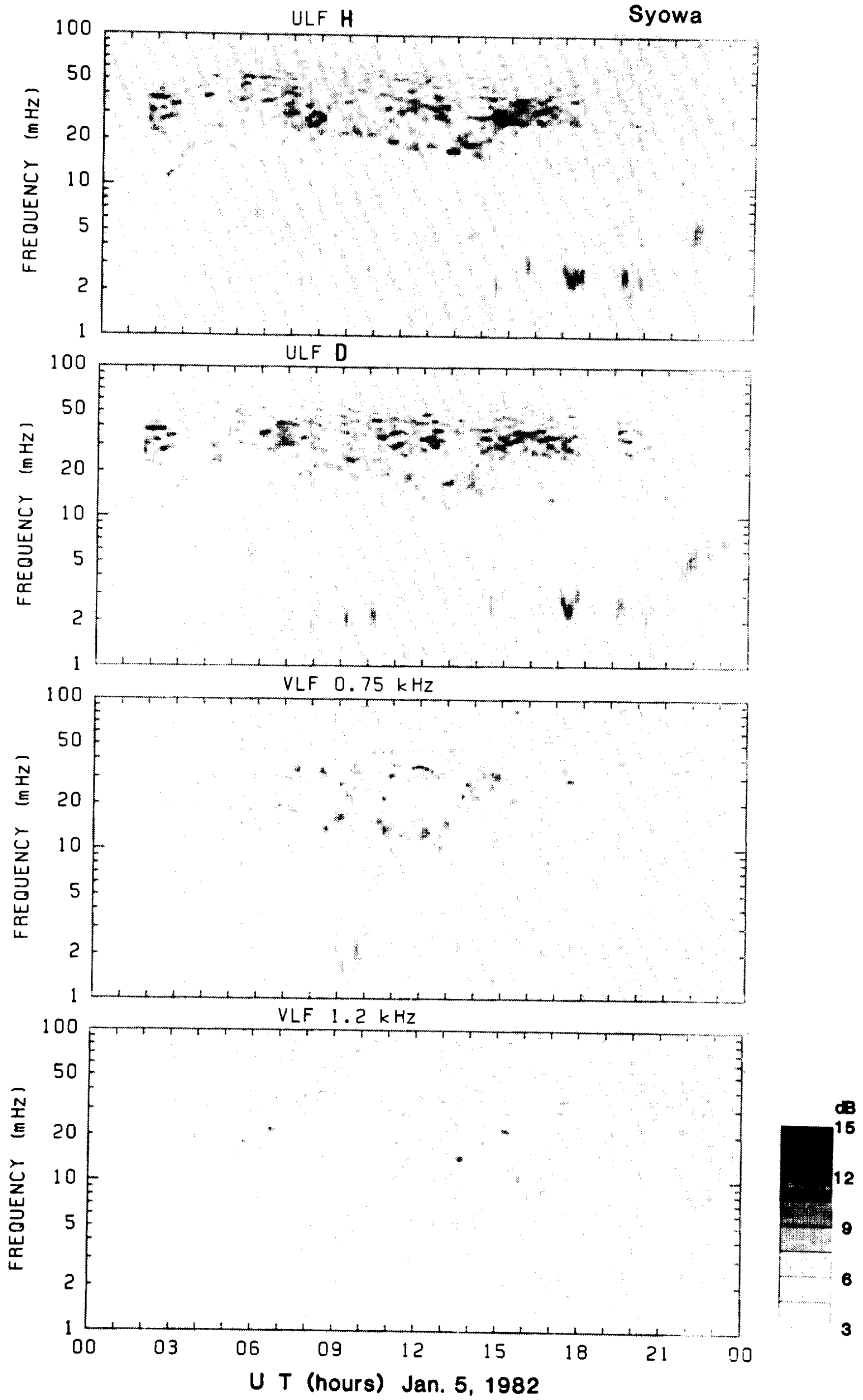

Fig. 2b. Dynamic spectra of magnetic field and VLF data recorded at Syowa Station on January 5, 1982 UT.

South Pole and Syowa Station. The major difference between the magnetic observations at the two stations is that at Syowa the enhanced activity in the Pc 3 band existed for almost the entire magnetic local day (UT$\simeq$MLT at Syowa), until about hour 20, when the activity ceased as well at South Pole. The quasi- periodic VLF activity was not as strong at Syowa, compared to South Pole. Only during portions of the interval

~08–15 UT (around local noon at Syowa) was there some evidence of significant QP activity in the auroral zone.

It is worth noting that the Pc 3 band of magnetic pulsation consists of several spectral peaks, which appear to be spectral subbands in the Pc 3 band. This feature is more distinct in the dynamic spectra of the Syowa data than the South Pole data. One such subband is clearly seen in the *H*-component at Syowa, starting from ~06 UT with a frequency of ~25 mHz and lasting to ~17 UT with a frequency of ~15 mHz. In addition to the intense Pc 3 band, there is also a band of wave enhancement at ~2–4 mHz (Pc 5 band) that occurs sporadically throughout the day. These spectral characteristics suggest the existence of harmonic hydromagnetic structure, especially at Syowa in the auroral zone. This possibility is discussed later.

In a later study, incorporating both ground-based (auroral zone) and satellite (geosynchronous orbit) data, TONEGAWA *et al.* (1984) reported that there are two predominant spectral bands found in the data from the Syowa geomagnetic latitude region. These two bands are similar to those reported in this paper, with often a spectral band gap appearing between the ~3–10 mHz and the ~20–80 mHz bands. Noticing a tendency for a switching of the power between the bands on some of the days, TONEGAWA *et al.* (1984) concluded that there appear to be different driving sources for the two bands. WOLFE (1980), WOLFE *et al.* (1980), and WOLFE and MELONI (1981) reached a similar conclusion from a very different type of analysis of geomagnetic data.

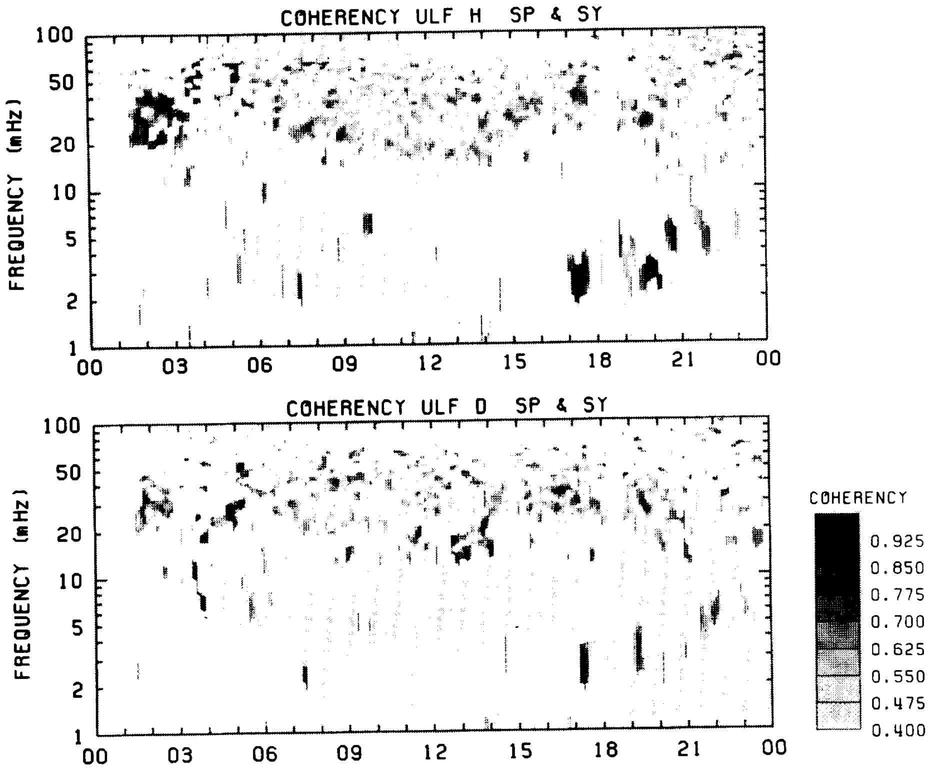

Fig. 3. Coherence levels from a cross-spectral analysis of South Pole and Syowa data for January 5, 1982 UT.

As reported in LANZEROTTI *et al.* (1985), the polarizations of the magnetic field variations at South Pole in the Pc 3 band were right-handed (clockwise rotation of the magnetic vector looking along the magnetic field) prior to ~1800 UT. After this time, the polarization changed to a mixed left-handed/right-handed character. At Syowa, a predominant linear polarization prevailed during most of the interval of overlap with South Pole. From ~04–08 UT the polarization was right handed while from ~08–18 UT it was slightly left handed.

A cross-correlation analysis was performed between the corresponding magnetic field components at the two stations. The coherencies from these analyses are shown in Fig. 3, with eight levels of discrimination between 0.4 and 1.0. These results indicate that there is a significant level of coherence ($\gtrsim$0.7) between the respective Pc 3 band magnetic variation signals during ~06–21 UT and during local night, ~01–03. Further, there is a high coherence ($\gtrsim$0.8) at times in the Pc 5 band during the interval ~17–22 UT.

3. Discussion

This preliminary investigation of data obtained simultaneously at high latitudes on field lines which map close to the magnetopause and at lower latitudes in the auroral zone shows that the Pc 5 and Pc 3 band hydromagnetic wave activity was highly correlated between the two stations, particularly during local night (Pc 5) and during the interval around local noon at South Pole, where a strong QP/GP event was seen. The local day results have important implications for processes related to hydromagnetic wave generation and propagation into the Earth's magnetosphere. South Pole Station, located on closed field lines during the interval of study (LANZEROTTI *et al.*, 1985) is closer to the magnetopause than is Syowa. Solar wind energy can be converted into hydromagnetic energy in the magnetosphere either through instability conditions on the magnetopause (*e.g.*, the Kelvin-Helmholtz instability) or directly via up-stream solar wind generated waves (possibly at the bow shock) penetrating the magnetopause (see, for example, WOLFE *et al.*, 1980; WOLFE, 1980). South Pole Station should therefore observe nearly directly the results of solar wind energy conversion to hydromagnetic waves.

One of the most interesting aspects of the data analyzed here is that the Pc 3 band activity was observed for a much longer time at Syowa than it was at South Pole, with the activity terminating at both stations at approximately the same time. A tentative suggestion for this behavior is that a lower (auroral) latitude station responds to a wave source over a wider range of longitude than does a station at higher latitudes, closer to the source region. This implies that the hydromagnetic energy input into the magnetosphere propagates both radially and azimuthally. A station such as South Pole, close to field lines along the magnetopause, essentially measures the strength and azimuthal extent of the input wave energy source. The restricted activity of Pc 3 around local noon at South Pole also suggests that a major energy source of the observed Pc 3 is up-stream solar wind-generated waves rather than magnetopause waves excited by the Kelvin-Helmholtz instability. This is because the growth rate of the instability should be low around local noon where a stagnation point of the solar wind is located. Further, the polarization (right-handed) and time of change in polarization are qualitatively inconsistent with a Kelvin-Helmholtz source.

The source wave propagating into the inner magnetosphere (*i.e.*, Syowa) may excite a standing Alfvén wave at a resonance point where the frequency of a standing wave coincides with that of the source wave. Strong evidence for the harmonic structure of Pc 3–5 magnetic pulsations was recently provided for data observed both at the geosynchronous orbit and on the ground in the auroral zone (TAKAHASHI and MCPHERRON, 1982; TONEGAWA *et al.*, 1984; TONEGAWA and FUKUNISHI, 1984). TONEGAWA and FUKUNISHI (1984) showed that the Pc 4/5 band (~3–10 mHz) observed at Syowa was the fundamental mode of a standing Alfvén wave, while the Pc 3 band (~20–100 mHz) contained the higher harmonics (usually third to sixth). We examine in Fig. 4 whether the Syowa magnetic pulsations presented here have such a feature or

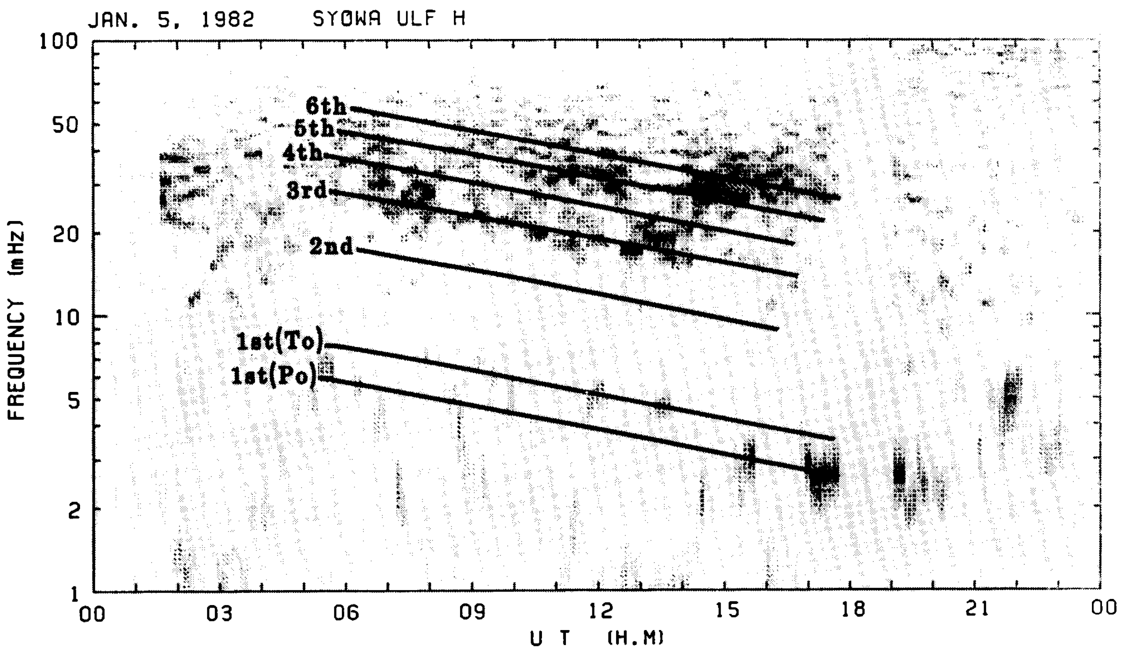

Fig. 4. Harmonic relation on the dynamic spectra of magnetic field data recorded at Syowa Station on January 5, 1982 UT. The sloping straight lines represent a harmonic relation based on the theoretical estimation given by CUMMINGS *et al. (1969). See the details in the text.*

not by using the same procedure as that employed by TONEGAWA *et al.* (1984). A sloping straight line, designated "3rd" in the figure, was first drawn through the spectral subband which appeared most distinctly in the *H*-component at Syowa. The other harmonic lines were then drawn by using ratios among the eigenfrequencies of a standing Alfvén wave. The ratios used were those given by CUMMINGS *et al.* (1969) (see details in TONEGAWA *et al.*, 1984). The assumed harmonic lines higher than the third fall in the observed Pc 3 band; the fundamental harmonic lines of the toroidal and poloidal modes appear to fit the sporadically-observed Pc 5 band. The results of Fig. 4, therefore, suggest the possible existence of harmonic structure for the spectral bands observed at Syowa during this day. However, the absence of an intense Pc 5 band on this day makes the harmonic structure less clear than for the cases discussed earlier by TONEGAWA *et al.* (1984). The lack of an intense Pc 5 band may only indicate less external energy source in the frequency range of Pc 5 for this day.

All of the above ideas and concepts are being followed-up with further data studies and theoretical considerations and will be reported in the future.

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