Application of Conversational Spectral Analysis Program (CSAP) System for Magnetic Pulsations Observed at Mizuho and Syowa Stations

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会話型スペクトル解析システム (CSAP) による解析
—みずほ・昭和基地での地磁気脈動同時観測—

岩渕美代子*・佐藤夏雄*・福西　浩*

要旨: 会話型スペクトル解析システム (CSAP システム) を用いて, 1976年11月17日のみずほ・昭和基地で同時に観測された地磁気脈動データの解析を行った. 本論文では, 解析の手順, CSAP システムの概要, および解析結果を示し, CSAP システムが地磁気脈動データの解析に非常に有効であることを示す.

Abstract: Conversational spectral analysis program (CSAP) system is applied to the simultaneous magnetic pulsation data of November 17, 1976 when various kinds of ULF phenomena were observed at Syowa and Mizuho Stations. In this paper, the analysis procedure, the outline of the CSAP system with graphic display terminal and analysis results are shown and discussed. The results show that the CSAP system is useful for studying magnetic pulsation data

1. Introduction

Magnetic pulsations were observed simultaneously at Syowa and Mizuho Stations in 1976–1977 by induction magnetometers. The geomagnetic coordinates of Syowa and Mizuho are −70.03°, and 79.39°, and −72.32° and 80.62°, respectively. The output signals from the induction magnetometers were recorded on magnetic tapes. The CSAP system which was developed by IWABUCHI *et al.* (1978) has been applied to analysis of the magnetic pulsation data of November 17, 1976 when various kinds of ULF phenomena, such as Pi, Pc 1, Pc 3, and Pc 4 pulsations, were observed.

2. Analysis Procedure

2.1. AD conversion

The original data are recorded in analogue magnetic tapes. HITAC 10-II mini-computer system at the National Institute of Polar Research was used to convert the

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analogue type of data to the digital magnetic tapes. The sampling time of AD conversion is 4 miliseconds and the reproduction speed of analogue data recorder is 100 times the original recording speed. The *H*, *D* and *Z* components which were recorded in the three channels of the magnetic tapes were converted simultaneously The conversion time is 15 minutes for one day data.

2. 2. Time mark fitting

1 Hz sine waves with a duration of 30 seconds are recorded every hour as time marks, superimposed on magnetic pulsation data The number of sampling points between successive time marks scatters about ±1% around the mean value at each station The mean value is also different between the two stations, *i. e* , the mean value at Mizuho is generally larger than that at Syowa Such a scattering and a difference are mainly due to the fluctuation of the recording speed Therefore, the original sampling points were interpolated to get the constant number of points, 9000 points, between successive time marks. The reading of time marks was done by the use of HITAC M-160II graphic display terminal and the CSAP system

2. 3. Spectral analysis

There are six components of data, *i. e* , *H*, *D* and *Z* components of the two stations. Cross spectrum, phase, coherency and polarization parameters were computed for each two components by using the CSAP system with graphic display terminal.

3. CSAP System with Graphic Display Terminal

Fig 1 shows the transaction flow of the CSAP system The CSAP system was developed by IWABUCHI *et al* (1978) for the spectral analysis of general wave phenomena One of the most convenient functions of the system is the ability to analyze one or two dimensional time series data over and over again by the use of graphic display terminal Users can easily select a necessary part of data for analysis from the original data and also can select the type of filters (Chebyshev type high-pass, low-pass, band-pass and band-reject filteres) and spectral analysis methods such as Blackman-Tukey, Fast-Fourier-Transform and Maximum-Entropy methods (by Burg's algorithm and by auto-regressive method) The dynamic spectra also can be obtained by using the modified CSAP system

The details of the system are discussed in the paper by IWABUCHI *et al* (1978)

4. Results and Discussions

Fig 2 shows the data of magnetic pulsations at Syowa and Mizuho Stations in the time intervals of 0000–2000 UT on November 17, 1976 The time given in UT (universal

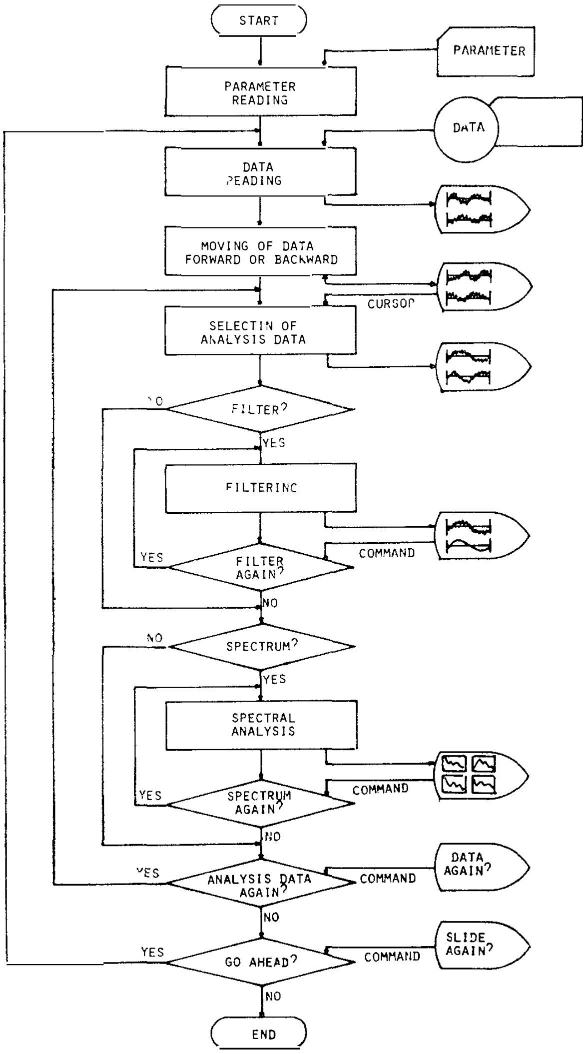


Fig 1. Flow chart of the CSAP (conversational spectral analysis program) system by HITAC H-160II computer and graphic display terminal

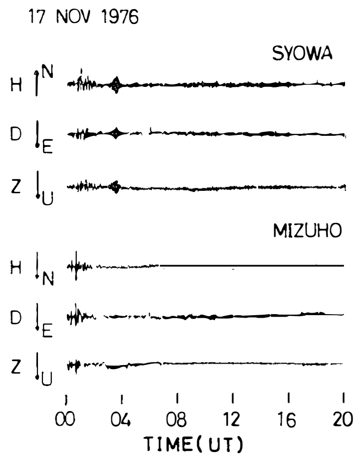


Fig 2 Records of magnetic pulsations by an induction magnetometer at Syowa (upper) and Mizuho (lower) on November 17, 1976.

time) is nearly equal to MLT (magnetic local time) at Syowa and Mizuho Stations. Fig. 3 shows the dynamic spectra of H and D components of magnetic pulsations at Syowa (upper) and Mizuho (lower) Stations. The power spectra are displayed in logarithmic scale and the dynamic range is about $\sim$100 dB. The high noise level seen at $\sim$0800 UT in the H spectrum of Syowa is due to an impulsive noise which was recorded on the original tape. The exponentially decaying shape seen at $\sim$0700 UT in the H and D spectra of Mizuho is due to a data gap in the original tape. We analyzed in detail the three typical phenomena; the Pc 4 waves (0319: 09–0332: 48 UT), the Pc 1 waves (0447: 57–0451: 22 UT) and the Pc 3 waves (1501: 15–1508: 05 UT). Several spectral methods such as Blackman-Tukey (BT), Fast-Fourier-Transform (FFT) and

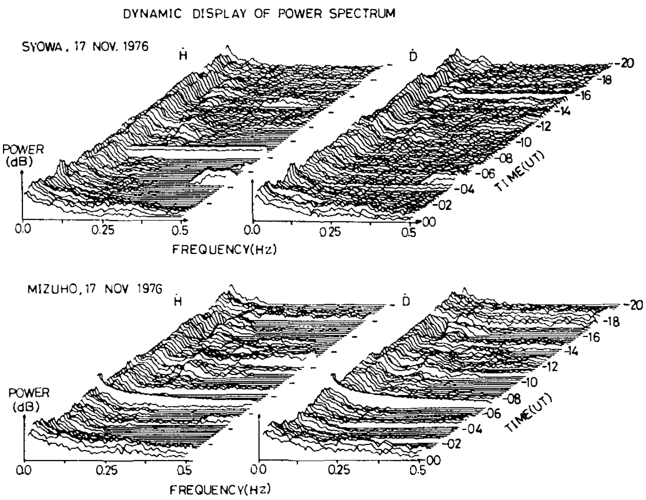


Fig. 3. Dynamic display of the power spectra of H and D components of magnetic pulsations at Syowa (upper) and Mizuho (lower) on November 17, 1976. The power spectra were by FFT method with hamming data window.

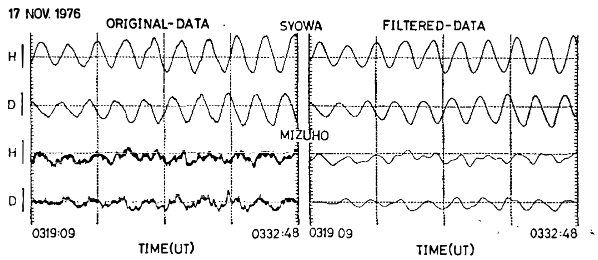


Fig. 4. Original (left) and low-pass filtered (right) wave forms of magnetic pulsations in the time interval of 0319: 09–0332: 48 UT.

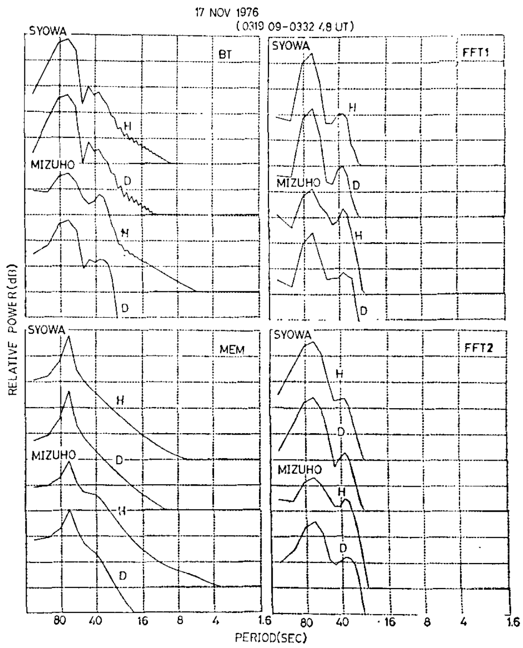


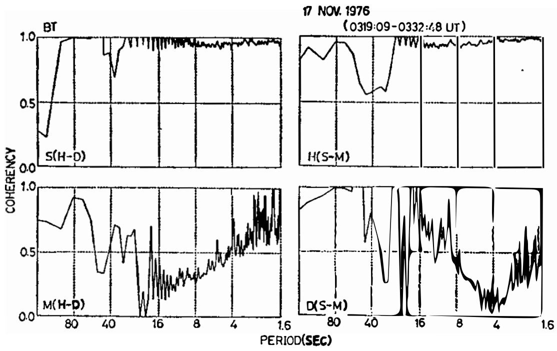
Fig. 5. Relative power spectra for the filtered data computed by BT, FFT1, FFT2 and MEM-AR.
BT: Hanning spectral window, prewhitening coefficient = 0.65.
FFT1: Hamming data window.
FFT2: Spheroidal prolate data window.
MEM-AR: No criterion for Syowa (9 dim.) and FPE criterion for Mizuho (12 dim.).

Maximum-Entropy Method by Auto-Regressive (MEM-AR) and Chebyshev filters are applied and discussed.

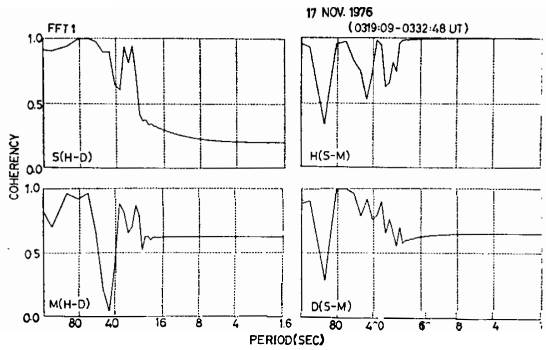
4. 1. Pc 4 waves

Fig. 4 shows original (left) and filtered (right) wave forms for the *H* and *D* components of magnetic pulsations from 0319: 09 UT to 0319: 48 UT on November 17, 1976. Chebyshev low-pass filters are applied; the cut-off frequency, the half-power point and the ripple are 0.025 Hz, 0.03 Hz and 0.02 respectively.

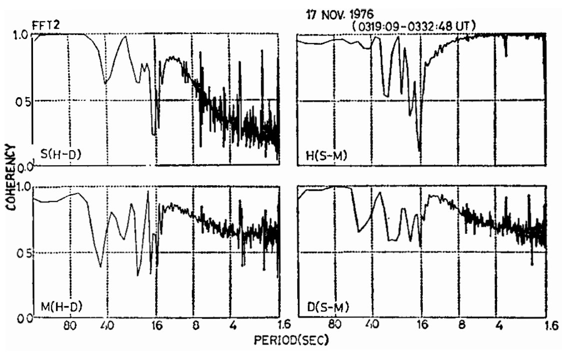
Fig. 5 shows the power spectra computed for the filtered data by the four different methods; BT with hanning spectral window, FFT with hamming data window, FFT with spheroidal prolate data window (THOMSON *et al.*, 1976) and MEM-AR with Akaike FPE criterion (AKAIKE *et al.*, 1972). The sinusoidal wave form seen at Syowa corresponds to the power density peak at the period of ~ 70 seconds. It is interesting to



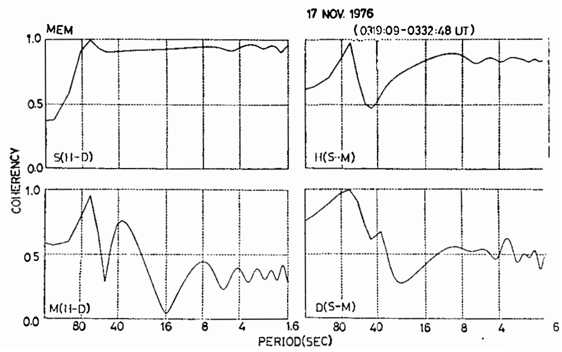
a. BT: Hanning spectral window, pre-whitening coefficient = 0.65.



b. FFT1: Hamming data window.

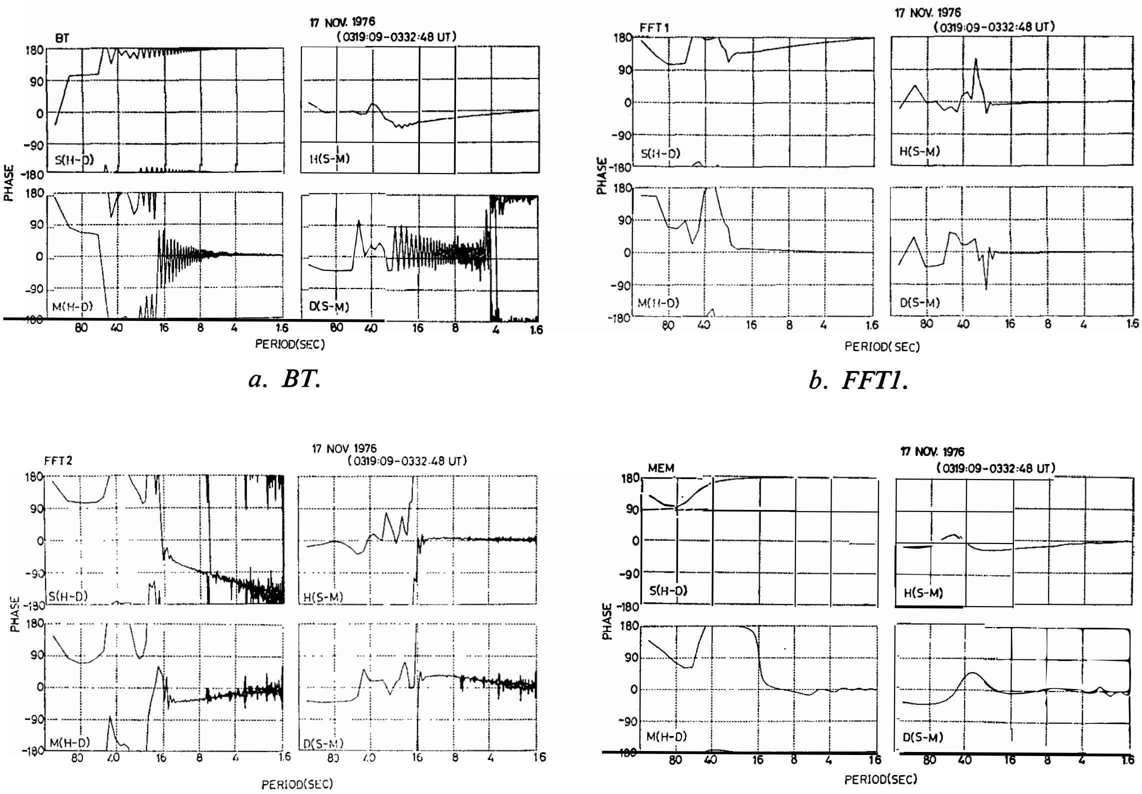


c. FFT2: Spheroidal prolate data window.



d. MEM-AR: No criterion for Syowa (9 dim.) and FPE criterion for others (12 dim. for Mizuho, 14 dim. for H component, 14 dim. for D component).

Fig. 6. Coherencies between H and D components at Syowa (upperleft) and Mizuho (lowerleft), coherencies between the two stations of H component (upperright) and D component (lowerright).



a. BT. *b. FFT1.* *c. FFT2.* *d. MEM-AR.*

Fig. 7. Phases between H and D components at Syowa (upperleft) and Mizuho (lowerleft), phases between the two stations of H component (upperright) and D component (lowerright) computed by BT (a), FFT1 (b), FFT2 (c) and MEM-AR (d).

note that the distinct Pc 4 waves at Syowa Station are not so obviously seen at Mizuho Station which is only ~270 km apart from Syowa. The results suggests that this type of wave is localized in a narrow latitude range. The four methods give almost the same results. It is seen that the results of BT with hanning window and FFT with spheroidal prolate window resemble each other, that the FFT with hamming window tends to show a larger peak than others and that the side-lobes of MEM-AR spectra are very small.

Figs. 6a-d, 7a-d show the coherency (Fig. 6) and phase (Fig. 7) relations in the time interval of 0319: 09–0332: 48 UT computed by the four methods; BT(a), FFT with hamming window (b), FFT with spheroidal prolate window (c) and MEM-AR (d). It is found in Fig. 6 that the coherencies at the period of ~70 seconds are very high; *i. e.*, the coherencies between *H* and *D* components at Syowa and Mizuho are ~1 and ~0.9, and the coherencies between Syowa and Mizuho are ~0.95 (*H* component) and ~1 (*D* component). It is seen in Fig. 7 that the phase differences between *H* and *D* components at both the stations are almost out of phase, ~110° and ~70° respectively, while the phase differences between the stations are almost in phase, ~0° and ~−40° for *H* and *D* components respectively.

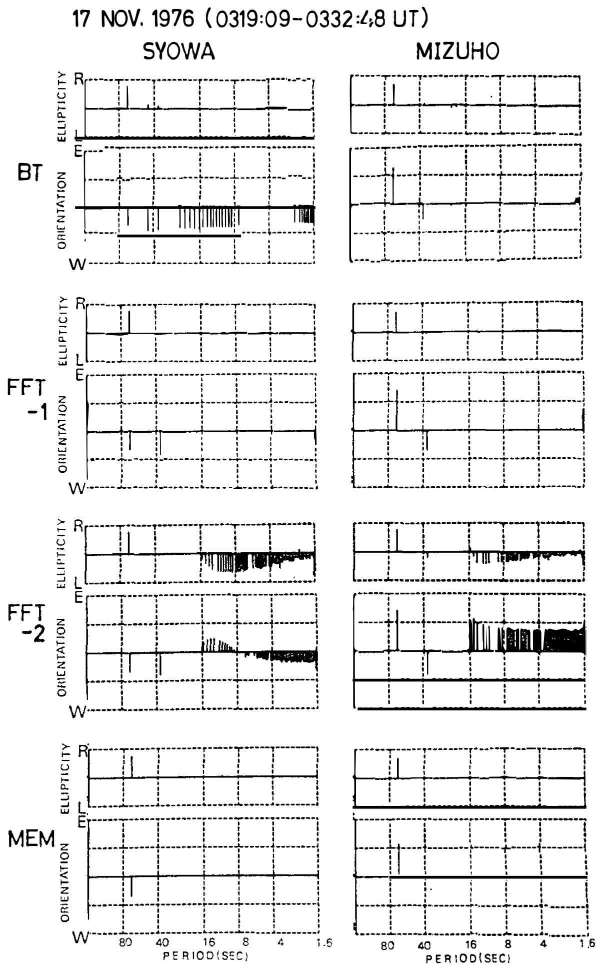


Fig. 8. Polarization parameters at Syowa (left) and Mizuho (right). The spectral methods are BT, FFT1, FFT2 and MEM-AR from upper to lower.

In Fig. 8, the ellipticity and orientation of major axis are shown for Syowa data (left) and Mizuho data (right) computed by the four methods. It is found that the orientation is in the northwest direction at Syowa and in the northeast direction at Mizuho, whereas the sense of polarization (ellipticity) is right-handed at both the stations.

From Fig. 6 to Fig. 8, the spectra computed by the four spectral methods show the results consistent with each other, whereas it is noticeable that the side-lobes of MEM-AR spectra are very small and are most suitable to emphasize the dominant peak. But it must be also said that the MEM-AR method is sometimes inadequate for the filtered data; or FPE criterion cannot give the best-fit model. For example, MEM-AR model cannot be determined well by FPE criterion for the filtered H and D components at Syowa in the time interval of 0319:09–0332:48 UT; FPE criterion suggests the 56-dimension model but the spectra are not consistent with other methods. We applied the MEM-AR model of unfiltered data, 9-dimension model, to filtered data. It may be because the MEM-AR method is not so effective for sinusoidal waves, or may be because the Chebyshev filteres are made by averaging the data with finite polynomials over time domain and filtering induces the artificial systematic error into the raw time series to decrease the merit of MEM-AR that applies also the finite polynomial model to time series.

The effects of filtering on the spectral amplitude, coherency, phase and polarization parameters are negligibly small. The figures in Appendix show the spectral results for the original data from 0319: 09 UT to 0332: 48 UT on November 17, 1976. The differences between Figs. 4–8 and the figures in Appendix show the effects of filtering.

4.2. Pc 1 waves

Fig. 9 shows original and filtered wave forms and the power spectra for the H and D components in the time interval of 0447: 57–0451: 22 UT. Chebyshev high-pass filters are applied; the cut-off frequency, the half-power point and the ripple are 0.35 Hz, 0.3 Hz and 0.02 respectively. The power spectra were computed by the three methods; BT with hanning spectral window, FFT with spheroidal prolate data window and MEM-AR with Akaike FPE criterion. Large spectral peaks are seen at $\sim$0.45 Hz at both the stations. However, it is noted that the spectral peak by BT and FFT consists of two subpeaks at 0.42 Hz and 0.48 Hz at both the stations, while the MEM-AR spectral peak

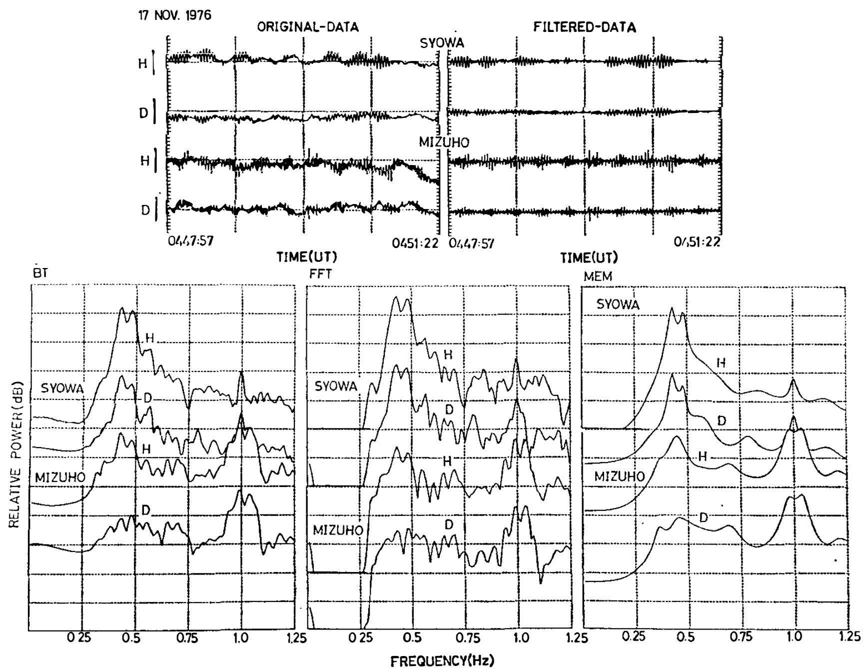
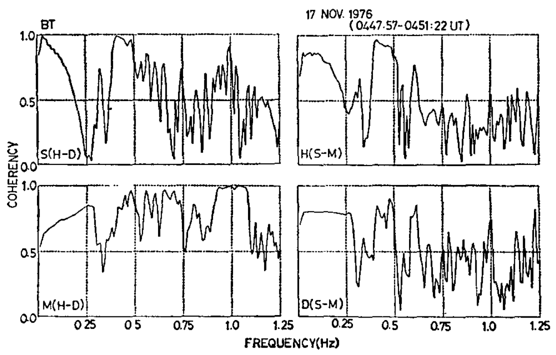
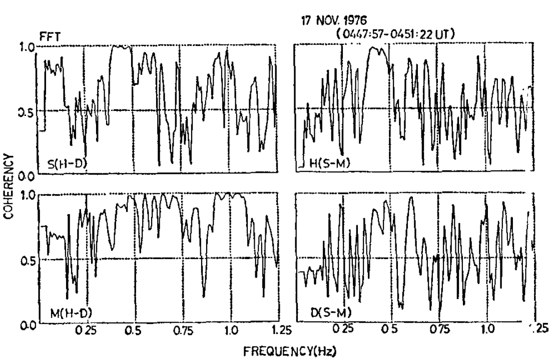


Fig. 9. The upper is original (left) and high-pass filtered (right) wave forms of magnetic pulsations in the time interval of 0447: 57–0451: 22 UT. The lower show the relative power spectra for the filtered data computed by BT, FFT and MEM-AR.

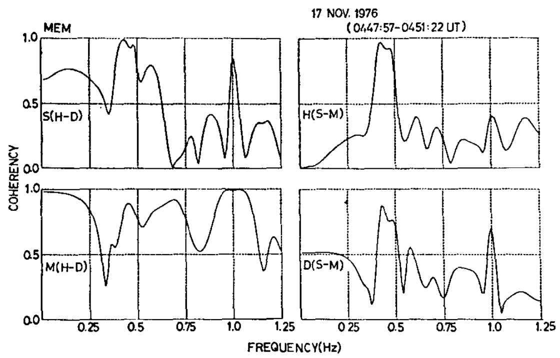
BT: Hanning spectral window, pre-whitening coefficient=0.65.
FFT: Spheroidal prolate data window.
MEM-AR: FPE criterion (13 dim. for Syowa and 13 dim. for Mizuho).



a. *BT: Hanning spectral window, pre-whitening coefficient = 0.65.*



b. *FFT: Spheroidal prolate data window.*



c. *MEM-AR: FPE criterion (13 dim. for Syowa and Mizuho, 15 dim. for H component, 14 dim. for D component).*

Fig. 10. Coherencies between H and D components at Syowa (upperleft) and Mizuho (lowerleft), coherencies between the two stations of H component (upperright) and D component (lowerright).

at Mizuho is seen only at 0.44 Hz. The spectral peaks seen at the frequency of 1.0 Hz are due to time marks.

Figs. 10a–c show the coherency relations computed by the three methods; BT (a), FFT (b) and MEM-AR (c). The coherencies of BT and FFT spectra are almost the same, although those of FFT spectra tend to give higher coherencies; the coherencies between the *H* and *D* components are ~1 (Syowa) and ~0.9 (Mizuho) at the peak of ~0.42 Hz, ~0.95 (both the stations) at the peak of ~0.44 Hz, whereas the coherencies between Syowa and Mizuho are ~0.95 (*H* component) and ~0.85 (*D* component) at the peak of ~0.42 Hz and ~0.9 (both components) at the peak of ~0.44 Hz. Although the MEM-AR spectral form differs from BT or FFT spectra, the coherencies of MEM-AR spectra are consistent with those of BT or FFT spectra in general. Because of the one peak MEM-AR spectrum at Mizuho, the coherency form is also one peak at the frequency of ~0.45 Hz at Mizuho.

4.3. Pc 3 waves

Fig. 11 shows original and filtered wave forms and power spectra for the *H* and *D* components in the time interval of 1501:15–1508:05 UT. Chebyshev low-pass filters are applied; the cut-off frequency, the half-power point and the ripple are 0.25 Hz, 0.3 Hz and 0.02 respectively. The power spectra were computed by the three methods; BT with hanning spectral window, FFT with spheroidal prolate data window and MEM-AR with Akaike FPE criterion. On the whole, the spectral peaks computed by the three methods are ~33 and ~20 seconds at both the stations, although *H* spectral peaks computed by BT and FFT are not ~33 seconds but ~40 seconds and ~20 seconds peak are not seen in FFT *D* spectrum of Mizuho and not in all MEM-AR spectra.

Figs. 12a–c, 13a–c show the coherency (Fig. 12) and phase (Fig. 13) relations. Fig. 12 shows that the coherencies of the spectra computed by the three methods at ~33 seconds are high but the coherencies at ~20 seconds are not consistent among the three methods because of the different spectral forms. The coherencies between *H* and *D* components at ~33 seconds are ~0.8 (Syowa) and ~0.9 (Mizuho) in BT spectra, ~1 (Syowa) and ~0.9 (Mizuho) in FFT spectra, ~0.85 (Syowa) and ~0.9 (Mizuho) in

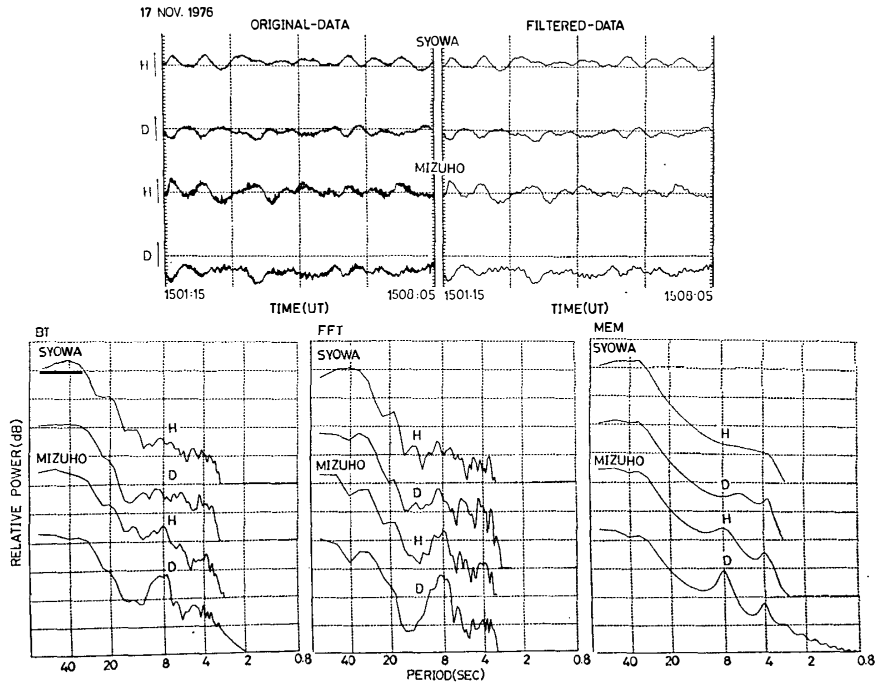
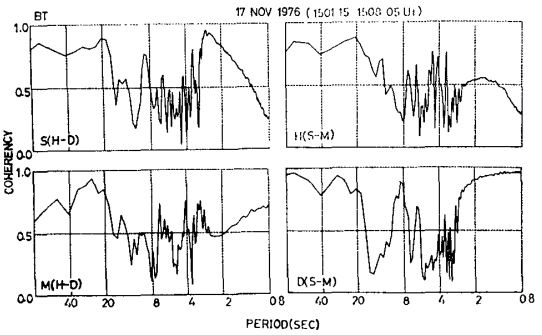
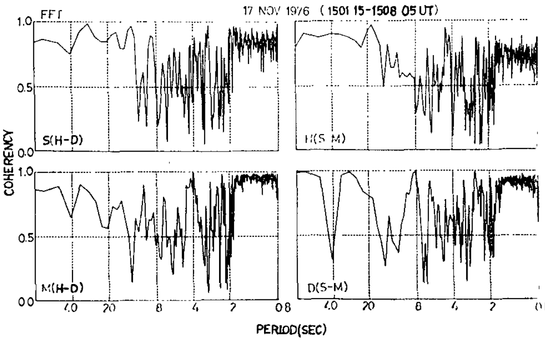


Fig. 11. The upper is original (left) and low-pass filtered (right) wave forms of magnetic pulsations in the time interval of 1501: 15–1508: 05. The lower is the relative power spectra for the filtered data computed by BT, FFT and MEM-AR.

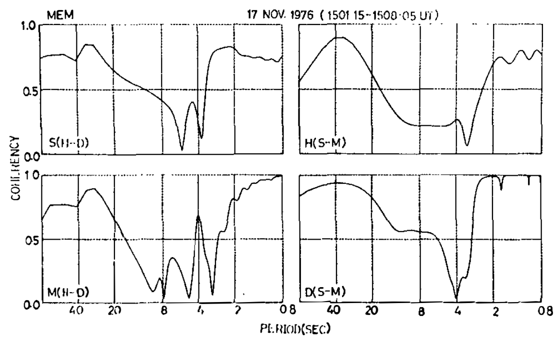
BT: Hanning spectral window, pre-whitening coefficient=0.65.
FFT: Spheroidal prolate data window.
MEM-AR: FPE criterion (16 dim. for Syowa, 23 dim. for Mizuho).



a. BT: Hanning spectral window, pre-whitening coefficient=0.65.



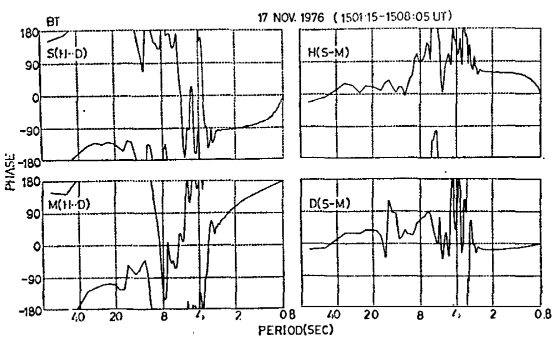
b. FFT: Spheroidal prolate data window.



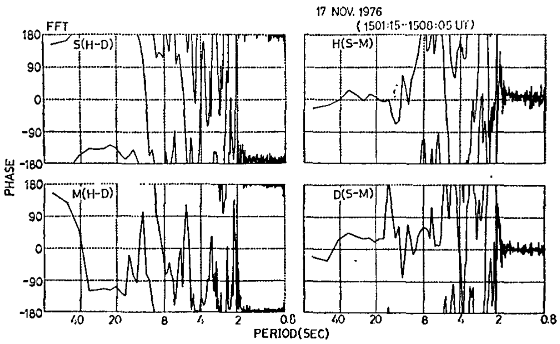
c. MEM-AR: FPE criterion (16 dim. for Syowa, 23 dim. for Mizuho, 10 dim. for H component, 12 dim. for D component).

Fig. 12. Coherencies between H and D components at Syowa (upperleft) and Mizuho (lowerleft), coherencies between the two stations of H component (upperright) and D component (lowerright).

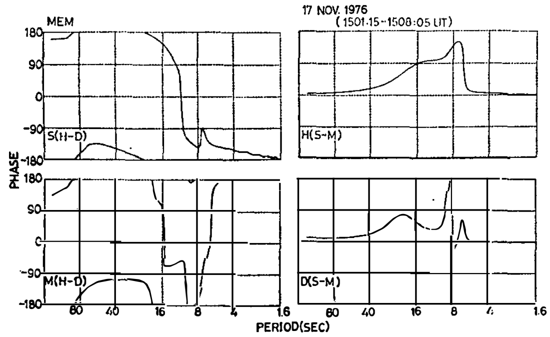
MEM-AR spectra, whereas the *H–D* coherencies at ~20 seconds are ~0.9 (Syowa) and ~0.85 (Mizuho) in BT spectra, ~0.9 (Syowa) and ~0.6 (Mizuho) in FFT spectra, ~0.65 (both the stations) in MEM-AR spectra. The coherencies between Syowa and Mizuho at ~33 seconds are ~0.8 (*H* component) and ~0.95 (*D* component) in BT spectra, ~0.85 (*H* component) and ~1 (*D* component) in FFT spectra, ~0.9 (*H* component) and ~0.95 (*D* component) in MEM-AR spectra, whereas the Syowa-Mizuho coherencies at ~20 seconds are ~0.9 (*H* component) and ~0.8 (*D* component) in BT spectra, ~0.95 (*H* component) and ~0.8 (*D* component) in FFT spectra, ~0.6 (*H* component) and ~0.8 (*D* component) in MEM-AR spectra. FFT spectra seems to give higher coherencies than those of the other methods. Figs. 13a–c show that the phase results are very consistent among the three methods; the phase differences between *H* and *D* components are almost out of phase, ~ −130° (Syowa) and ~ −120° (Mizuho), while the phase differences between the two stations are almost in phase, 20°–30°, for



a. *BT.*



b. *FFT.*



c. *MEM-AR.*

Fig. 13. Phases between H and D components at Syowa (upperleft) and Mizuho (lowerleft), phases between the two stations of H component (upperright) and D component (lowerright) computed by BT (a), FFT (b) and MEM-AR (c).

H and *D* components at the period of ~33 and ~20 seconds.

Fig. 14 shows the polarization parameters of Syowa (left) and Mizuho (right) computed by BT (upper), FFT (middle) and MEM-AR (lower). It is seen in Fig. 14 that the polarization parameters of Syowa and Mizuho resembles each other; the ellipticity and orientation at the period of 33–40 seconds are linear polarization and northwest direction respectively, and those at the period of ~20 seconds are left-handed polarization and northwest direction respectively. Because of the lack of dominant spectral peak, the polarization parameters at ~20 seconds are not computed in MEM-AR spectra.

4. 4. Discussions

Characteristics of Pc 1, 3 and 4 pulsations observed on November 17, 1976 at Syowa and Mizuho Stations are summarized as follows.

1) Pc 4 waves with a period of ~70 seconds were localized in latitude. That is, a large spectral peak was seen at Syowa while only a small spectral peak was seen at Mizuho. However, it is interesting to note that the coherency between Syowa and Mizuho was high, especially remarkable in *D* component.

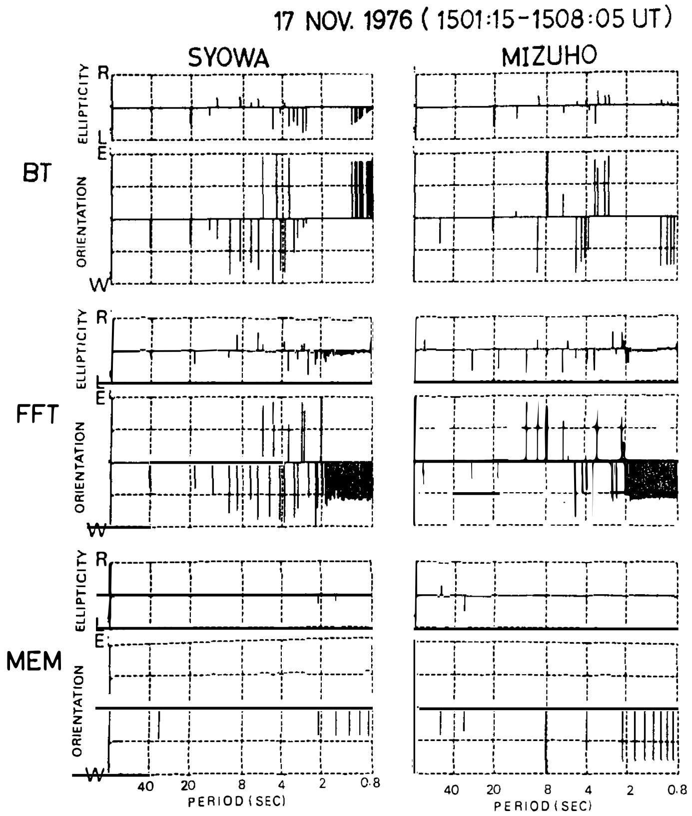


Fig. 14. Polarization parameters at Syowa (left) and Mizuho (right). The spectral methods are BT, FFT and MEM-AR from upper to lower.

2) Pc 1 waves showed a high coherency between Syowa and Mizuho, more remarkable in H component. The spectral forms varied with the methods. MEM-AR method does not show the detail spectral structure.

3) Pc3 waves were observed in the time interval of ~0600–~1800 UT. The periods changed with the magnetic local time, *i. e.*, the periods of dominant peaks become longer from ~15 seconds at 0600 UT to ~40 seconds at 1800 UT. The coherencies between H and D components were sometimes high and sometimes low, the latter case is due to the difference in the periods of the spectral peaks. The D component coherency between Syowa and Mizuho was much higher than the H component coherency.

Although the analysis was done for only one day data, the results show that the spectral analysis system given in this paper is useful for studying magnetic pulsation data. We are going to continue these analyses to get the statistical results.

Acknowledgments

The simultaneous observations of magnetic pulsations at Syowa and Mizuho Stations were carried out as one of the IMS projects of the National Institute of Polar Research by the wintering party of the 17th Japanese Antarctic Research Expedition, headed by Prof. T. YOSHINO. We are grateful to all members of the wintering party for permitting the use of these data.

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Appendix

Figs. A-1–4 show the spectral results for the original (unfiltered) data in the time interval of 0319: 09–0332: 48 UT. Figs. A-1–4 correspond with Figs. 5–8 respec-

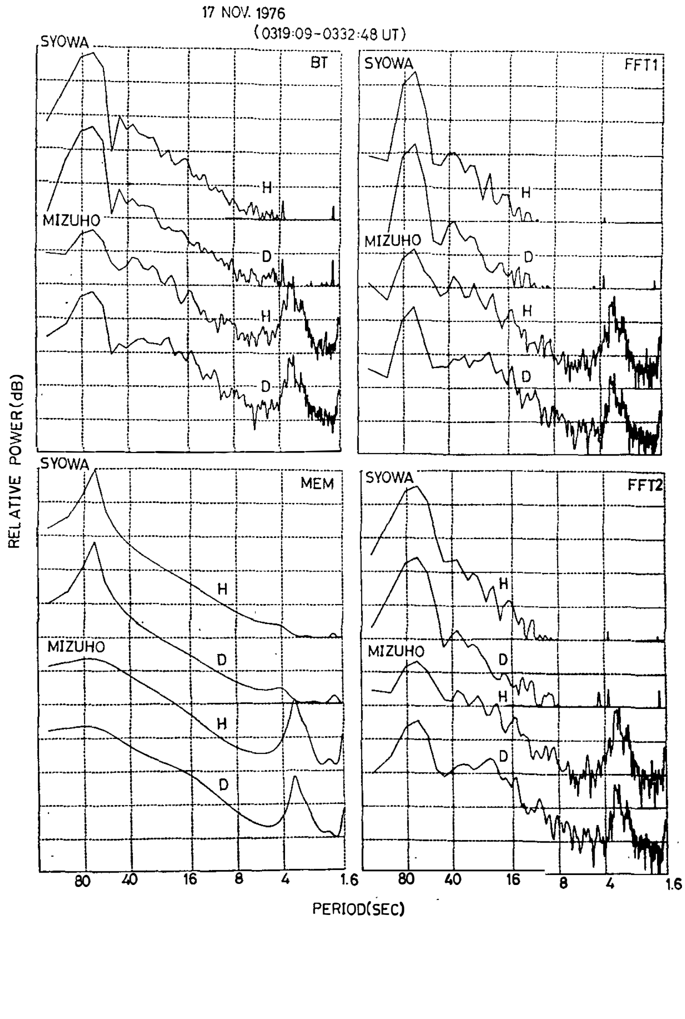
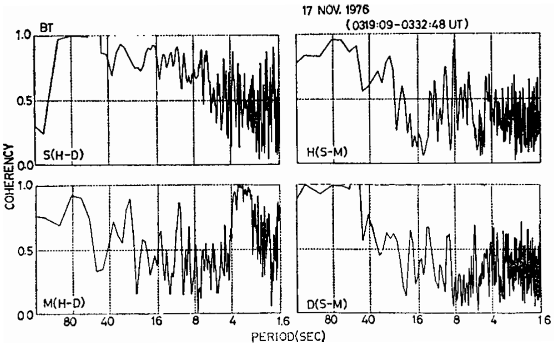
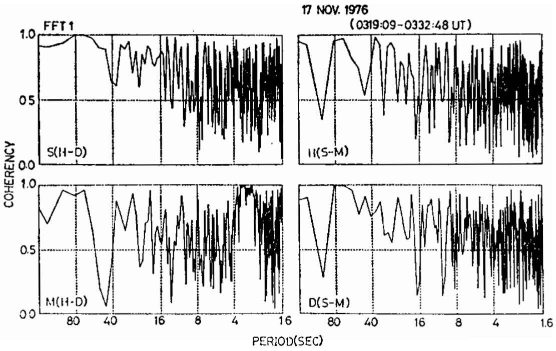


Fig. A-1. Unfiltered relative power spectra computed by BT, FFT1, FFT2 and MEM-AR.
BT: Hanning spectral window, pre-whitening coefficient =0.65.
FFT1: Hamming data window.
FFT2: Spheroidal prolate data window.
MEM-AR: FPE criterion (9 dim. for Syowa, 12 dim. for Mizuho).

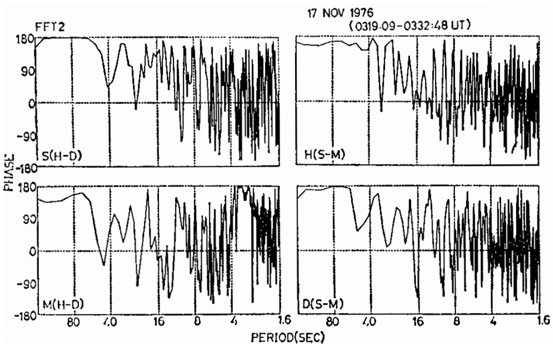
tively; Fig. A-1 shows the unfiltered relative power spectra, Figs. A-2a–d show the unfiltered coherencies, Figs. A-3a–d show the unfiltered phases and Fig. A-4 shows the unfiltered polarization parameters.



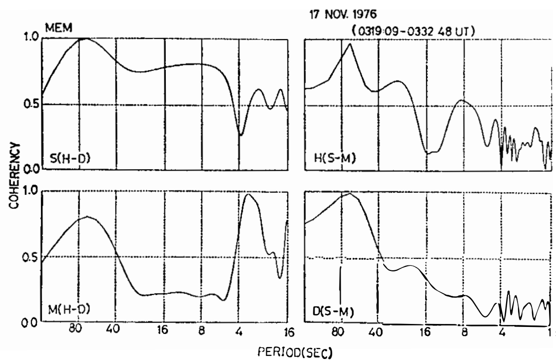
a. BT: Hanning spectral window.



b. FFT1 Hamming data window.

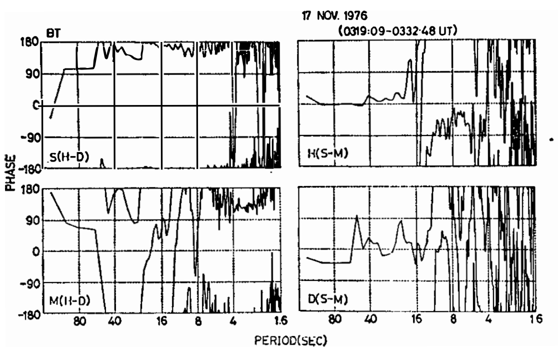


c. FFT2: Spheroidal prolate data window.

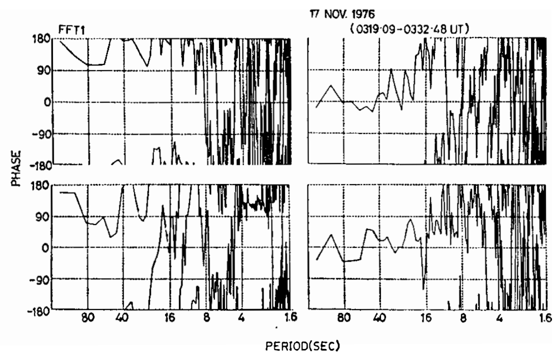


d. MEM-AR: FPE criterion (9 dim. for Syowa, 12 dim. for Mizuho, 22 dim. for H component, 14 dim. for D component).

Fig. A-2. Unfiltered coherencies between H and D components at Syowa (upperleft) and Mizuho (lowerleft), coherencies between the two stations of H component (upperright) and D component (lowerright).

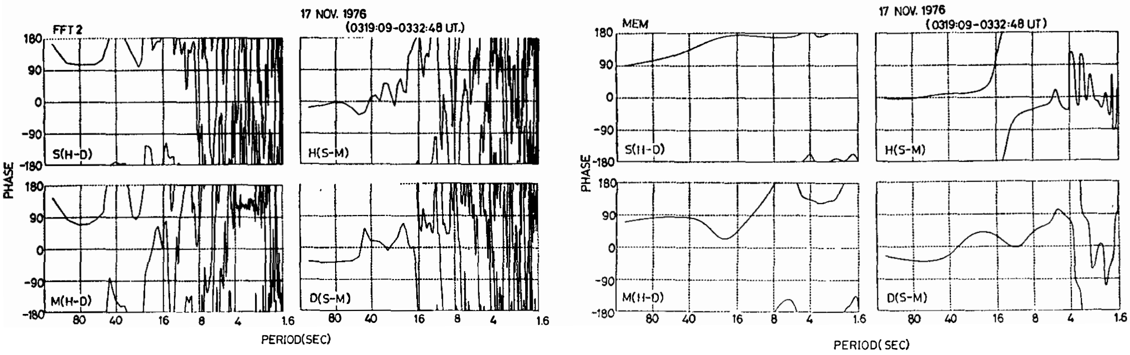


a. BT



b. FFT1.

Fig. A-3



c. *FFT2.* d. *MEM-AR.*

Fig. A-3. Unfiltered phases between H and D components at Syowa (upperleft) and Mizuho (lowerleft), phases between the two stations of H component (upperright) by BT (a), FFT1 (b), FFT2 (c) and MEM-AR (d).

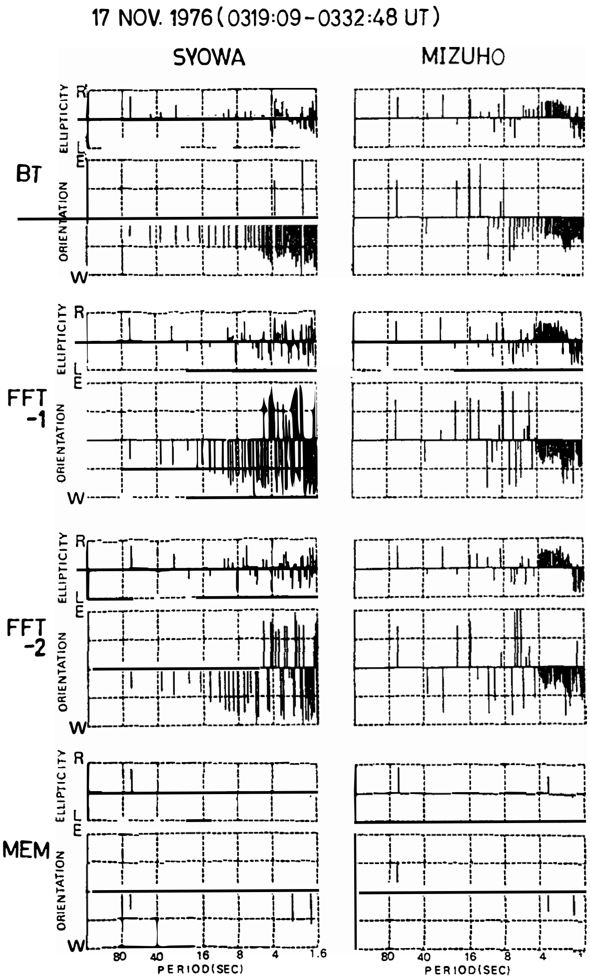


Fig. A-4. Unfiltered polarization parameters at Syowa (left) and Mizuho (right). The spectral methods are BT, FFT1, FFT2 and MEM-AR from upper to lower.