

MAGNETIC PULSATION CONJUGACY AND ITS MECHANISMS

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Abstract: A brief review and discussion is given of an investigation of the characteristics of the naturally-occurring ULF plasma waves in the magnetosphere near $L=4$. The investigation was carried out using similarly-instrumented magnetometer stations at Siple, Antarctica and in the conjugate region at Lac Rebours, Quebec. The waves were predominantly in the Pc-3 frequency range. No magnetospheric waves that satisfied an imposed strict selection criterion were observed after ~ 1700 LT. Approximately half of the 94 accepted events were left-hand elliptically polarized, with no significant change in polarization characteristics observed as a function of local time. However, a distinct preferential orientation direction as a function of local time was observed for the major axes of the polarization ellipses. Approximately 16% of the events had opposite polarizations in the two hemispheres; this may be a manifestation of occasional station non-conjugacy combined with a narrow (in latitude) extent of wave localization. All but two of the events were symmetrical about the meridian plane, implying an odd-mode standing oscillation of the geomagnetic field lines. A significant local time dependence observed in the relative orientations of the plane of the Pc-3 waves is interpreted as a possible effect of the ionosphere on the transmission of the ULF waves.

Introduction

The earth's magnetosphere is only one of two* naturally-occurring plasma environments in which the astrophysically-important MHD Alfvén waves can presently be studied in detail. The frequencies of the MHD waves occurring in the magnetosphere are such that, except for measurements made at the apogees of elliptically-orbiting spacecraft or on circularly-orbiting spacecraft, it is difficult to measure several cycles of a single wave event. Furthermore, measurements from a single spacecraft do not permit determinations of the spatial extent of most MHD events.

The use of measurements made simultaneously at conjugate points on the earth's surface has the potential of serving well for the study of the global extent and the nature of MHD waves in the earth's magnetosphere. Indeed, the first conclusive evidence that many of the rapid variations observed in the earth's field were like hydromagnetic waves was reported by SUGIURA (1961) using conjugate-point data. The Antarctic continent and several of the surrounding islands provide ideal locations in the southern hemisphere for the deployment of scientific stations conjugate to many northern locales.

* The second being the solar wind.

Recent reviews of conjugate magnetospheric phenomena have been written by WESCOTT (1966), CAMPBELL (1968), and OGUTI (1969). Following the early conjugate-point telluric current work of MATHER *et al.* (1964), the largest number of wave events studied and reported (without considering possible seasonal effects) have resulted from measurements reported by NAGATA *et al.* (1963, 1966) from the Syowa-Reykjavik conjugate pair ($L \sim 6.8$; wave periods ~ 100 to 500 sec) and reported by VAN-CHI *et al.* (1968) from the Kerguelen-Sogra conjugate pair ($L \sim 3.3$; wave periods ~ 10 to 45 sec). ANNEXSTAD and WILSON (1968) reported on twenty ~ 100 sec waves observed at College, Alaska and at Macquarie Island in the South Pacific.

The most-quoted result of the conjugate wave studies cited above has been the observation that, statistically, the polarization of the waves appears to change from predominantly left-handed (as viewed in the direction of the field line) to predominantly right-handed as the station pair passes local noon.* This result was summarized by NAGATA *et al.* (1963) for their Pc-5 observations by the schematic drawing of Fig. 1. The change in wave polarization about local noon has been used as evidence for the importance of surface waves on the magnetosphere boundary as a source of the measured pulsations (*e. g.*, DUNGEY, 1955; ATKINSON and WATANABE, 1960; DUNGEY and SOUTHWOOD, 1970). The surface waves may arise via the Kelvin-Helmholtz instability (*e. g.*, GERWIN, 1968; SOUTHWOOD, 1968). It is quite clear that a systematic investigation needs to be made of ULF phenomena at all frequencies at conjugate points at other geomagnetic latitudes in order to establish the characteristic modes of MHD waves in the earth's magnetosphere. At the present time, with the exception of the results summarized in Fig. 1, this information is essentially totally lacking.

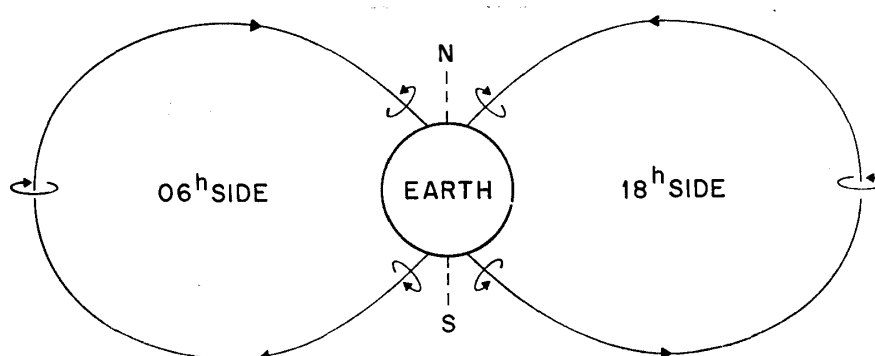


Fig. 1. Rotation of the polarization vector of the transverse mode of hydromagnetic waves corresponding to Pc-5 frequencies, as seen from the sun (after NAGATA *et al.*, 1963).

* This change in the sense of polarization for waves detected at conjugate points has also been reported for pulsations observed in a single hemisphere (*e. g.*, SAMSON *et al.*, 1971) and for storm sudden commencements (WILSON and SUGIURA, 1961).

The establishment by the U. S. National Science Foundation of Siple Station (76°55'S, 83°55'W geographic) near $L=4$ on the Antarctic continent provided an opportunity to begin an intensive detailed investigation of magnetospheric MHD phenomena near the nominal plasmopause location. During the interval 14 December 1970 to 24 January 1971 magnetic field measurements were made at Siple and at its conjugate location near Lac Rebours, Quebec (47°52'N, 72°27'W).^{*} The instrumentation at each station consists of a temperature-compensated fluxgate magnetometer with an $\sim 0.2 \gamma$ noise level and a dynamic range of $\pm 1000 \gamma$. The magnetometers are modified versions of the standard Canadian EMR field magnetometer (TRIGG *et al.*, 1971). The field values, measured for each of the three axis to a resolution of 0.06γ , are sampled at 2-sec intervals and written in a computer-compatible format on magnetic tape. Housekeeping parameters are recorded every 10 minutes to provide a monitor of the overall system performance. A crystal-controlled digital clock maintains a time reference accurate to within one second over a one-month period.

Summarized in this paper are the initial studies by Bell Laboratories of magnetospheric wave phenomena near $L=4$. Although most of the results presented here have been previously published (LANZEROTTI *et al.*, 1972a, b), some of the data presentations and discussions contained herein are new. In addition, some more recent results from this on-going program permit new insights to be made into the physical nature of the ULF phenomena.

Event Selection and Classification

In order to study, on a statistical basis, the nature of the predominant wave events observed near $L=4$, certain selection criteria were placed on the events to be analyzed. These criteria were imposed to insure that, insofar as possible, the same wave, of magnetospheric origin, was being observed at each station. Using a sliding average, magnetic field variations with periods $\tau > 4$ min were removed from each of the vector field measurements at each station. Other than this, however, *no selection was made as to wave frequency*, as it was desired to determine, statistically, *which wave frequencies predominated* when the other selection criteria (enumerated below) were satisfied.

After subtraction of the sliding average, graphs of the resulting vector components of the detected magnetic pulsations (generally a few gammas in amplitude) measured during moderately quiet magnetic conditions ($K_p < 3$) were scanned visually for evidence of coincident (at conjugate points), quasi-sinusoidal ($\tau \sim 18$ to 150 sec) variations. Using both visual inspection and power spectral analyses, nonmonochromatic waves ($\Delta\tau/\tau > \text{few percent}$) were rejected. The remaining events were further processed by narrow bandwidth filtering at a frequency and bandwidth determined from the power spectra.

The filtered wave components were plotted as hodograms in three orthogonal

^{*} These stations, together with a latitudinal array in Quebec and New Hampshire, were also operated in December 1971, January and December 1972, and for most of 1973.

planes H - D , H - Z , and D - Z . The total maximum vector amplitude $(H^2 + D^2 + Z^2)^{1/2}$ and the wave ellipticity ϵ in the plane of the wave at maximum amplitude were computed. Events at the two stations with maximum amplitudes occurring in different cycles or with maximum amplitudes differing by more than 50% were rejected. Also rejected were waves whose major axis changed orientation direction with respect to the fixed field line, or whose ellipticity variations during an event, $\Delta\epsilon$, were $> \pm 0.1$ around the maximum cycle at either station. No wave had $\epsilon \geq 0.9$; waves with $\epsilon \leq 0.05$ were classed as linear. Out of ~ 300 possible conjugate events, imposition of the selection criteria left 94 acceptable events distributed in local time between local midnight and 1700 LT (see Fig. 3). Essentially no conjugate pulsation events satisfying the above criteria were found between ~ 1700 and ~ 2300 LT.

The distribution of events that satisfied the selection criteria, as a function of event period (in bins of ten-second width), is shown in Fig. 2. It can be seen from this histogram that, on a statistical basis, events of periods ~ 20 sec to ~ 50 sec (frequency ~ 10 mHz to ~ 50 mHz; Pc-3 band) overwhelmingly predominate in the observations at $L \sim 4$. As such, the discussions that follow concerning the pulsation events will be concerned with the characteristics of Pc-3-type waves near $L=4$ in the magnetosphere.

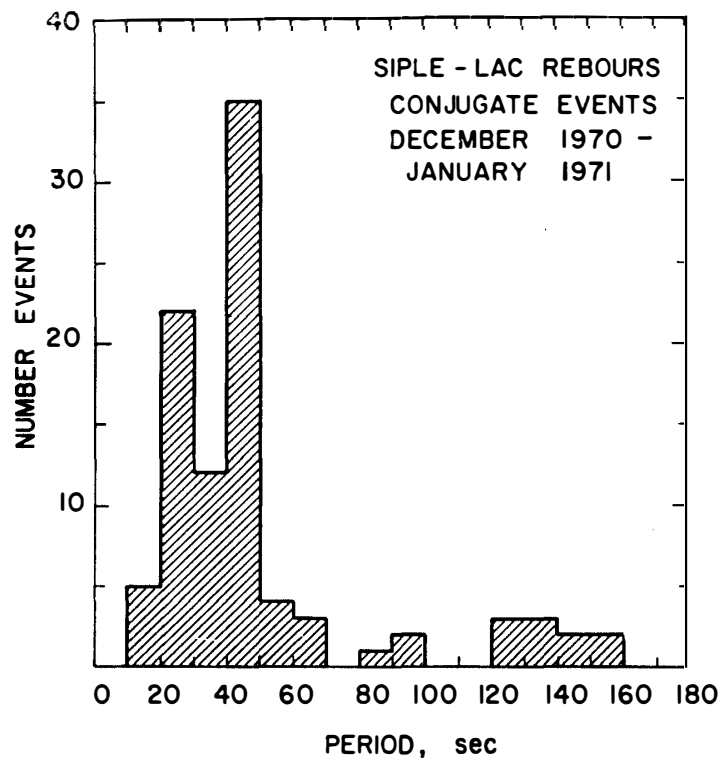


Fig. 2. Plot of the number of selected events as a function of period at the two conjugate points, Siple and Lac Reboours.

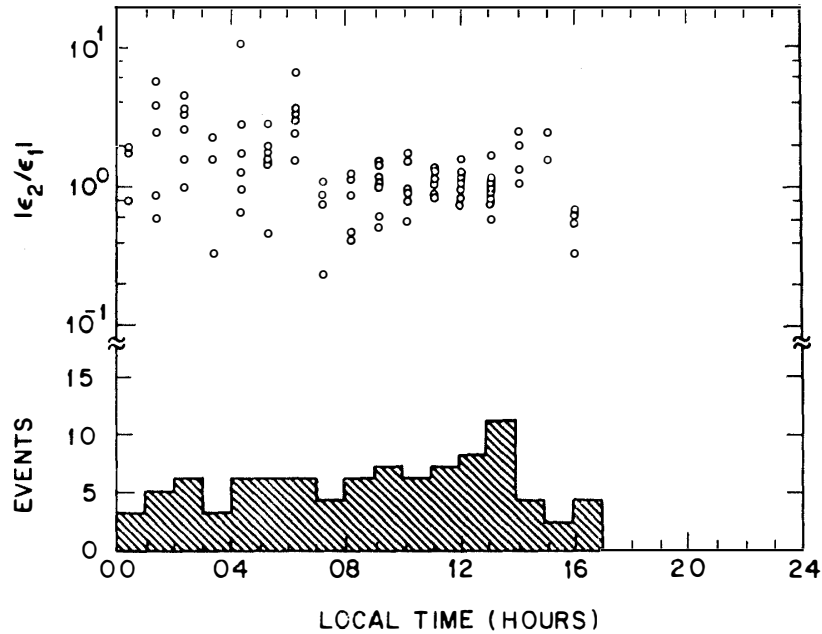


Fig. 3. Ratios of the ellipticities of the waves as measured at the conjugate stations. Plotted at the bottom is the distribution of selected events in local time.

The distribution in local time of the ratios of the wave ellipticities at Lac Rebours (station 2) to the wave ellipticities at Siple (station 1) are shown in Fig. 3. Plotted at the bottom of this Figure is the distribution of the selected events in local time. No systematic local time dependence is seen in the ratios of the wave ellipticities; a decrease in the spread in the ellipticity ratios among the several events at each hour is noted after ~ 0800 local time.

Wave Polarization

Of the 94 magnetic pulsation events that satisfied the selection criteria, 62 had elliptical polarizations at both stations and were either left-hand (LH) or right-hand (RH) waves.* Of the 62 waves, 44 were left-handed waves and 18 were right-handed waves. Figure 4a shows Siple and Lac Rebours hodograms in the H - D plane for a typical left-hand polarized wave. The wave illustrated in Fig. 4a has symmetry about the meridian plane, as did 60 of the 62 events.

In addition to the 62 wave events with elliptical polarizations at both conjugate stations, 14 waves were detected that had approximately linear polarizations at one or both of the stations. All of these waves had symmetry about the meridian plane.

* As usual, left-hand waves are defined to be rotating counter-clockwise when viewed in the direction of the geomagnetic field. Also by convention, the magnetic field is taken into the H - D plane in the northern hemisphere and out of the H - D plane in the southern hemisphere.

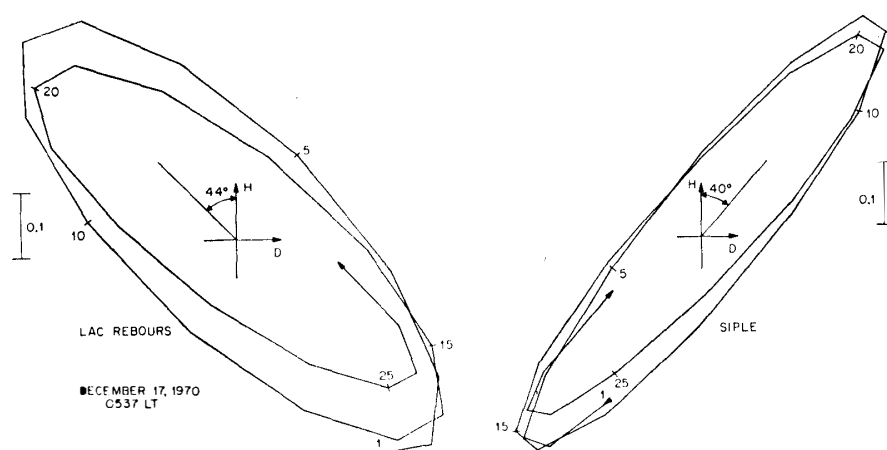


Fig. 4a. *H-D plane hodograms measured at Siple and Lac Rebours of a typical left-hand polarized wave symmetrical about the meridian plane. The time difference between each two consecutive hodogram points is equal to two seconds.*

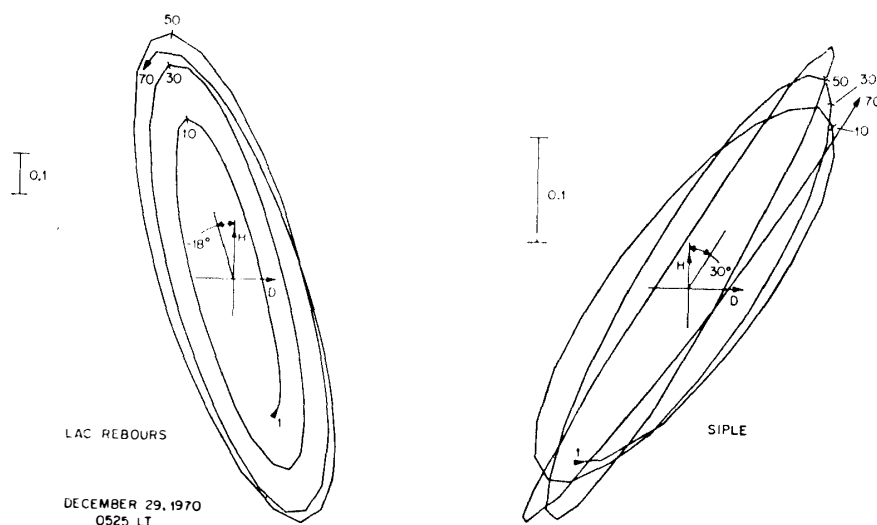


Fig. 4b. *H-D plane hodograms at conjugate points of a wave that is left-hand polarized in the northern hemisphere and right hand polarized in the southern hemisphere.*

Out of the 94 events, 15 waves, or 16% of the events, were found with elliptical polarization at both stations but with opposite rotational sense at the two stations. By each selection criterion cited in the previous section, these waves with anomalous rotation sense were good events. Figure 4b contains Siple and Lac Rebours hodograms for a wave event with left-handed polarization in the northern hemisphere and right-handed polarization in the southern hemisphere. A possible explanation of observations such as these is discussed below.

The percentages of occurrences of left-hand and right-hand waves as a function of local time are shown in Fig. 5. Plotted here are histograms for the conjugate waves that were left-handed and right-handed, as well as those events that had linear polarizations at Siple. Also plotted in Fig. 5 are those events that were measured to have opposite polarizations at the conjugate stations*.

The histograms of Fig. 5 indicate that there is no strong tendency for the

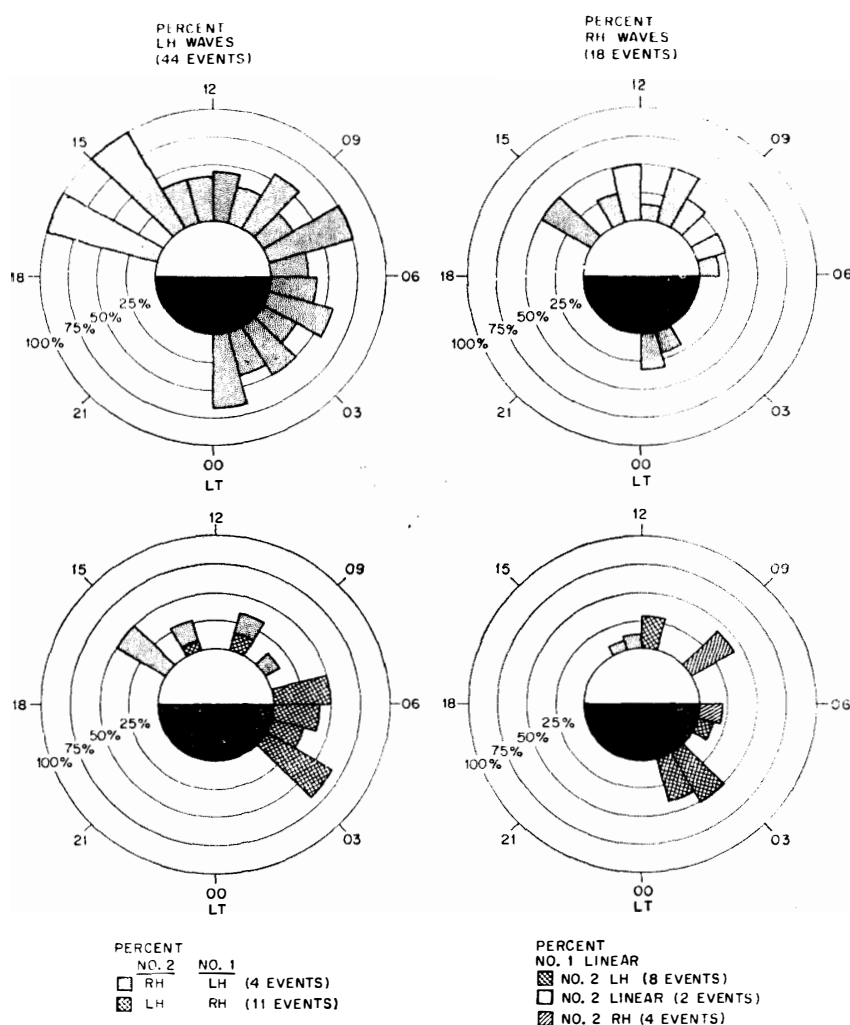


Fig. 5. Percentages of occurrence of types of polarizations of the conjugate waves at Siple (station 1) and Lac Rebours (station 2) as a function of local time. Upper left: events with left-hand polarization. Upper right: events with right-hand polarization. Lower left: events with opposite polarizations in the two hemispheres. Lower right: events with linear polarization at Siple and any polarization at Lac Rebours.

* Three events not plotted in Fig. 5 had linear polarization at Lac Rebours.

wave polarizations to shift from predominantly left-hand to predominantly right-hand around local noon. The highest percentage of RH waves occurs during the local daytime hours. Approximately 75% of the events with opposite polarizations in the two conjugate areas had LH polarizations at Lac Rebours and RH polarizations at Siple; these events tend to occur during the hours before local noon.

Wave Orientation

On a statistical basis, the direction of orientation of the major axis of the polarization ellipse of each wave showed a strong preferential orientation in each hemisphere. The preferential orientations were dependent upon local time. Plotted as a function of local time in Fig. 6 are the angles, with respect to the northern direction, of the major axis of the polarization ellipse of each event. These data show a strong preference for the northern-hemisphere waves to have their polari-

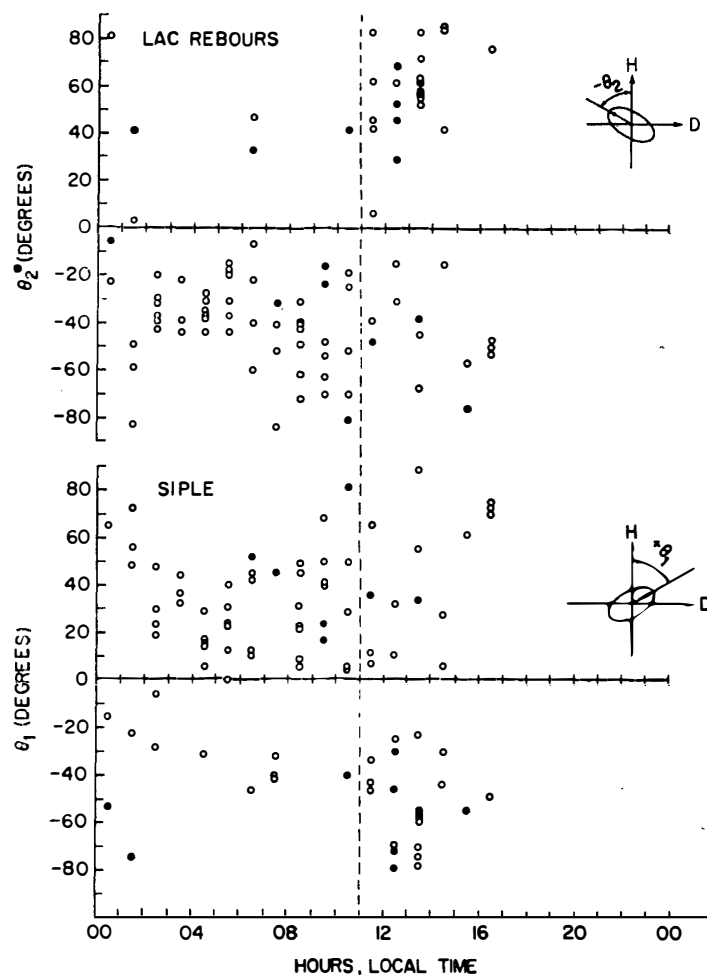


Fig. 6. Orientation angles of the major axes in the H - D plane of polarization ellipses at Lac Rebours and Siple. The dashed line is to illustrate the pre-noon/post-noon asymmetry.

zation angles in the northwest ($-\theta_2$) direction (particularly before local noon), whereas the southern-hemisphere waves have their polarization angles in the northeast ($+\theta_1$) direction (particularly before local noon). The solid points in Fig. 6 correspond to RH wave events. At both stations, beginning at approximately local noon, the ellipse orientation angles become increasingly mixed.

A similar preferential direction of orientation of wave events was reported by VAN-CHI *et al.* (1968) for Pc-3 data obtained from the Kerguelen-Sogra ($L \sim 3.3$) conjugate pair. The orientation angles of their local morning events fell in the same quadrants as for the work discussed here.

The mixed orientations noted after local noon in Fig. 6 may arise from two main sources. First, all wave frequencies are included in the data of Fig. 6; FUKUNISHI and LANZEROTTI (1974b) have shown that Pc-3 frequency waves tend to obey the preferential orientation directions more than do Pc-4 frequency waves. Secondly, the data of Fig. 6 are statistical in the sense that events on many different days are included. FUKUNISHI and LANZEROTTI (1974b) have found from the analysis of a single day of data with many magnetic pulsation events that the orientation direction after local noon for Pc-3 frequencies is much better defined (*i. e.* almost purely $+\theta_2$ and $-\theta_1$) than for the statistical data in Fig. 6.

The symmetry of the orientation angles of the wave events about the meridian plane was usually quite good (LANZEROTTI *et al.*, 1972b). That is, it was found that $|\theta_1 - \theta_2| \lesssim 25^\circ$. If large differences in crustal uniformities existed in one or both hemispheres, it might be expected that $|\theta_1 - \theta_2|$ would be much larger than that observed, as no selection criteria was imposed on the similarity, between hemispheres, of the ellipse orientation angle.

Tilt Angle of Wave Plane

As mentioned earlier in the discussion of the selection criteria, the characteristics of the pulsation events in the principal planes of the waves were computed and investigated. In particular, the tilt (from the horizontal plane) of the principal wave plane was compared in each hemisphere for the individual events. The main purpose of this investigation was to search for a possible ionospheric effect on the transmission of ULF waves from the magnetosphere to the ground. The ionosphere over Siple was continuously sunlit during the period of investigation while the ionosphere over Lac Rebours underwent a diurnal solar illumination cycle.

An effect that is expected to occur for a wave incident on the surface of a uniform conductor of large horizontal extent (*e. g.*, the ionosphere, the earth's crust, or the ocean surface) is a reduction in the amplitude of the vertical wave component ΔZ relative to the amplitude of the horizontal component $\Delta(H, D)$ [$\Delta(H, D) \equiv (\Delta H^2 + \Delta D^2)^{1/2}$]. The magnetic effect will arise from the currents induced in the conductor by the incident wave.

The relative wave orientation at maximum wave intensity was investigated for each event by computing the tangent of the vertical Parkinson (1959, 1962)

angle Ψ defined here as

$$\Psi = \tan^{-1} \frac{\Delta Z_{\max}}{\Delta(H,D)_{\max}}. \quad (1)$$

The local time dependence of the difference between $\tan \Psi_2$ and $\tan \Psi_1$ (for Lac Rebours and Siple, respectively) for each event is shown in Fig. 7b. This comparison of the wave orientations at the two stations, which minimizes the effects of possible systematic source changes (INOUE and SCHAEFFER, 1970), indicates a clear local time dependence in the relative wave orientations. A linear least-squares fit made to the data between 0000 and 1300 LT gives an indication of the reliability of the observed local time dependence. The correlation coefficient of the fit ($-.64$) indicates a probability $P < 1$ in 10^5 for a chance occurrence of the systematic local time change. The t-test on the correlation coefficient indicates a $P < 1$

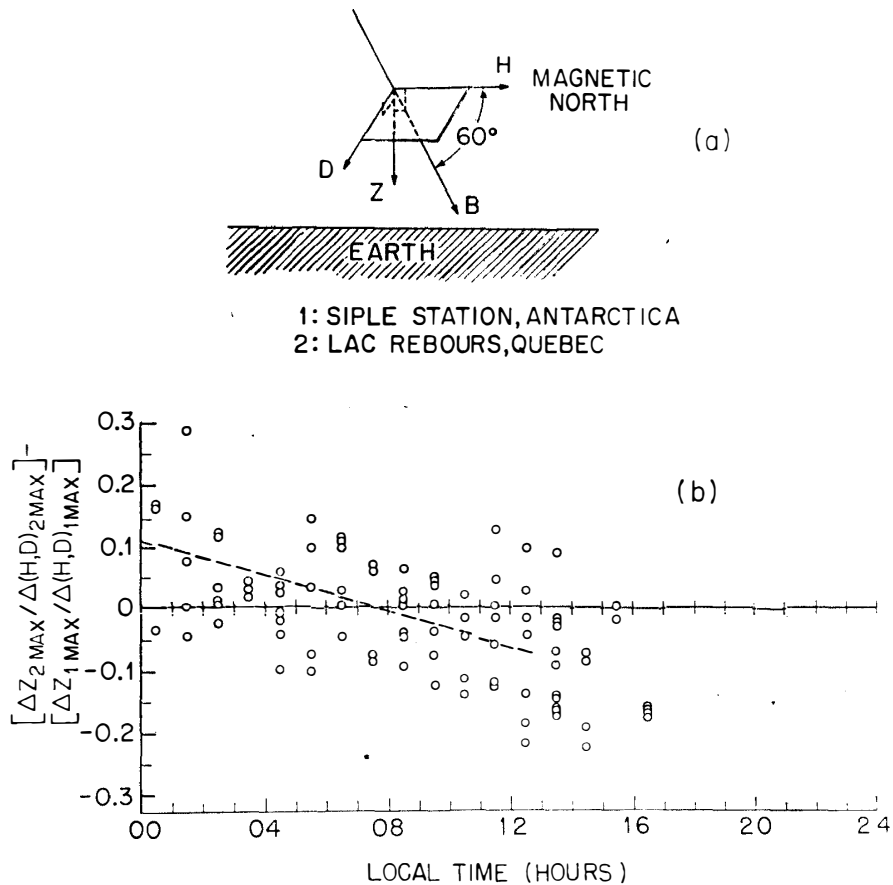


Fig. 7. a) Orientation at Lac Rebours (station 2) of the measured components of the changes in the earth's magnetic field. At Siple (station 1), Z is directed upward. b) Local time dependence of the difference in the plane of orientation of the plasma waves measured at the two conjugate stations.

in 10° for the null hypothesis to be correct.* The local time change observed in the relative orientations of the magnetospheric plasma waves measured at the conjugate stations can be attributed to changes in the ionospheric transmission of these waves at different local times.

Considerations of the local time dependence of $\tan \psi$ at the individual stations separately gave the surprising result that, to a statistically significant occurrence probability, the local time dependence was most evident in the Siple data (LANZEROTTI *et al.*, 1972a). Because it is impossible to separate source and ionospheric effects (as well as possible ground effects) from measurements of $\tan \psi$ made at individual stations, these surprising results cannot be used to draw definitive conclusions about whether the ionosphere over the northern hemisphere or the ionosphere over the southern hemisphere is exerting the greatest effect on wave transmission during the December solstice. If this caution is remembered, however, then the results of LANZEROTTI *et al.* (1972a), interpreted as a purely ionospheric effect, suggest that, on the average, the local night, daylit ionosphere over the Antarctic station has enhanced densities or density gradients, or both (probably in the E region), that affect ULF wave transmission during the local night hours and produce a significant change in the plane of the wave orientation. The Lac Rebour data suggest that, on the average, the density gradients and densities in the nighttime (probably E-region) ionosphere are such that ULF wave transmission is the same under both light and dark ionospheric conditions. Possible explanations for these results were offered by LANZEROTTI *et al.* (1972a). They included asymmetries in the particle mirror heights in the two hemispheres (lower over Siple) and a local time dependence in the particle precipitation patterns due to closer proximity of the stations to the auroral oval during local night.

It is clear that further investigations of possible ionospheric influences on ULF waves need to be made. One such investigation, currently being conducted by Bell Laboratories, involves the measurement of ULF waves at conjugate points during the local day while the Antarctic ionosphere is in darkness (southern winter conditions) and the northern ionosphere is sunlit. The results from this investigation should provide important new insights into the general question of ionospheric effects on ULF wave transmission.

Discussion

Several of the more prominent conclusions of the morphological study of the ULF wave characteristics near $L=4$ during the December solstice are shown in Fig. 8. As the distribution of wave periods in Fig. 2 indicates, the summarized

* The linear fit was made only to the first 13 hours. Although it is likely that the local time dependence being studied is a periodic function, roughly symmetrical about local noon and midnight, the absence of local evening events prevented the use of a more sophisticated fitting function such as a sinusoid, whose phase could also be varied. However, the data of Fig. 7b do not give evidence for a change in $\tan \psi$ after local noon.

results of Fig. 8 are essentially for Pc-3-type waves. Figure 8a illustrates the case of a left-handed polarized wave, symmetrical about the meridian plane (corresponding to the predominantly observed situation). Further, the major axes of the ellipses of the waves are oriented primarily in the northwest quadrant ($-\theta_2$) in the northern hemisphere and predominantly in the northeast quadrant ($+\theta_1$) in the southern hemisphere (particularly for waves observed before local noon).

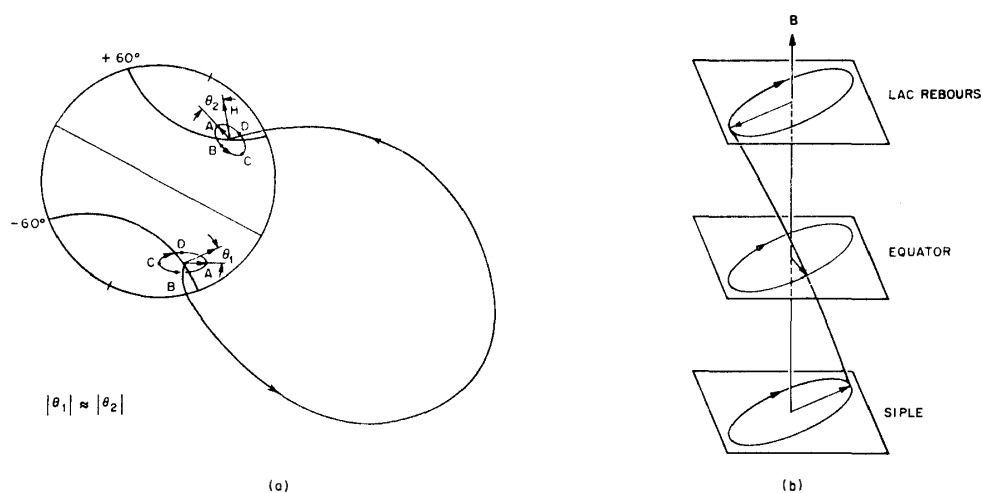


Fig. 8. The orientation and polarization of the dominant magnetospheric wave observed during the 1970-1971 December solstice.

Figure 8b explains the observed wave polarization by illustrating the observed ellipticities along a "straightened" field line. The observations suggest that the waves can be visualized as confined to an elliptical volume about the $L=4$ field line with the wave vectors rotating inside the elliptical "tube". These waves can be considered odd-mode standing-wave oscillations of the geomagnetic field lines. This conclusion on the symmetry of the waves is, of course, different from the Pc-5 results of NAGATA *et al.* (1963) (shown in Fig. 1) of a pure transverse equatorial wave with the horizontal wave components in the opposite hemispheres out of phase (even-mode standing waves). The results on the wave symmetries are also inconsistent with the Pc-4 conclusions of CUMMINGS *et al.* (1969) from an analysis of ATS-1 satellite data.

The interpretations of the Pc-3 wave polarization and orientation results reviewed here have been discussed by LANZEROTTI *et al.* (1972b) and CHEN and HASEGAWA (1974). It was considered by LANZEROTTI *et al.* (1972b) that, ignoring the possibility of the superposition of two linearly polarized waves, the LH elliptically-polarized Pc-3 results would appear to imply the observation of a left-handed surface wave. A body wave (such as the anisotropic or isotropic resonance mode of the magnetosphere) would tend to be ruled out because such a wave is linearly polarized.

CHEN and HASEGAWA (1974) have extensively investigated the theoretical

implications of these and other (VAN-CHI *et al.*, 1968; SAMSON *et al.*, 1971; SAMSON and ROSTOKER, 1972) magnetic pulsation results. They have shown through quite general considerations that, because of magnetospheric plasma non-uniformities and the curvature of the dipole field-lines, surface waves excited at the magnetopause can couple to the shear Alfvén wave of the local resonant field lines inside the magnetosphere. They find that near the resonant field line, the shear Alfvén wave exists (with the resulting linear polarization). On either side of the resonant field line, an elliptically-polarized wave exists, with the sense of polarization opposite on either side of the local resonance and dependent upon the direction of azimuthal wave propagation.* The considerations of CHEN and HASEGAWA with regard to the wave coupling at plasma non-uniformities appear to explain the observations of Fig. 6, *i. e.*, the abrupt change in the orientations of the wave ellipses around local noon.

One of the significant puzzling facts of the results is the existence of waves with opposite polarizations in the two hemispheres. The work by INOUE (1973) and CHEN and HASEGAWA (1974) on the nature of the latitude dependence of wave polarizations around a strongly localized source yields some theoretical insight into possible explanations of the opposite polarization observations. That is, if the source of the Pc-3 waves is quite narrow and if for some reason conjugacy is not very good for a given event, then the opposite polarizations could imply that the conjugate stations were actually on opposite sides of the (latitudinal) source localization region at the time of the event. That is, if $F(x)$ is the latitudinal localization, then the ellipticity in the horizontal plane can be given as (INOUE, 1973)

$$\frac{B_D}{B_H} = \frac{|k|}{1/F(x) dF(x)/dx} \quad (2)$$

where $|k|$ is the wave number in the y (azimuthal) direction. Taking $F(x)$ as a Gaussian distribution for example, the derivative in the denominator of (2) will change signs across the localization peak and thus the direction of polarization will be opposite on opposite sides of $F(x)_{\max}$.

The major difficulty in using the above explanation for the opposite polarizations in conjugate regions is that the degree of wave localization near $L=4$ is unknown. According to magnetic field model calculations, the point conjugate to Siple station lies within ~ 50 km of Lac Rebours (LANZEROTTI *et al.*, 1972b; SURKAN and LANZEROTTI, 1974). There is some evidence, however, that in terms of geomagnetic power levels (measured in January 1972 in the frequency band 0.35 mHz to 100 mHz) Siple is more closely conjugate to a station near $L=4.4$ than to Lac Rebours (SURKAN and LANZEROTTI, 1974). Some recent work by FUKUNISHI and LANZEROTTI (1974b) on the latitudinal changes in wave polarizations near $L=4$ indicate that at times the wave localization may be quite narrow (perhaps ≤ 100 km). Thus, although further work is certainly needed, it is possible that the opposite polariza-

* This dependence of polarization sense upon the latitudinal extent of wave localization has also been treated by INOUE (1973; see below), who did not, however, consider explicit processes for producing the localization.

tions at conjugate points arises from small degrees of non-conjugacy together with highly localized (in the latitudinal direction) wave sources.

No wave events that satisfied the selection criteria were observed during the local afternoon hours (cf. Fig. 5). The field fluctuations in the local evening were found to be most often quite irregular with no coherent quasi-monochromatic waves evident (LANZEROTTI *et al.*, 1972b). This observation could be interpreted as an effect of the plasmopause; *i. e.*, perhaps in the local afternoon, when the conjugate pair would most likely be inside the plasmasphere, the Pc-3-type waves would not be observed. Such an explanation is consistent with recent work of FUKUNISHI and LANZEROTTI (1974a) and MACLENNAN *et al.* (1974) who report evidence for enhanced levels in the power in the Pc-3 band occurring at higher latitudes than for the power in the Pc-4 band. This has been interpreted as evidence for the plasmopause existing at a latitude between the latitudes where the Pc-3 and Pc-4 band peak amplitudes occur*. Statistical results suggesting such a relationship have also been reported by ORR and MATTHEW (1971) and ORR (1973).

The disappearance of events after ~ 1700 LT has some resemblance to the local-time dependence found in wave events on ATS-1 in January 1967 (CUMMINGS *et al.*, 1969). The local time dependence in Fig. 5 also appears consistent to some extent with the results of some previous statistical studies on the frequency of occurrence of wave-like field variations ($\tau \sim 5-45$ sec) using non-conjugate ground-based data (JACOBS and SINNO, 1960 a, b).

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* However, an examination of the latitude dependence of the amplitude of several Pc-3 events, together with the statistical location of the plasmopause corresponding to the K_p conditions at the time of each event, suggested to КОПЫТЕНКО *et al.* (1973) that Pc-3 pulsations have a peak amplitude within the plasmasphere.

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