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HYDROMAGNETIC PHENOMENA AT THE MAGNETOPAUSE AND IN THE MAGNETOSPHERE

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Spacecraft and ground-based techniques have been used jointly in recent years to study hydromagnetic waves and currents at high dayside latitudes along geomagnetic field lines which connect through the boundary layer and magnetopause. This paper reviews some current observational work and relates it to present theoretical ideas. Topics covered include: a) transmission of hydromagnetic waves across the magnetopause and into the magnetosphere; b) relationships of hydromagnetic power and waves to interplanetary solar wind parameters; c) relationship of localized field-aligned currents to magnetopause and boundary layer processes; d) ionosphere electric fields and auroral emissions accompanying localized field-aligned currents.

FENÔMENOS HIDROMAGNÉTICOS NA MAGNETOPAUSA E NA MAGNETOSFERA – Medidas a bordo de veículos espaciais e na superfície terrestre têm sido usadas para estudar ondas e correntes hidromagnéticas, de regiões de alta latitude e de período diurno, que fluem ao longo das linhas do campo geomagnético através da magnetopausa e da camada adjacente de contorno ("boundary layer"). Este artigo apresenta uma revisão de alguns dos trabalhos observacionais mais recentes, examinando-os sob o ponto de vista de conceitos teóricos atuais. Os tópicos abordados incluem: a) a transmissão de ondas hidromagnéticas através da magnetopausa e dentro da magnetosfera; b) o relacionamento das ondas hidromagnéticas e seus espectros de potência com os parâmetros interplanetários do vento solar; c) o relacionamento entre as correntes localizadas ao longo das linhas de campo magnético com os processos físicos que ocorrem na magnetopausa e na camada adjacente de contorno; d) a ocorrência de campos elétricos ionosféricos e emissões aurorais acompanhando correntes localizadas ao longo das linhas do campo geomagnético.

I. INTRODUCTION

Since its discovery, the Earth's magnetopause has been a geospace region of intense investigation both by spacecraft and, where feasible, by ground-based techniques. The importance of the magnetopause arises because it is one of the "cellular boundaries" in cosmic plasmas which separate plasma regimes of vastly different characteristics (Alfvén, 1981). The transmission of hydromagnetic waves and energy across the magnetopause and the conversion of solar wind dynamic pressure to hydromagnetic energy inside the magnetosphere is a topic of significant importance in understanding the stability of the magnetopause and the mechanisms by which energy can be exchanged across similar cellular boundaries within cosmic plasmas.

In addition to extensive spacecraft studies of the fine scale structure of the magnetopause and of the possible magnetic field reconnection processes which may occur on the boundary, a number of ground-based investigations have also examined magnetopause processes. These include studies of hydromagnetic waves in the polar ionosphere and of other electric and magnetic fields which are associated with magnetopause processes as they would be transmitted along magnetopause flux tubes to the high latitude ionosphere. For example, Bolshakova & Troitskaya (1982), Olson (1986) and Cole et al. (1986) have all investigated magnetic field fluctuations at high geomagnetic latitudes which may be associated with the magnetopause and the magnetospheric low latitude boundary layer. Fraser-Smith (1982) reviewed aspects of the hydromagnetic wave situation a few years ago. Characteristic hydromagnetic features are found in the data which can be associated with magnetopause wave processes, as well as with a direct penetration of solar wind energy to ionospheric altitudes.

Some recent hydromagnetic wave studies reported from our Laboratories are discussed in Section III. Section IV discusses some present investigations of the large magnetic impulse events which have been recorded at high geomagnetic latitudes on the dayside of the Earth. The impulse events are probably related to special magnetopause and/or boundary layer processes, and thus the research on their occurrence and characteristics is an area of much active investigation at present.

Further details on the topics discussed in the following sections are contained in the references which occur throughout the text.

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II. OBSERVATIONS

The ground-based data discussions herein were obtained primarily from Bell Laboratories instrumentation installed at the high latitude stations South Pole (SP), Antarctica, and Iqaluit (IQ), Northwest Territories, Canada. These stations are located approximately at opposite ends of a geomagnetic flux tube. For low levels of geomagnetic activity, this flux tube will pass close to, or along, the dayside magnetopause. The locations of SP, IQ, and Sondre Stromfjord (SS), Greenland, are shown in Fig. 1, where the Antarctic continent has been mapped along geomagnetic coordinates to the northern hemisphere (courtesy of M. Rycroft and R. Greenwald). As noted, during local daytime conditions the geomagnetic latitude of these two stations places their connecting flux tube close to the nominal geomagnetic cusp. However, the precise geomagnetic locations of the stations can change as a function of local time and with geomagnetic activity; magnetospheric models for such high latitudes are not very accurate. This is therefore a problem that requires further investigation, one which would ideally include simultaneous low altitude spacecraft measurements of the last closed field lines over a conjugate station pair.

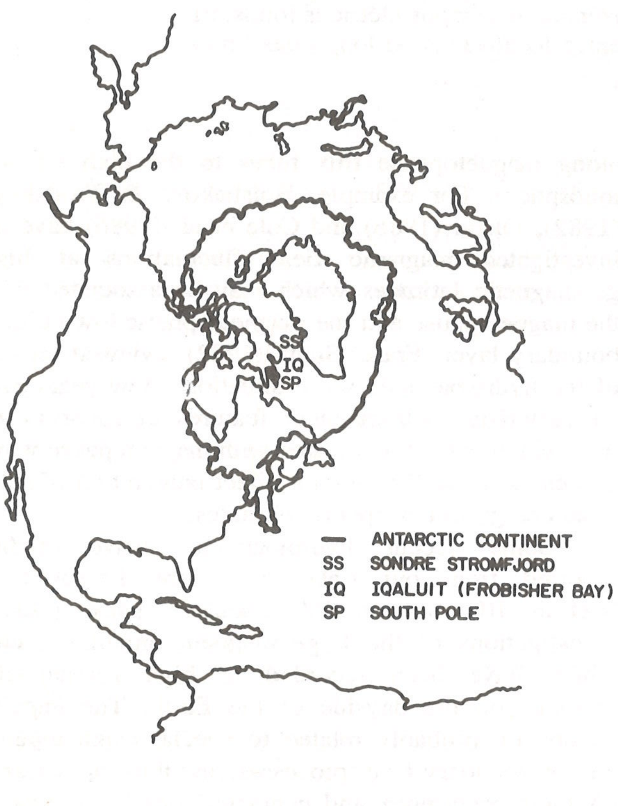


Figure 1. Locations of the principal ground-based observing stations mentioned in this paper at Iqaluit (IQ), Northwest Territories, Canada, Sondre Stromfjord (SS), Greenland, and South Pole (SP) Station, Antarctica. The Antarctica continent has been mapped in geomagnetic coordinates to the northern hemisphere.

At both SP and IQ the magnetometers are flux gates with noise levels of ~ 0.2 nT. The data in three orthogonal components (H-component, geomagnetic south-north; D-component, geomagnetic west-east; vertical, positive increase looking in the direction of the field) are recorded digitally at both stations with a one second (SP) and a five second (IQ) digitization interval. The digitization amplitude at each location, provided by 14 bit analog to digital converters, is 0.06 nT. In addition to the sampling of the magnetic field data in the three magnetic components, each data record (10 minutes) also contains various performance parameters of the instruments and the data acquisition system in order to provide measures of the system performance.

III. HYDROMAGNETIC WAVES

This section contains some recent studies of hydromagnetic waves made at high magnetic latitudes on the dayside of the Earth and their occurrence relationship to interplanetary plasma conditions. A number of investigations have reported studies of the simultaneous occurrence of waves in the Pc 3 frequency band (~ 0.02 to 0.1 Hz) in the solar wind and inside the magnetosphere (e.g., Engebretson et al., 1987). Furthermore, several statistical studies at both high (Slawinski et al., 1988; Engebretson et al., 1986) and low (Gul'elmi, 1974, and work references therein) latitudes have found a dependence of the frequency of the hydromagnetic waves (for a percentage of the observations) on the interplanetary magnetic field magnitude. The frequency dependent hydromagnetic wave branch is similar to that found by Russell & Hoppe (1981) for the frequency dependence of ion cyclotron waves observed in the solar wind on the interplanetary field magnitude.

In contrast, only a few studies have specifically examined hydromagnetic fluctuation phenomena in the magnetosheath, at the magnetopause, and directly across the magnetopause in order to examine the penetration of wave energy from the solar wind into the magnetosphere proper (Wolfe & Kaufmann, 1975; Verzariu, 1973; Greenstadt et al., 1983). Results from a recent study using data from the ISEE-2 spacecraft as it entered the magnetosphere and from ground-based data taken at SP, at the end of a flux tube connecting through the region where the spacecraft entered the magnetosphere near the equator, are shown in Fig. 2. The magnetopause crossing by the ISEE spacecraft occurred within an hour or so local noon. Amplitudes plotted in this figure are the power spectral amplitudes at the frequencies denoted, where the two frequencies were selected from power spectra of the ground-based data (the spacecraft spectra were less structured in general than were the spectra from the ground data, although the oscillations at the higher frequency were strongly visually evident as well in the spacecraft data (Lanzerotti et al., 1989)). Because of the different spectral techniques used for the spacecraft data and for the ground data, the amplitudes cannot be compared directly between the two locations. It is clear, however, from the ISEE data that the amplitudes of the fluctuations inside the magnetosphere are significantly attenuated from those in the magnetosheath. Inside the magnetosphere, the power levels of the fluctuations at the two frequencies decrease with increasing radial distance from the magnetopause. The radial dependence of the fall-off is less than would be expected from theoretical considerations of surface wave attenuation inside the magnetosphere (Lanzerotti et al., 1989).

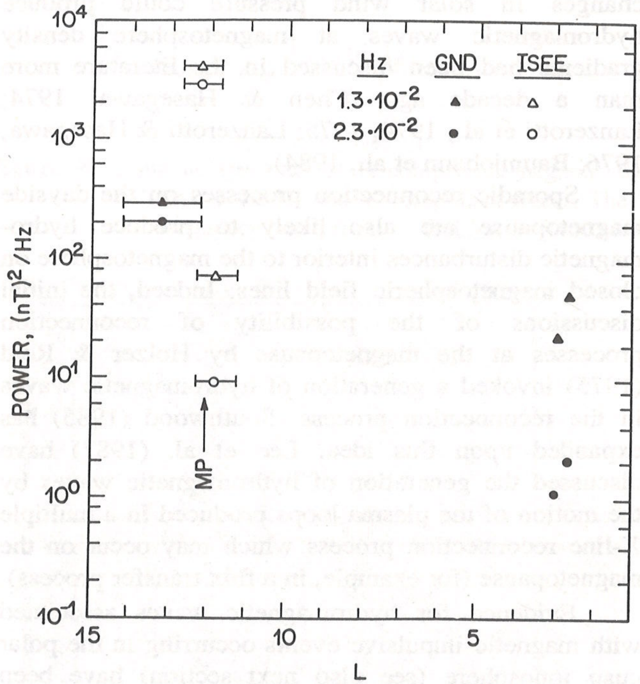


Figure 2. Power spectral levels of magnetic field fluctuations at two frequencies as measured on the ground and on the ISEE-2 spacecraft. Data are plotted as a function of L-value, although precise values near the magnetopause are uncertain and depend upon magnetosphere model used (Lanzerotti et al., 1989).

Lanzerotti et al. (1989) concluded that the decrease in wave amplitude across the magnetopause (as seen from the ISEE data) is consistent with the fast mode wave transmission across the magnetopause, wherein little energy is expected to be transmitted (see Wolfe & Kaufmann, 1975). There was no evidence in the interplanetary medium at the location of the IMP-8 spacecraft for hydromagnetic waves with frequencies similar to those in the magnetosheath and in the magnetosphere. However, that is not to say that such waves may have existed elsewhere in the interplanetary medium. Such examination of the penetration of energy into the magnetosphere requires investigation at a wide range of local time along the dayside magnetopause.

In order to examine further the existence of hydromagnetic waves within the magnetosphere on solar wind conditions, several colleagues and I have carried out a variety of statistical studies, comparing primarily ground-based observations with interplanetary conditions measured by spacecraft. Shown in Fig. 3 (Wolfe et al., 1987) are the results of a multivariate analysis of the occurrence of hydromagnetic broadband power in the Pc 3 band with interplanetary solar wind conditions (interplanetary solar wind speed V and the three directions of the interplanetary magnetic field in the solar magnetospheric (GSM) coordinate system). The multivariate analysis was performed using the "C_p" statistics (Mallows, 1973), a parameter which provides a "Goodness of Fit" and is defined as

$$C_p = [\frac{1}{s^2}] RSS_p - (N - 2p) \quad (1)$$

where s^2 is an estimate of the variance σ^2, RRS_p is the residual sum of the squares, N is the number of data points, and p is the number of variables (Daniel & Wood, 1980). This study was done by using the four independent variables individually, and then two at a time, three at a time, and then all four in order to calculate the fits to a selected dependent variable. Therefore, C_p measures the total squared error in the dependent variable for each linear least squares fit. The best fit to the variables is determined by the minimum value of C_p which is found for any given set of variables.

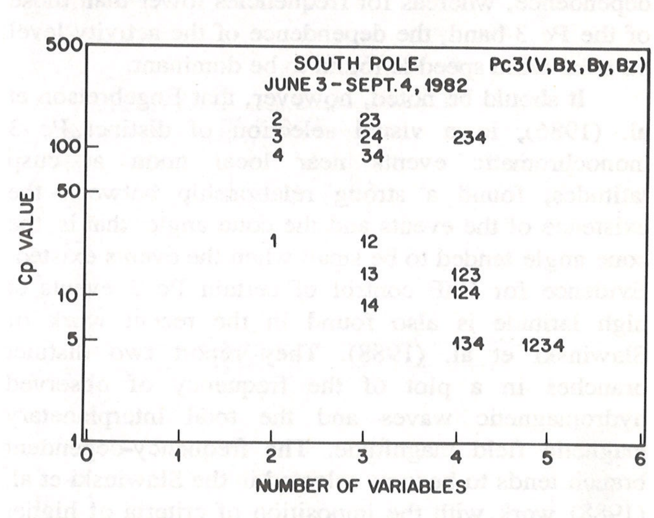


Figure 3. The value of the C_p statistic for a given number of variables (p). The power in the Pc 3 frequency band is found to be most highly associated with solar wind speed V (variable number 1) and then with B_z (variable number 4). The B_x component (variable number 2) is found to be not significantly associated with the Pc 3 power.

The results of the analysis shown in Fig. 3 illustrate that the power levels in the Pc 3 frequency band tend to be controlled most sensitively by V and by the interplanetary magnetic field (IMF) direction perpendicular to the ecplitic plane, Bz (variables denoted as number 1 and 4 in the figure). Adding the solar wind interplanetary field east-west direction, By (variable number 3), makes the fit somewhat, but not dramatically, better. For a single variable, it is clear that the solar wind speed is dominant in producing enhanced power levels in this frequency band at the high latitude South Pole Station.

A similar study using linear correlations of individual solar wind parameters and the IMF direction relative to the Earth-sun line was done by Yumoto et al. (1987). They found no dependence of the power levels in the Pc 3 frequency band (as determined from a cusp-latitude station) on the cone angle of the interplanetary magnetic field. The IMF "cone angle" θ_{xB} is defined as

$$\theta_{xB} = \cos^{-1} (|B_x|/B) \qquad (2)$$

and gives the angle between the interplanetary field direction and the radial direction between the Earth and the sun.

These high latitude results of Yumoto et al. (1987), are different from those found in studies of data acquired at lower latitudes, L-values ~ 2 to 4. For these low latitude cases, studies by Wolfe and colleagues (Wolfe, 1980; Wolfe et al., 1980, 1985) show that for the Pc 3 frequency band there tends to be both a solar wind speed and an IMF cone angle dependence, whereas for frequencies lower than those of the Pc 3 band, the dependence of the activity level on solar wind speed is found to be dominant.

It should be noted, however, that Engebretson et al. (1986), in a visual selection of distinct Pc 3 monochromatic events near local noon at cusp latitudes, found a strong relationship between the existence of the events and the cone angle: that is, the cone angle tended to be small when the events existed. Evidence for IMF control of certain Pc 3 events at high latitude is also found in the recent work of Slawinski et al. (1988). They report two distinct branches in a plot of the frequency of observed hydromagnetic waves and the total interplanetary magnetic field magnitude. The frequency-dependent branch tends to become selected in the Slawinski et al. (1988) work with the imposition of criteria of higher levels of energy. The results are similar to those of Gul'elmi (1974) based upon a visual selection process.

There are other external sources that can stimulate hydromagnetic energy and waves within the magnetosphere. One such source includes the excitation of the Kelvin-Helmholtz instability on the magnetopause produced by the flow of the solar wind along the magnetosphere boundary. Tests of the onset conditions for the Kelvin-Helmholtz instability at the magnetopause have not been very conclusive after many years of study of the magnetopause, and it still remains to be seen as to the importance of this mechanism. A recent paper by Song et al. (1988) calls into some question the validity of the Kelvin-Helmholtz mechanism for longer period (of the order of 8 minutes or more) hydromagnetic fluctuations inside the magnetosphere. In addition, recent work by Sibeck and colleagues have shown that pressure pulses in the solar wind are perhaps more influential in producing some longer period hydromagnetic waves than had been thought previously (Sibeck et al., 1987, 1989), even though the mechanisms by which small changes in solar wind pressure could produce hydromagnetic waves at magnetosphere density gradients had been discussed in the literature more than a decade ago (Chen & Hasegawa, 1974; Lanzerotti et al., 1974, 1975; Lanzerotti & Hasegawa, 1976; Baumjohann et al., 1984).

Sporadic reconnection processes on the dayside magnetopause are also likely to produce hydromagnetic disturbances interior to the magnetosphere on closed magnetospheric field lines. Indeed, the initial discussions of the possibility of reconnection processes at the magnetopause by Holzer & Reid (1975) invoked a generation of hydromagnetic waves in the reconnection process. Southwood (1985) has expanded upon this idea. Lee et al. (1987) have discussed the generation of hydromagnetic waves by the motion of the plasma loops produced in a multiple X-line reconnection process which may occur on the magnetopause (for example, in a flux transfer process).

Evidence for hydromagnetic waves associated with magnetic impulsive events occurring in the polar cusp ionosphere (see also next section) have been presented by Lanzerotti & Maclennan (1988). A dynamic power spectrum of the magnetic field fluctuations in the south-north component from South Pole during a several hour interval in October 1985 are shown in Fig. 4. Under the figure are shown the time-intensity traces of the south-north and vertical components of the magnetic field. The vertical component shows two impulses (at ~ 1215 UT and ~ 1420 UT) in the data (see following section). The hydromagnetic fluctuations which occur following the first large magnetic impulse were considerably larger than those occurring prior to the impulse and show up clearly in the dynamic spectrum beginning after ~ 1215 UT. The frequencies of the emissions begin at ~ 0.005 Hz and decrease slowly with time to ~ 0.0025 Hz during hours 16 and 17 UT. Such longer period fluctuations often appear to be enhanced following impulse events. The solar wind/magnetopause conditions appear to change with the occurrence of such magnetic impulse events so that the existence and amplitudes of hydromagnetic fluctuations are significantly enhanced following such occurrences.

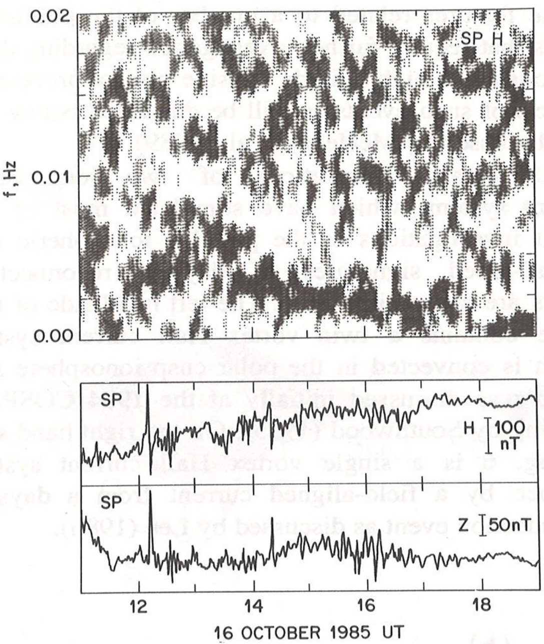


Figure 4. Dynamic spectrum of H-component magnetic data from South Pole (0-0.02 Hz) from 11-19 UT. Plotted at the bottom are the H- and V-component traces. The dynamic spectrum shows a decrease in the central frequency of the low frequency band, from ~ 0.005 to ~ 0.002 Hz over this time interval.

Whatever the source(s) of the hydromagnetic waves at the magnetopause, Tonegawa et al. (1985) have pointed out, in a study of data from SP and the Japanese Antarctic station Syowa, that the local time (azimuthal) extent of waves seen at the auroral-zone station Syowa is much broader than is the extent seen at the cusp-latitude location. Figures 5a, b show this clearly. The enhancement of wave activity in the band at f ~ 3 mHz exists for only a few hours around SP local noon time. In contrast, the activity in this band at the auroral zone station Syowa was present, with some short interruptions, for many hours before and after Syowa local noon (~ 2 UT). Tonegawa et al. (1985) conclude that the external wave source spreads considerably in the azimuthal direction once the energy has entered the magnetosphere. Further collaborative work with the Japanese investigators on this problem is in progress.

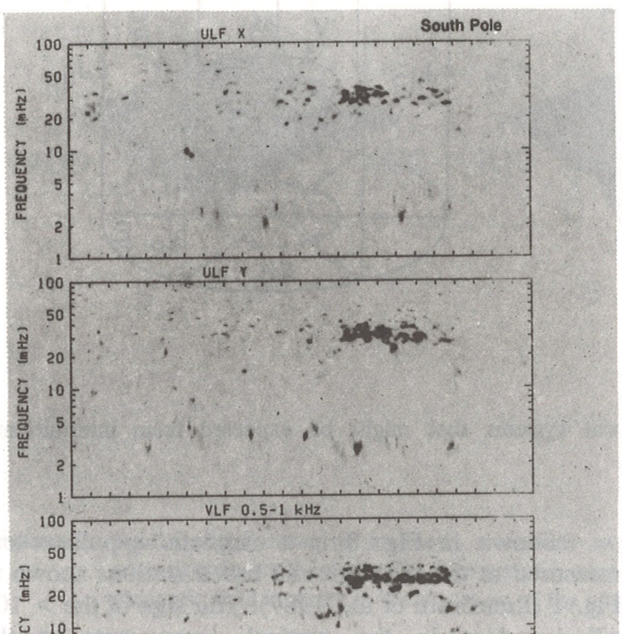


Figure 5a. Dynamic spectra of magnetic field and VLF data recorded at South Pole Station on 5 January 1982 UT (from Tonegawa et al., 1985).

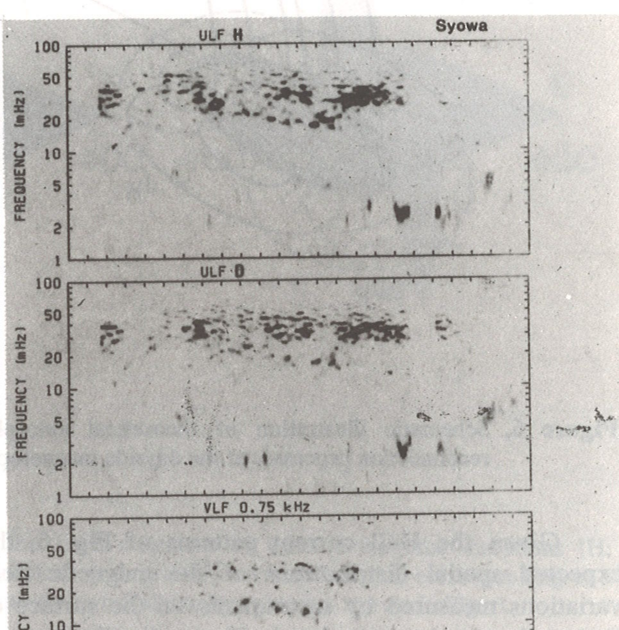


Figure 5b. Dynamic spectra of magnetic field and VLF data recorded at Syowa Station on 5 January 1982 UT (from Tonegawa et al., 1985).

IV. IMPULSIVE MAGNETIC EVENTS

Much recent work in studies of high latitude (magnetospheric cusp-associated) ground-based magnetic field phenomena has been stimulated by theoretical discussions of the possible signatures that might provide evidence for the occurrence of reconnection processes (either sporadic or quasi-periodic) at the dayside magnetopause (e.g., Bolshakova & Troitskaya, 1982; Goertz et al., 1985; Lanzerotti et al., 1986, 1987; Friis-Christensen et al., 1988; Sandholt et al., 1986; Glassmeier et al., 1990). While it is not at all clear at the present time that the "impulsive" magnetic signals that have been discussed and highlighted in the data are associated with dayside reconnection events, there are, nevertheless, several unique features related to a number of the published events that require further investigation regarding their relationship to high latitude dayside plasma processes. Aspects of such events as will be discussed below are also discussed by McHenry et al. (1989).

Schematic illustrations of two ionospheric current systems which have stimulated most of the recent investigations of the possible ionospheric and ground-based signatures of dayside reconnection events are shown in Fig. 6. The left hand side of this figure contains a twin vortex Hall current system which is convected in the polar cusp ionosphere and which was discussed initially at the 1984 COSPAR Meeting by Southwood (1985). On the right hand side of Fig. 6 is a single vortex Hall current system produce by a field-aligned current from a dayside reconnection event as discussed by Lee (1986).

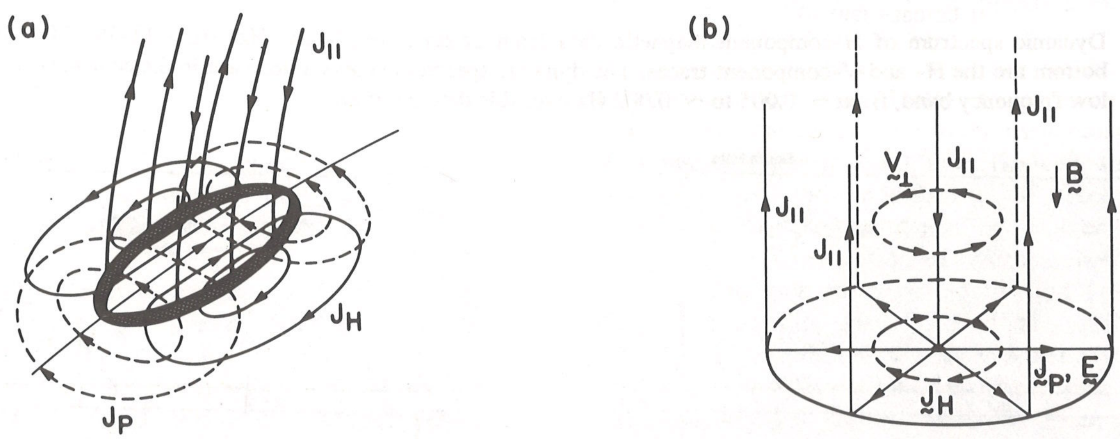


Figure 6. Schematic illustration of theoretical ionospheric current systems that might be expected from intermittent reconnection processes at the dayside magnetopause.

Given the Hall current patterns of Fig. 6, the expected spatial distributions of the magnetic field variations measured by instruments on the surface of the earth can be calculated. These distributions of magnetic variations are shown in Fig. 7, where the sizes of the loops of the Hall currents (taken to be circles in all cases) are selected to give the spatial dimensions shown in the figures. The vertical amplitude scales were arbitrary and depend upon the assumed Hall current loop sizes and magnitudes. Its clear that the single current loop in Fig. 6 establishes an unique, single-sign magnetic field perturbation in the vertical component of the vector magnetic field measurements. The relative sizes of the magnetic field perturbation peaks associated with the dual current loop system in Fig. 7 depend upon the relative sizes (spatial scale and current intensity) of the current loops, and also upon the ionospheric conductivities associated with the individual loops.

Shown in Fig. 8 is a magnetic impulse event measured at the three ground-based stations shown in Fig. 1 (Lanzerotti et al., 1987). The sign of the > 100 nT impulses in the vertical components at the conjugate stations of Iqaluit and South Pole shows that the field-aligned current producing the Hall current loop is directed into the ionosphere in both hemisphere. This is also the direction of the field-aligned current which produces the event at Sondre Stromfjord. The dotted line in each figure shows a qualitative fit of a single Hall current loop (Fig. 6) to the observations. The agreement between the observations and the "model" is reasonably good if a current loop of approximately 200 km in diameter is produced by an incident field-aligned current of ~ 2 x 10^5 amps. The vertical dashed line through the peaks of the events at the three stations shows a time delay between the observations at SS and IQ; the delay suggests an east to west propagation of the disturbance

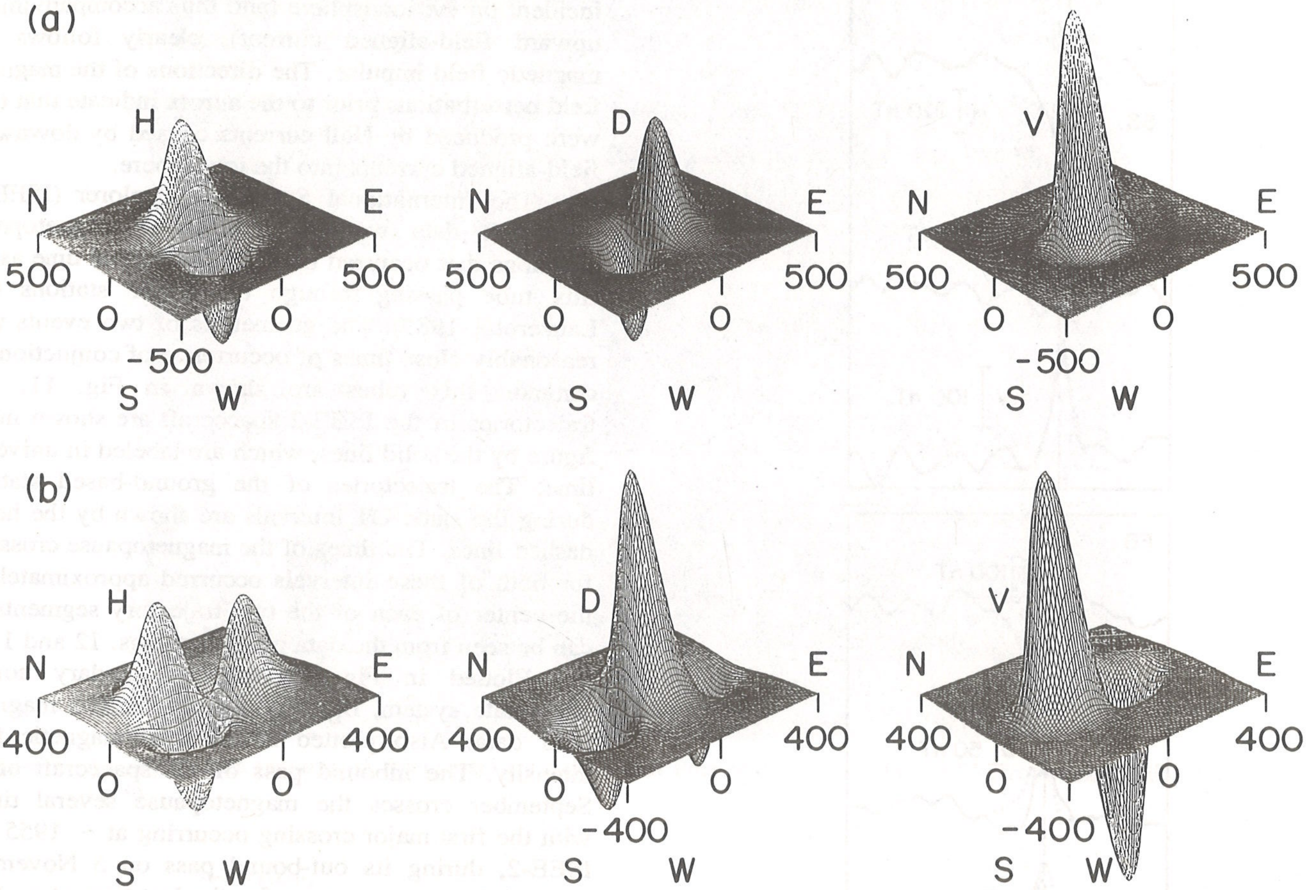


Figure 7. Spatial distribution of magnetic variations expected at the Earth's surface in three orthogonal directions (H: geomagnetic south-north; D: geomagnetic west-east; V: vertical, with positive vertical variation corresponding to a magnetic field increase in the direction of the main field) from the two Hall current patterns shown in Fig. 6.

of ~ 4 to 6 km/s. Arnoldly et al. (1988) has noted that ion cyclotron-frequency waves (f ~ 1 Hz) with enhanced amplitudes are often observed superimposed on such magnetic impulses.

The interplanetary magnetic field B_Z component was negative for the event shown in Fig. 8. However, Lanzerotti et al. (1988) and Trivedi et al. (1987) showed that for some dozen distinct conjugate magnetic impulse events there were no clear associations with the interplanetary magnetic field in the B_Z direction. McHenry et al. (1989) have also reported no clear B_Z dependence to their traveling ionospheric vortices. Whether this completely rules out reconnection as a source of the events remains a matter of some debate.

An important observation of optical emissions in association with magnetic impulse events has been reported by Fukunishi & Lanzerotti (1989). These authors show, for the three impulse events where data were available, that the optical aurora as seen by an all-sky camera was significantly enhanced in the zenith for a several minute interval following an impulse event. All-sky camera pictures of the sky over South Pole station for the time interval around an impulse event on 26 July 1985 are shown in Fig. 9. These photographs show clearly that during the interval 1247-1250 UT there was significant auroral brightening in the zenith.

The magnetic variations, showing an impulse event at SP and IQ at this time, are shown in Fig. 10. The interval of enhanced aurora evident in Fig. 9 is shown by the solid bar at the top of the magnetic field traces. The enhanced aurora, produced by electrons incident on the ionosphere (and thus accompanying an upward field-aligned current), clearly follows the magnetic field impulse. The directions of the magnetic field perturbations prior to the aurora indicate that they were produced by Hall currents caused by downward field-aligned currents into the ionosphere.

The International Sun-Earth Explorer (ISEE-2) spacecraft data were examined for magnetopause crossings that occurred near the same local time as the flux tube passing through the IQ/SP stations (see Lanzerotti, 1989). The geometries of two events with reasonably close times of occurrence of conjuctions of common flux tubes are shown in Fig. 11. The trajectories of the ISEE-2 spacecraft are shown in the figure by the solid lines, which are labeled in universal time. The trajectories of the ground-based stations during the same UT intervals are shown by the heavy dashed lines. The times of the magnetopause crossings for both of these intervals occurred approximately in the center of each of the two trajectory segments, as can be seen from the data plotted in Figs. 12 and 13.

Plotted in Fig. 12 in the boundary normal coordinate system, B_b, B_m, B_1, are ISEE-2 magnetic field data. Also plotted is the total magnetic field intensity. The inbound pass of the spacecraft on 27 September crosses the magnetopause several times, with the first major crossing occurring at ~ 1955 UT. ISEE-2, during its out-bound pass on 5 November, crossed the magnetopause for the last time at ~ 1355 UT. The B_n component on 27 September shows evidence for several fluctuations which can be identified as flux transfer events (FTE's) during the interval prior to the crossing of the magnetopause. There may be one or two such events during the 5 November crossing, particularly at ~ 1420 UT, although such perturbations in the B_n component are not as evident in this crossing as they are in the 27 September case.

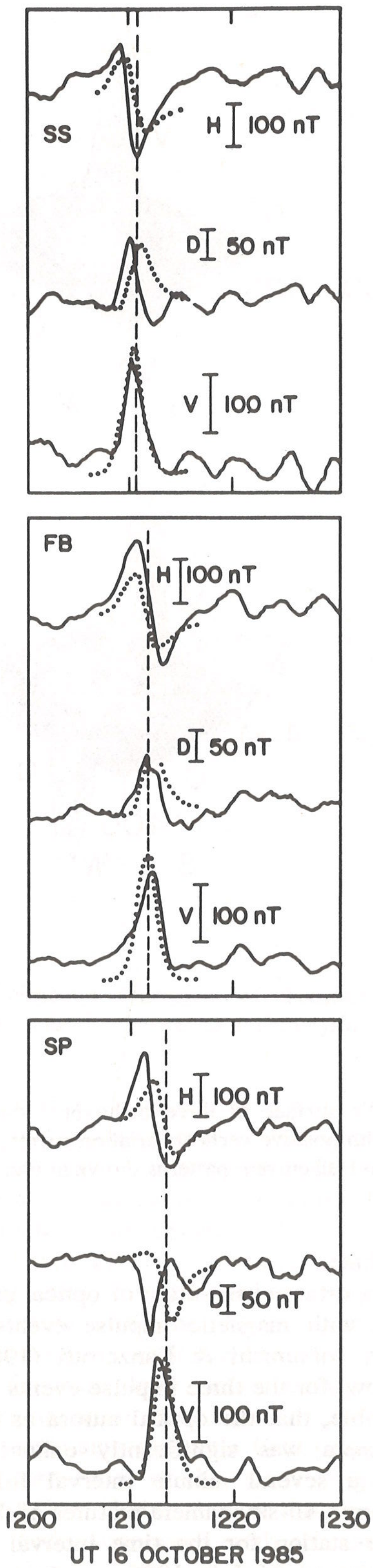


Figure 8. Magnetic field variations measured at IQ (formerly Frobisher Bay, FB), SP, and SS on 16 October 1985. The dashed vertical lines are to guide the eye. The dotted lines superimposed on the magnetic traces are the signatures expected from an ionospheric Hall current loop convected across the observing locations (from Lanzerotti et al., 1987).

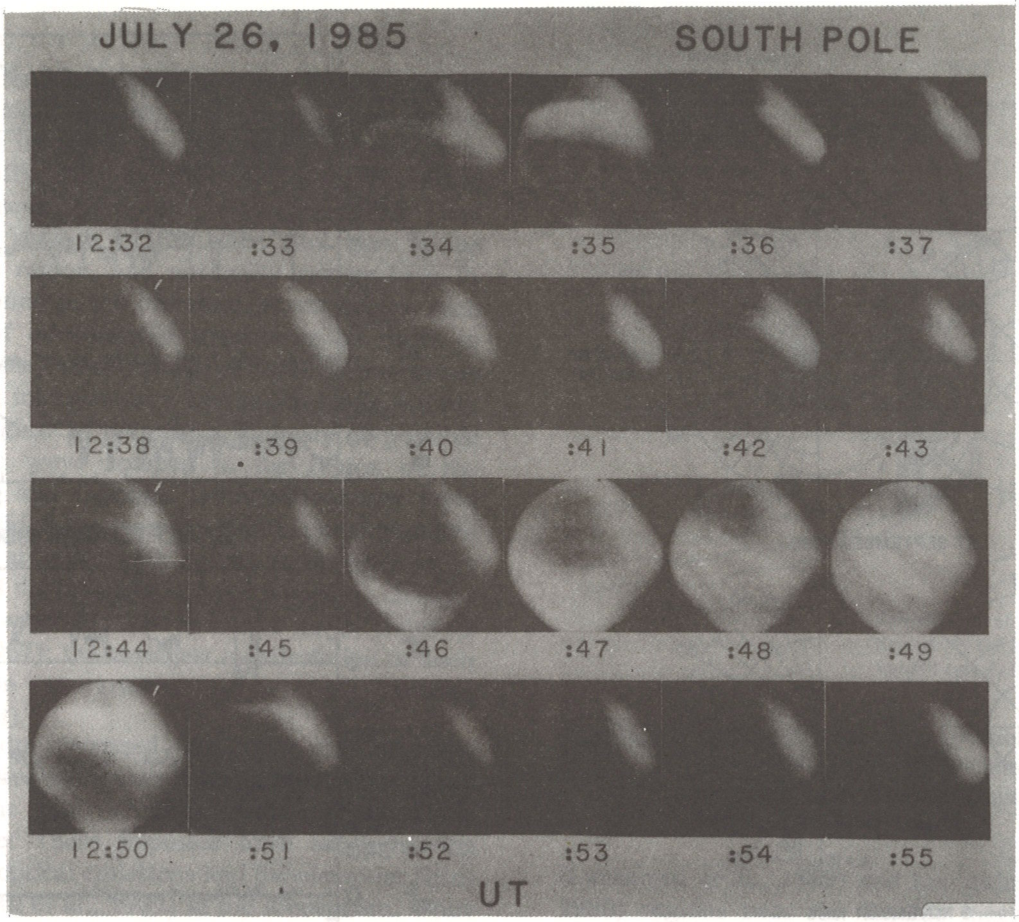
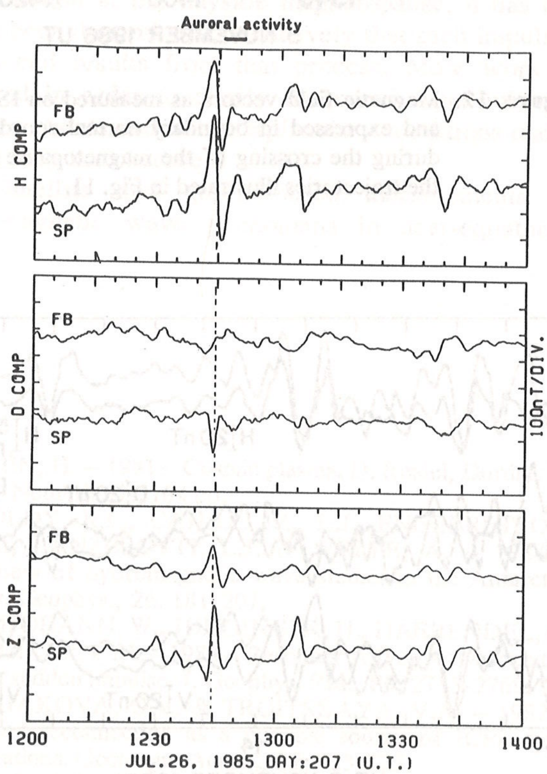


Figure 9. All-sky camera pictures of the ionosphere over South Pole Station on 26 July 1985 (from Fukunishi & Lanzerotti, 1988).



The time-intensity magnetic field traces from IQ (solid lines) and SP (dashed lines) are shown in Fig. 13 for time intervals including the ISEE data of Fig. 12. The magnetic field traces from 27 September are reasonably quiet, with no evidence for large impulsive events such as those shown in Fig. 8. The IQ and SP magnetic field variations showed much more evidence for hydromagnetic wave activity during the 5 November event, but again there is no evidence for large, impulsive magnetic field changes. Thus, if some of the variations in the boundary normal (B_n) component of the 27 September event (Fig. 2) in particular are produced by sporadic dayside reconnection, there is no evidence of this, in terms of present understanding, in the high latitude magnetic field measured on the Earth's surface.

Figure 10. Magnetic impulse event at SP and IQ (formerly Frobisher Bay, FB) at ~ 1245 UT (~ 0845 LT) on 26 July 1985.

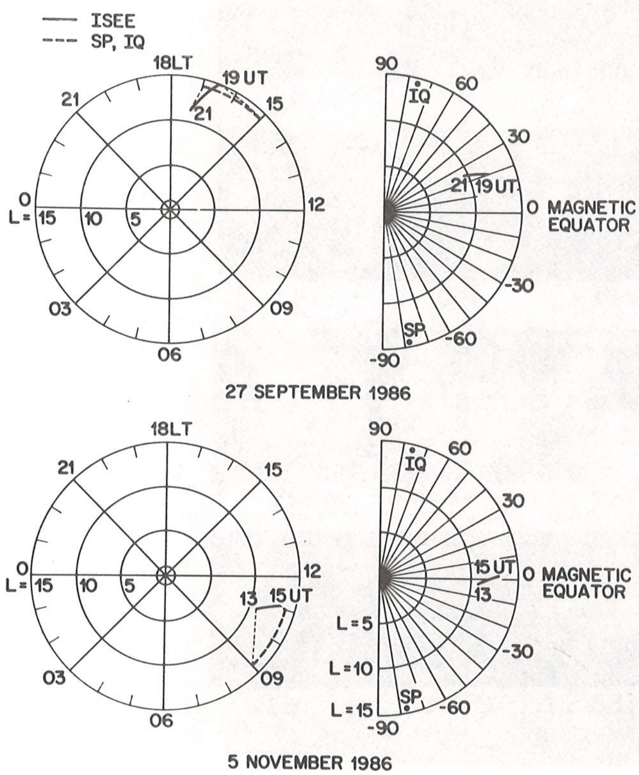


Figure 11. Trajectory segments of the ISEE-2 spacecraft (heavy solid lines, labeled in UT) at two times when the spacecraft crossed the magnetopause near the flux tube connecting SP and IQ. The tracks of SP and IQ in the same coordinate systems are shown by the heavy dashed lines.

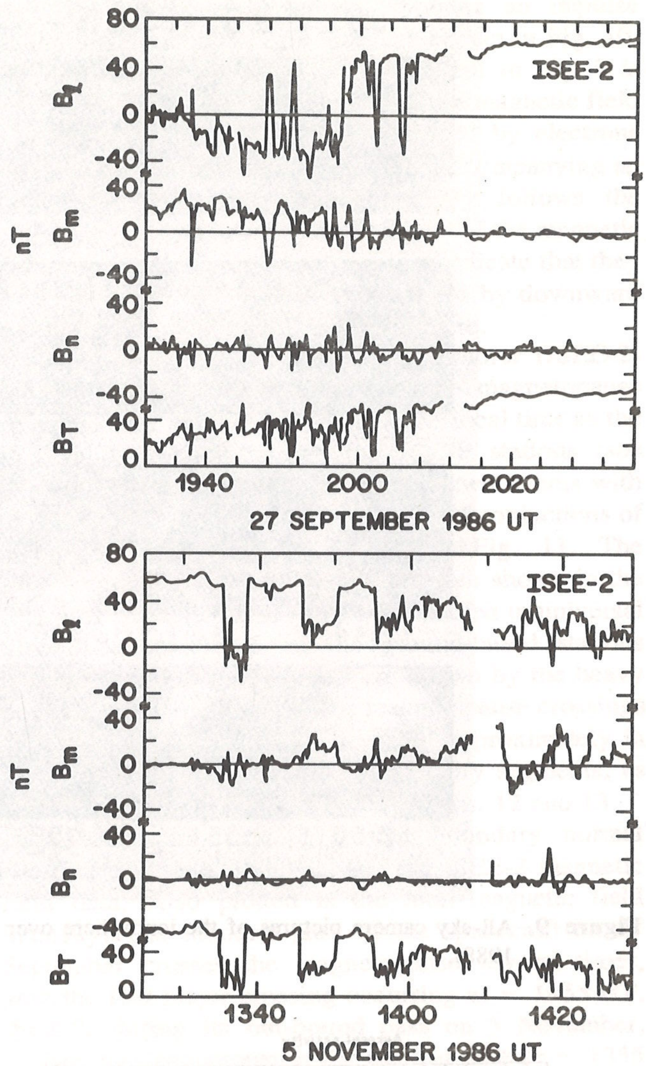


Figure 12. Magnetic field vectors as measured on ISEE-2 and expressed in boundary normal coordinates during the crossing of the magnetopause along the trajectories illustrated in Fig. 11.

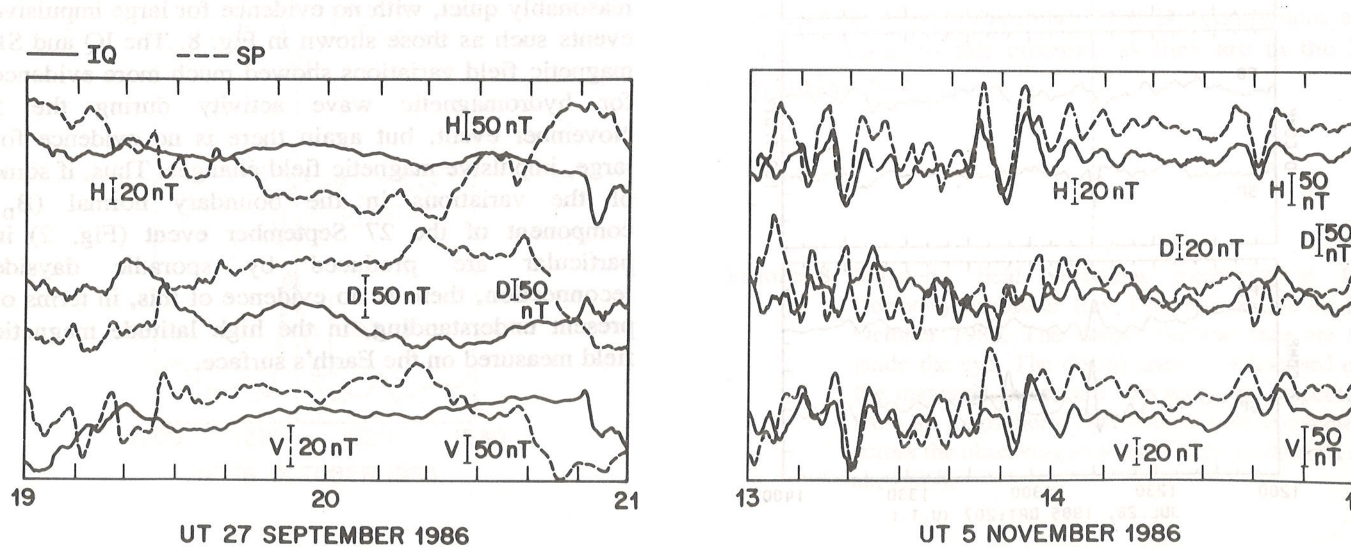


Figure 13. Time-intensity magnetic field data measured at IQ and SP during the ISEE-2 boundary crossing events of Fig. 12.

SUMMARY

This paper has briefly reviewed several current studies of high latitude, dayside hydromagnetic phenomena as measured on the ground and on spacecraft. The difficulties are formidable for achieving near-simultaneous coverage by spacecraft and ground-based stations of the same flux tube in the magnetopause region, and not many studies have as yet been reported in the literature. Nevertheless, such studies are of considerable importance in order to better understand the nature of the magnetopause under varying interplanetary and geomagnetic activity conditions. Figure 14 presents a summary of possible hydromagnetic wave sources in the region of the magnetopause and the low latitude boundary layer (from Fukunishi & Lanzerotti, 1989). Other possible sources exist as well, such as the waves excited by modulations of the magnetopause produced by changes in the solar wind dynamic pressure (e.g., Saito & Matsushita, 1967); the strongest manifestation of such a perturbation is known as an SC (sudden commencement).

The results discussed here show that there are large, impulsive-like variations in magnetic field records in the high latitude, cusp region of the magnetosphere. These impulses have accompanying effects in the optical emissions and the electrical fields (e.g., Lanzerotti et al., 1987) in the ionosphere. While the identification of such impulses by several authors was initially stimulated by considerations of possible models of the ionospheric signature of sporadic reconnection at the dayside magnetopause, it has not as yet been determined conclusively that such impulses do indeed results from that process. More work is required in order to clarify the occurrences of such impulse events and the interplanetary conditions under which they are observed.

Satellite and ground-based measurements of hydromagnetic wave phenomena in near-equatorial (Lanzerotti et al., 1989) and low altitude (Lanzerotti, 1989) regions near the dayside magnetopause show coincidences of similar frequency variations along a flux tube. Such data provide information on wave and energy transport across the magnetopause and into the interior of the magnetosphere.

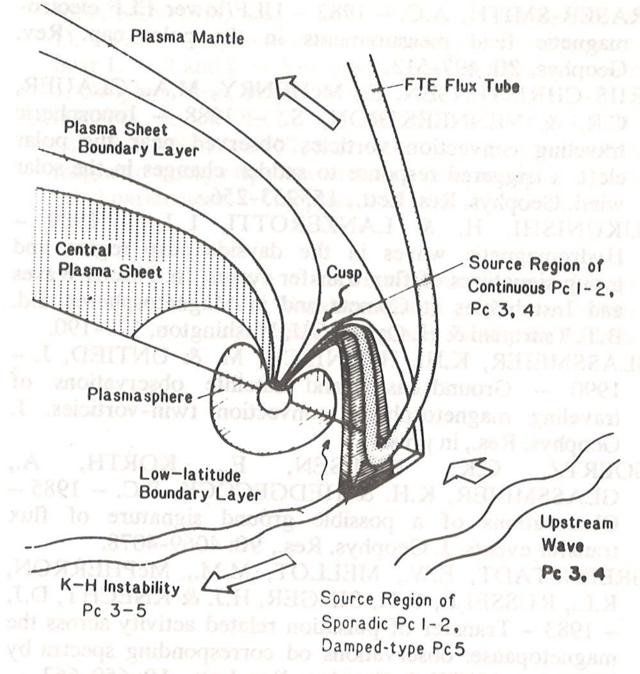


Figure 14. Summary schematic of possible hydromagnetic waves sources in the region of the Earth's magnetosphere (from Fukunishi & Lanzerotti, 1988).

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