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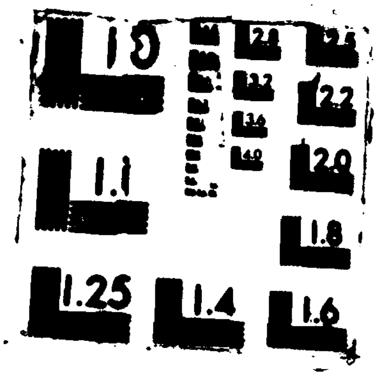
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Geomagnetic Pulsation Studies Using the AFGL Magnetometer Network

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June 1987

Final Report
1 December 1983 - 28 February 1987

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This contract funded a study of geomagnetic pulsations, the lowest frequency waves which occur naturally in the Earth's magnetosphere. The study used as its primary data source the AFGL Magnetometer Network which recorded midlatitude and subauroral magnetic variations continuously for six years, so obtaining an extremely valuable data set. In addition to this data, we used data from a variety of geostationary and other spacecraft to provide in situ magnetospheric measurements. The major aim of the study was to develop Pi2 pulsations which occur at substorm onset, as monitors and locators of magnetospheric activity. Other aims of the study were to study the higher frequency types of continuous pulsation which are believed to be generated via ion cyclotron resonance in the radiation belt, and to develop data management and analysis software. These latter aims were in preparation for the up-coming CRRES mission.

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19. Abstract cont.

We first showed that the midlatitude Pi2's are a reliable indicator of substorms and that their polarization pattern provides a good method of finding the local time of the main activity of a particular substorm. For small isolated substorms the center of the polarization pattern and the center of the midlatitude geomagnetic bay pattern produced by the dc substorm currents, coincide, but during more disturbed intervals this is not always true, as consecutive bays are not well separated from one another. Next we made use of the midlatitude signatures to spatially relate the other various signatures of substorm onset seen at geosynchronous orbit and in the auroral zone. We found that the main auroral surge forms about an hour west of the center of the Pi2 polarization pattern and that the longitude at which the surge forms separates the region of space near geosynchronous orbit where the geomagnetic field becomes more dipolar from that where it becomes more taillike. The region where an intense broadband burst of magnetic noise is observed at geosynchronous orbit is typically only an hour wide in local time and is at the same longitude as the center of the Pi2 polarization pattern center. Thus Pi2's do a good job of indicating the center of activity of a particular substorm.

Contents

1. Introduction

This contract funded a study of geomagnetic pulsations, the lowest frequency waves which occur naturally in the Earth's magnetosphere. The study used as its primary data source the AFGL Magnetometer Network which recorded midlatitude and subauroral magnetic variations continuously for six years, so obtaining an extremely valuable data set. In addition to this data, we used data from a variety of geostationary and other spacecraft to provide in situ magnetospheric measurements. The major aim of the study was to develop Pi2 pulsations which occur at substorm onset, as monitors and locators of magnetospheric activity. Other aims of the study were to study the higher frequency types of continuous pulsation which are believed to be generated via ion cyclotron resonance in the radiation belt, and to develop data management and analysis software. These latter aims were in preparation for the up-coming CRRES mission.

We first showed that the midlatitude Pi2's are a reliable indicator of substorms and that their polarization pattern provides a good method of finding the local time of the main activity of a particular substorm. For small isolated substorms the center of the polarization pattern and the center of the midlatitude geomagnetic bay pattern produced by the dc substorm currents, coincide, but during more disturbed intervals this is not always true, as consecutive bays are not well separated from one another. Next we made use of the midlatitude signatures to spatially relate the other various signatures of substorm onset seen at geosynchronous orbit and in the auroral zone. We found that the main auroral surge forms about an hour west of the center of the Pi2 polarization pattern and that the longitude at which the surge forms separates the region of space near geosynchronous orbit where the geomagnetic field becomes more dipolar from that where it becomes more taillike. The region where an intense broadband burst of magnetic noise is observed at geosynchronous orbit is typically only an hour wide in local time and is at the same longitude as the center of the Pi2 polarization pattern center. Thus Pi2's do a good job of indicating the center of activity of a particular substorm.

In the next section our scientific results and related efforts are described more fully. The final section of this report provides a list of publications, trips made, and collaborating scientists as well as fiscal information.

II. Work Completed

A. Midlatitude Pi2 Signatures

[Main references: Lester et al., 1984; Gelpi et al., 1985b]

The systematic variation with longitude of the polarization of Pi2 pulsations observed at midlatitudes plays a central role in much of the research carried out under this contract. The pattern was made clear by the earlier work of Lester et al. (1983), who showed that the orientation of the major axis of the polarization ellipse varies with longitude, such that it points due north at the center of the pattern, successively more to the east with increasing west longitude and vice versa. Lester et al. also showed that, at least for simple isolated substorms, the center of the polarization pattern coincided with the center of the geomagnetic bay pattern associated with the main substorm currents, the so called substorm current wedge (e.g. McPherron et al., 1973).

A major goal of this contract was to verify and further explore this signature and to make use of the signature to relate spatially a variety of substorm onset signatures. In our first paper (Lester et al., 1984) we extended the earlier work to look at a much larger range of longitudes than had been used in the initial study. By using the H component bay signatures as well as the D component ones, we could define the edges of the current wedge pattern as well as the center. In this way we could examine the polarization structure near to but outside the longitude range of the current wedge. We found that the pattern persisted at these greater longitudinal separations but that there was more scatter in the data from individual events. Figure 1 shows the individual polarization patterns of the 25 events used in this study. Only one event differs significantly from the expected pattern near the center but the pattern begins to break down more frequently at longitudes further from the center. This work verified that midlatitude Pi2 polarization patterns are best ordered in longitude by a longitude coordinate system based on the substorm bay signature, and that the polarization pattern itself can be used to determine the local time of a particular substorm, and probably more reliably than the dc current signatures during more active intervals.

Midlatitude Pi2 pulsations are predominantly lefthand polarized and their apparent longitudinal phase velocity is predominantly westward although righthanded polarizations and eastward phase velocity are both seen, perhaps in 10% of all cases (cf. Figure 1). In another paper (Gelpi et al., 1985b) we investigated whether these properties were related.

and examined in detail the relationship between wave polarization and the phase difference in the Pi2 signal observed between adjacent northern stations of the AFGL Magnetometer Network. We found that there was a strong correlation between the sign of the longitudinal phase velocity and the sense of polarization of Pi2's; westward propagating waves are lefthanded and vice versa. Furthermore we found that the east-west phase differences derived from the H and D components of Pi2 signals differed, but that the differences were correlated with the orientation of the polarization ellipse or polarization azimuth of the Pi2. Near the center of the polarization pattern, where the major axes pointed approximately north, phase differences derived from the H component were small while those drived from the D component were larger. The opposite occured near the edges of the pattern where the polarization ellipses pointed roughly east-west. This is the relationship expected from a model proposed by Southwood and Hughes (1985) (see Section D), who showed that the observed Pi2 polarization pattern could be obtained by superimposing two traveling wave signals of equal east-west wavelength, but traveling in opposite directions and with different amplitudes (Figure 2).

More theoretical work is clearly needed before we will understand the cause of the midlatitude Pi2 polarization pattern, but this work has clearly established the observational properties of the pattern, and has shown that the observed polarizations and phase differences are well correlated and self consistant. Even without a theoretical understanding, we can make use of this well defined signal pattern to order substorm data.

B. Geosynchronous Substorm Onset Signatures

[Main references: Gelpi et al., 1985a; Singer et al., 1985]

We spent a considerable effort using the midlatitude polarization pattern as a tool to try to order the substorm onset signatures seen by geosynchronous spacecraft, and with some success. Two significant publications resulted from this work, one a statistical survey (Gelpi et al., 1985a) the other a detailed case study (Singer et al., 1985).

In the statistical study we made use of 18 single and multiple onset substorms which contained 55 individual Pi2 events. The main part of this study made use of magnetometer data from the geosynchronous spacecraft GOES 2 which was located at a longitude between the AFGL Magnetometer Network stations at Rapid City and Camp Douglas, and data from these two stations, which are about a hour apart in magnetic local time. The events were split into four catagories depending on the polarizations at the two ground stations as can be seen at the bottom of Figure 3. These polarizations represent (from left to right) the substorm far from the location of the stations, the substorm centered east of the stations, the substorm centered between the two stations and the substorm centered west of the two stations. As the spacecraft was at a longitude between the two stations, the polarizations also give the location of the spacecraft with respect to the substorm center. We found that intense magnetic disturbances were only seen at geosynchronous orbit when the substorm was centered between the two ground stations, so was within half an hour in local time of the spacecraft indicating that the region of large magnetic disturbance is very localised. In contrast changes in field tilt in the meridional plane occured over a larger spread of longitudes. However, when the spacecraft was west of the center, only changes to a more taillike configuration were seen, while when the spacecraft was either near the center or east of it, only changes to a more dipolar configuration were seen. Thus we showed that the polarization pattern does order the geosynchronous magnetic signatures and that the region of intense magnetic disturbance is small.

The case study approach allows more diverse data sets to be collected and analysed together than is possible in a statistical study. This is especially important when studying a global phenonmemon such as substorms. In Singer et al. (1985) we investigated a single substorm using data from three spacecraft as well as the AFGL Magnetometer Network data to locate the substorm. The upper part of Figure 4 shows the locations of the spacecraft with respect to the substorm current wedge as determined from both the bay and Pi2 signatures from the ground. Two spacecraft, GOES 2 and SCATHA, are within the wedge while GOES 3 is to the west of it. The lower part of the figure shows the tilt and magnitude of the magnetic field at the three spacecraft. At both GOES 2 and SCATHA the main field becomes more dipolar while large irregular oscillations also occur. GOES 3, outside the wedge, no oscillations are seen, and the field becomes more taillike. These results confirm that the findings of the statistical study apply for a single substorm.

C. Correlations with Auroral Images and Electrojet Signatures

[Main references: Hughes and Singer, 1985; Gelpi et al., 1987]

Another very important aspect of our work has been investigating how the midlatitude substorm onset signatures are spatially related to the auroral zone signatures, that is the auroral features themselves and the locations of the substorm associated electrojet currents. As a single auroral zone observatory, be it a magnetic or an auroral observatory, is able to record only relatively local currents or aurora while the midlatitude signatures provide a much more global viewpoint, correlating the midlatitude signature with data from one or a few auroral zone observatories will not provide much insight. Instead the midlatitude signatures must be compared with the global auroral zone pattern. This is obtainable in two ways; the auroral emissions can be imaged from space by a spacecraft, thus providing a single view of a large part or even the whole auroral zone, or data from many ground stations can be brought together to provide a global picture. We have made use of both approaches.

An opportunity for an initial case study arose from the CDAW 6 workshop (see Section F). As part of this workshop, data from over a hundred auroral zone and midlatitude magnetic observatories was collected, merged into a single data set and inverted using an ionospheric conductivity model to give the pattern of ionospheric currents (Kamide et al., 1983). We made use of these results to compare the Pi2 polarization patterns we observed on the AFGL Magetometer Network with the location of the auroral zone currents associated with two substorms, one a rather small isolated substorm, the other a much larger multiple onset substorm. The results are described by Hughes and Singer (1985). Figure 5 summarises the results from the larger substorm. The five maps show the ionospheric currents derived from the global array of magnetic observations. The currents were computed every 5 min and are shown here for 1050 1110 UT. The first map shows the locations of the AFGL Magnetometer Network stations. Superimposed on the next four maps are the hodograms which show the Pi2 polarizations at the stations. By comparing consecutive maps, one can see that the center of the polarization pattern points to the region were the current vectors are increasing fastest. The polarizations can change dramatically in 5 min, but they are responding to changes in the auroral current system, and do trace where these currents are growing.

Opportunities such as CDAW 6 provided are rare. Our other study linking midlatitude and auroral signatures made use of the DMSP satellite images of the aurora (Gelpi et al., 1987). We found three cases where a DMSP satellite passed over the North American zone within minutes of a substorm onset being recorded on the AFGL Magnetometer Network. For each of these events we obtained in addition data from geosynchronous spacecraft and auroral zone magnetometers in order to try to obtain as complete a picture as possible of these onsets. The results from the three examples were remarkably consistant, and consistant with our earlier statistical work with the geosynchronous spacecraft. Figure 6 summarizes one of the events. It is a geomagnetic coordinate map showing the locations of the AFGL Magnetometer Network stations, the auroral observatories and the footprints of the geosynchronous spacecraft field lines relative to the auroral surge imaged by the DMSP satellite. Also shown are the hodograms of the Pi2 recorded on the AFGL Magnetometer Network. The center of the polarization pattern which is colocated with the center of the bay pattern, is about 1 hour east of the western edge of the surge. Combining this result with the geosynchronous results allowed us to draw the diagram in Figure 7 which shows the spatial relationships between substorm onset signatures at midlatitude, at auroral latitudes and at geosynchronous orbit. The western edge of the auroral surge, which forms about an hour west of the center of the midlatitude Pi2 polarization and bay patterns, corresponds at geosynchronous orbit to the boundary between the regions where the field becomes more taillike from where it becomes more dipolar and the western boundary of the region of intense magnetic disturbance.

D. Theory of Pi2 Pulsations

[Main references: Southwood and Hughes, 1985; Edwin et al., 1986]

A full theoretical understanding of Pi2 pulsations as yet eludes us, but during the course of this contract we have published two papers on the theory of Pi2 pulsations one concerning the spatial structure in the observed signals (Southwood and Hughes, 1985), the other addressing the question of the characteristic frequency of the signal (Edwin et al., 1986).

In the earlier paper we showed that refections of Alfven waves off the auroral ionosphere which has strong conductivity gradients at the edges of the precipitation regions, will give rise to circularly polarized waves. Superposition of two such waves of differing amplitude and traveling in opposite directions but with the same east-west wavelength gives rise to the observed polarization pattern. Such a superposition would occur if a wave were partially reflected off some boundary, perhaps the western edge of the auroral surge.

In the second paper we showed how dispersion of a broadband MHD signal as it propagates in a duct formed by a plasma inhomogeneity such as the plasma sheet in the geotail, gives rise to quasiperiodic wave packets. Using parameters characteristic of the plasma sheet, we showed that the quasiperiodic wave packet would have a period and duration similar to Pi2 wave packets.

E. Ion Cyclotron Waves

[Main reference: Ludlow et al., 1987]

We have also used data from the AFGL Magnetometer Network to study ion cyclotron waves generated in the earth's inner magnetosphere. These waves are recorded on the ground as Pc1 pulsations, waves with periods of around 1 Hz and so are best seen in the data from the search coil magnetometers. Our efforts have been concentrated around one long-lived and highly structured event which occured a few days after the main phase of a geomagnetic storm. Waves of this type are often generated as the cold plasma in the refilling plasmasphere interacts with the hot ions that were injected into the inner ring current during a magnetic storm so precipitating the ions. We believe this mechanisim operated here.

Our analysis was mainly concerned with trying to use the ground data to identify the source of these waves and to investigate how the signal was modified during its propagation from the source. We examined both the polarization of the waves at the various stations and how the phase of the signal varied between stations as functions of both frequency and time. We showed that waves were being generated on several different flux tubes simultaniously. One source region was clearly moving eastward, in the opposite sense to ion drift. More work is needed before we can provide a complete picture of this phenomenon, and most important will be the correlation of spacecraft and ground data.

F. Coordinated Data Analysis Workshops

We took part in two Coordinated Data Analysis Workshops run by the National Space Science Data Center, CDAW 6 and CDAW 8. Both of these workshops had as their focus energy transfer in the solar wind/magnetosphere/ionosphere system and as a result, magnetospheric substorms were a major part of the study. We helped supply AFGL Magnetometer Network data to both workshops, and in this data played an important role in both timing and locating the various substorm onsets. Both workshops provided an opportunity to obtain global observations of the substorm process. The data bases contained data from over a dozen spacecraft spread on various orbits throughout the earth's plasma environment as well as from dozens of ground based observatories. Our research effort as part of CDAW 6 was described in Section C. Analysis of the CDAW 8 data base is still ongoing. This workshop is particularly exciting as the data base contains both ISEE 3 observations from the deep geotail and auroral images from DE 1. We are currently correlating the midlatitude substorm onset signatures from the AFGL Magnetometer Network with the DE 1 auroral images. Initial results corroborate our work with the DMSP images also described in Section C.

G. Data Management and Analysis

An important part of our overall effort has been the development of data management and analysis software, not only for our own purposes although this project benefits greatly from such software as the project is data analysis intensive, but also as a general purpose tool that can be used by others. Our efforts can be divided into three interacting parts, a flexible data storage format that allows for easy access and retrieval, good data display programs that allow data to be displayed in a number of complementary ways, and a comprehensive suite of analysis programs that allow data, particularly time series data, to be analysed in a number of ways.

At the start of this contract we were using a data storage format based on the block data set concept. This concept was developed in the early 1970's, and for its time was revolutionary, but by 1984 other methods which were more flexible and which made use of advances in computer technology, notably the advances in mass online storage which allows large, random access files, had been developed. We chose to make use of the flatfile scheme and converted all our data processing to work using this more flexible format. Currently we have working flatfile data analysis and display programs running on both the Cyber and Vax systems at AFGL.

We have spent a considerable amount of effort on data display, for the success of any scientific effort depends to a large part on the ease with which data can be manipulated and displayed and on how well the display portrays the scientifically important content of the data. For wave and other time series data displaying parameters in frequency/time space (dynamic spectra) is a particularly powerful tool, so we have developed software to do this. We can display all the usual spectral and polarization parameters such as power, ellipticity and coherence in this way. We can also display one parameter using another as a turn on/off key; this is particularly useful, for example, for displaying the ellipiticity of a signal only when the degree of polarization is above some threshold value. In addition to these frequency/time displays, we have developed a full set of line plot programs for plotting time series and spectra making use of the graphics packages available at AFGL.

We have also developed our package of analysis routines. We have incorporated all of our standard data manipulation and analysis procedures (data despiking routines, time-series filtering, FFT spectral and cross spectral analysis, etc.) into the flatfile data management and analysis package we have developed. We also developed new analysis procedures as the need arose in our scientific effort. The new procedures that we have developed that will be of most general use are those that produce cross spectral parameters as functions of both frequency and time.

In summary, the flatfile analysis package we have developed is a powerful data analysis and display tool that can be used on any data that can be formatted into flatfiles, and we hope it will be widely used in the future.

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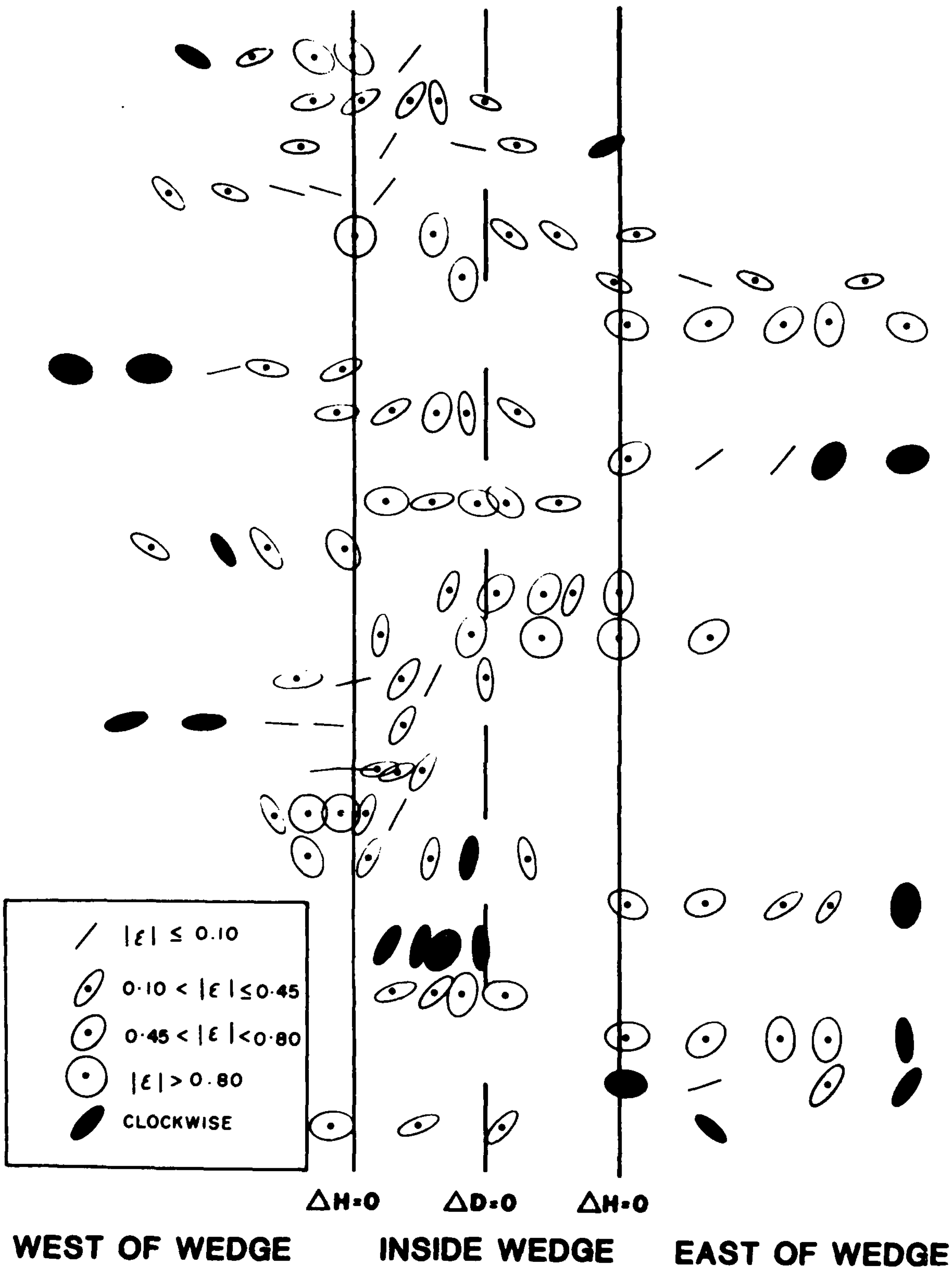

Figure 1: A schematic representation of the polarization pattern observed on the northern stations of the AFGL Magnetometer Network during 25 Pi2 pulsation events. The three vertical lines indicate the longitudes where the perturbation due to the bay is zero in either the H or D component which represent the edges and center of the substorm current wedge. Station spacing has been scaled separately for each event to fit this scheme. There is only one event for which the stations are within the wedge and the center of the polarization pattern does not coincide with the bay pattern center. (After Lester et al., 1984)

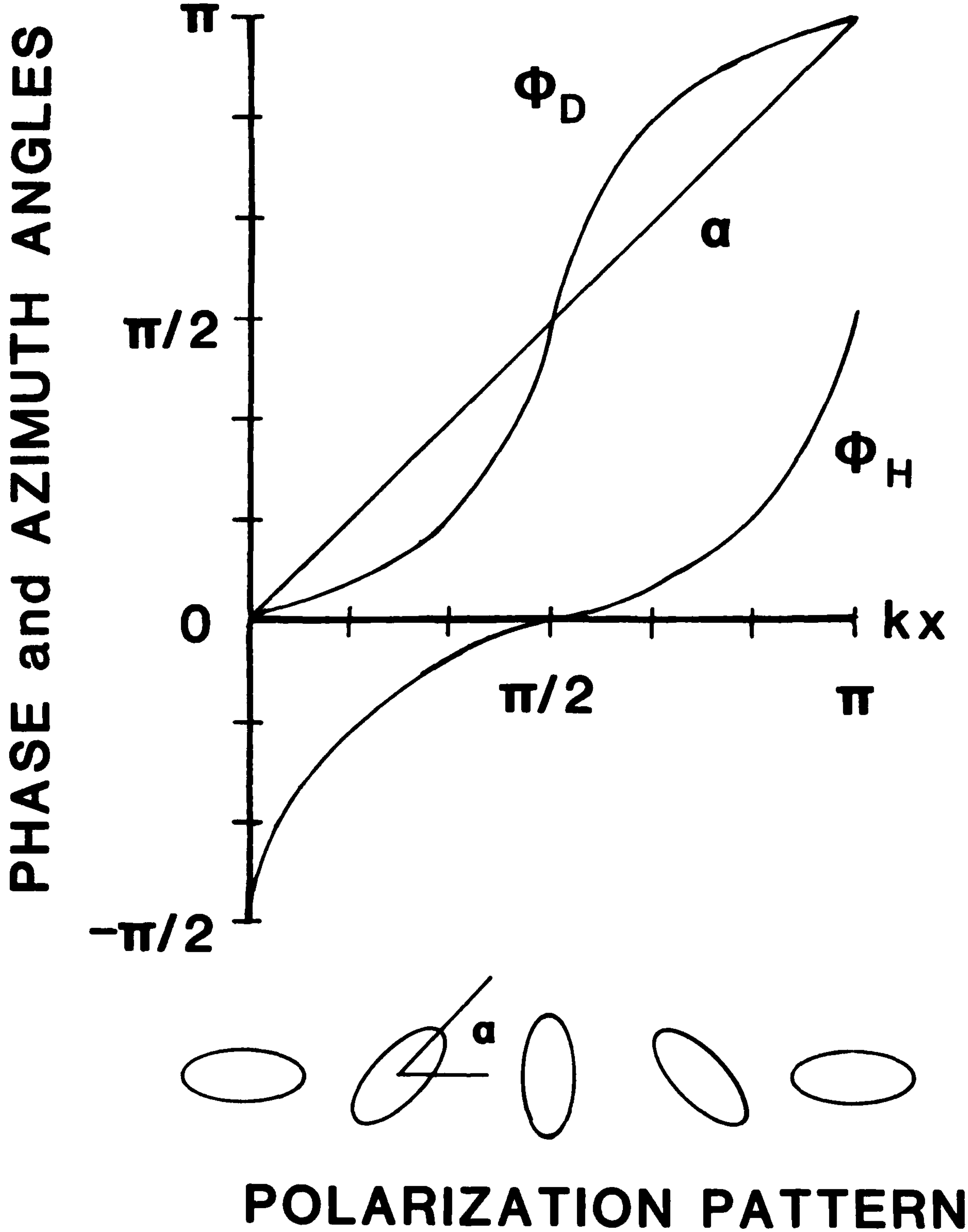

Figure 2: The phase variation of the H and D components of a Pi2 signal plotted as a function of longitude expected from the work of Southwood and Hughes (1985). Gelpi et al. (1985b) showed that near the center of the polarization pattern, the phase variation in the D component is much larger than that in the H component, whereas the opposite is true near the edges of the pattern, in line with this prediction. (After Gelpi et al., 1985b)

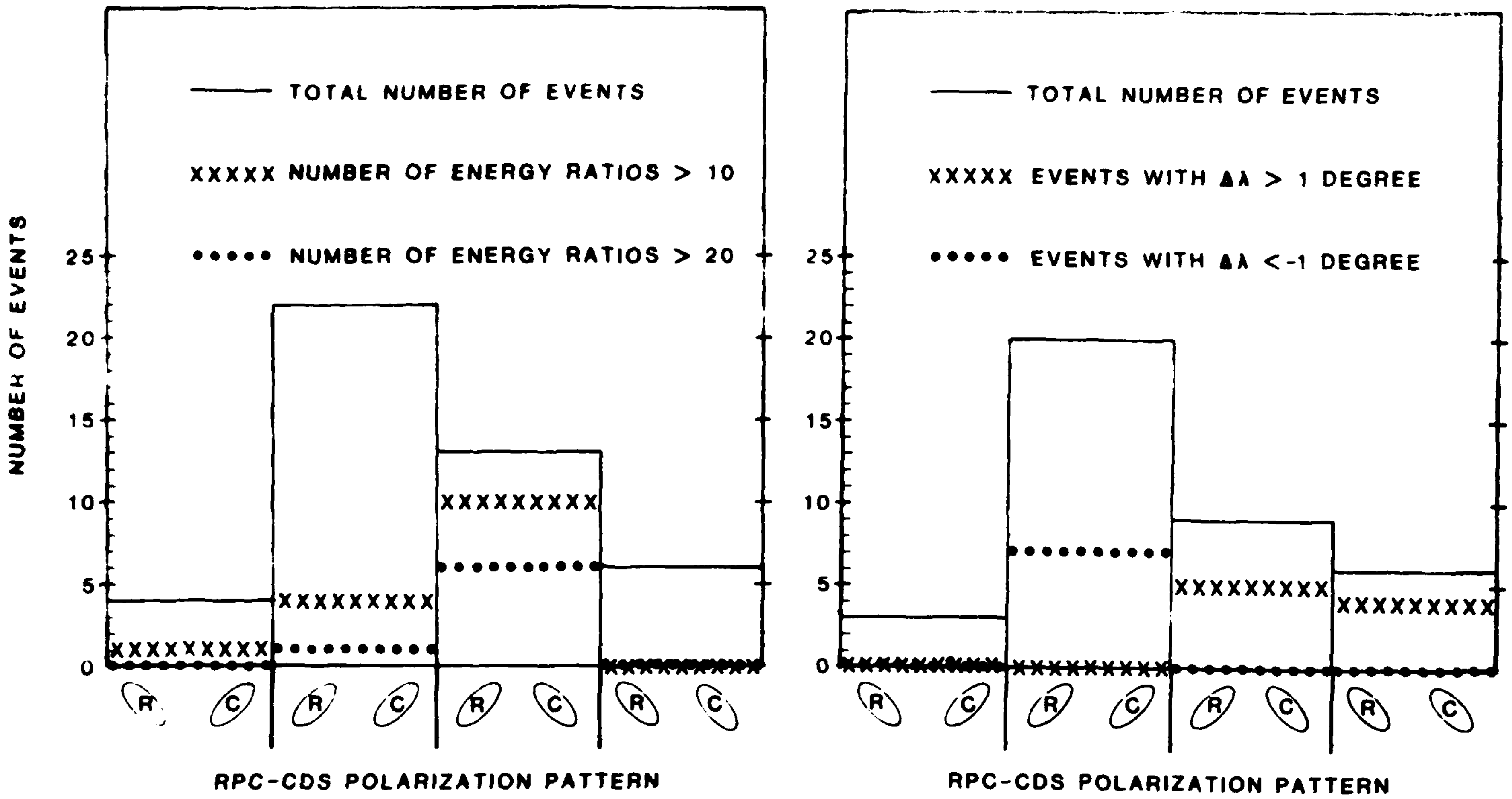

Figure 3: Histograms showing the substorm onset characteristics at GOES 2 in geosynchronous orbit *as a function of the Pi2 polarization at the two stations either side of the* spacecraft. The histogram on the right shows that when the center of the pattern is very close to (3rd column) or west of (4th column) the spacecraft the geomagnetic field becomes more dipolar whereas when the center is east of the spacecraft (2nd column) the field becomes more taillike. The histogram on the left shows that the most intense bursts of broadband noise occur almost exclusively when the spacecraft is very close to the center of the polarization pattern. (After Gelpi et al. 1985a

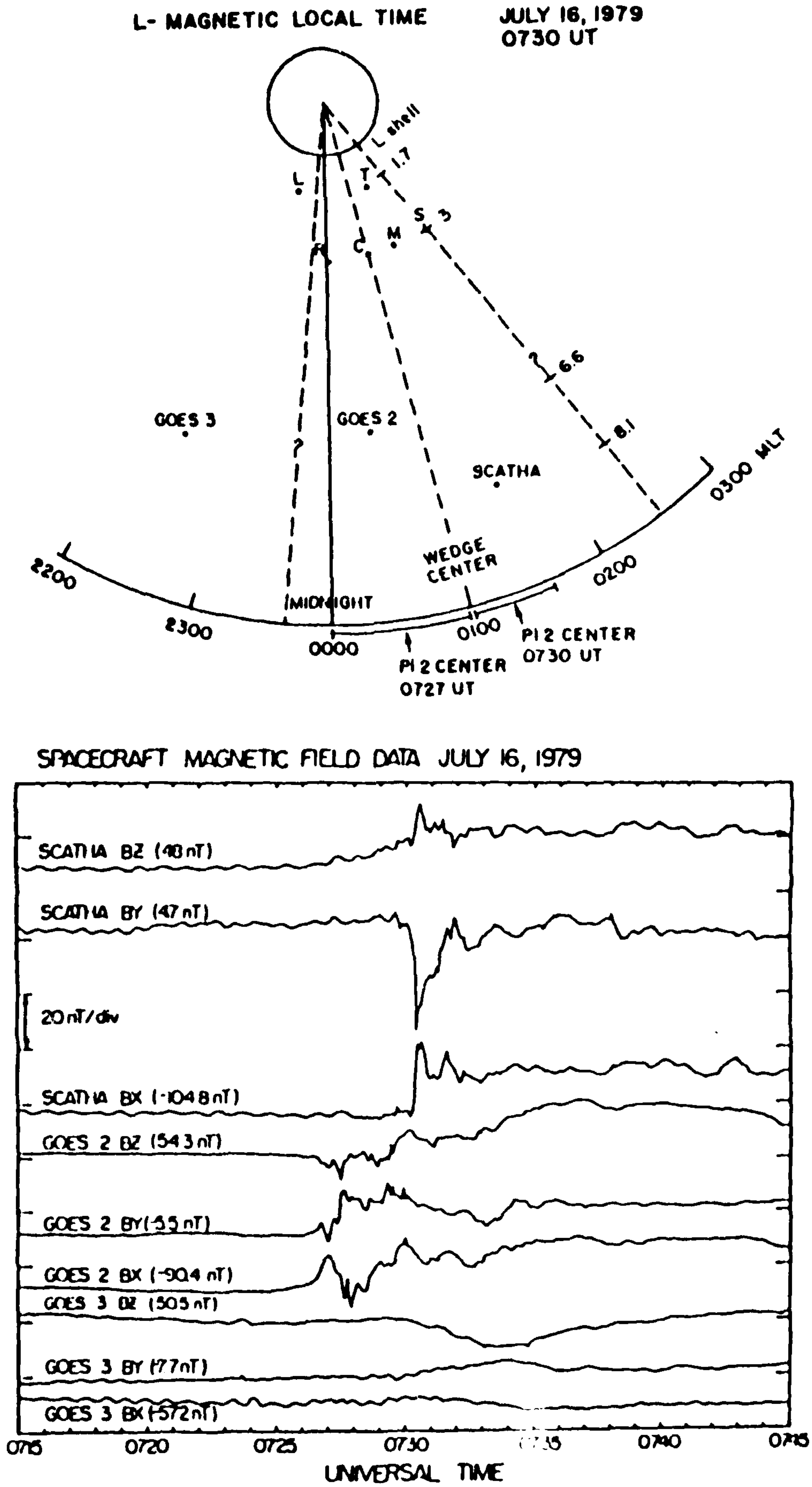

Figure 4: The upper part shows the locations of the AFGL Magnetometer Network stations and the three spacecraft used in the study of the event with respect to the features of the midlatitude onset signatures in L shell – magnetic local time space. Note that GOES 2 and SCATHA are within the wedge whereas GOES 3 is west of it. In the lower part, the magnitude and tilt of the magnetic field at the three spacecraft is shown. GOES 2 and SCATHA see noise bursts and the field become more dipolar while the field is relatively quiet and becomes more taillike at GOES 3. (After Singer et al., 1985)

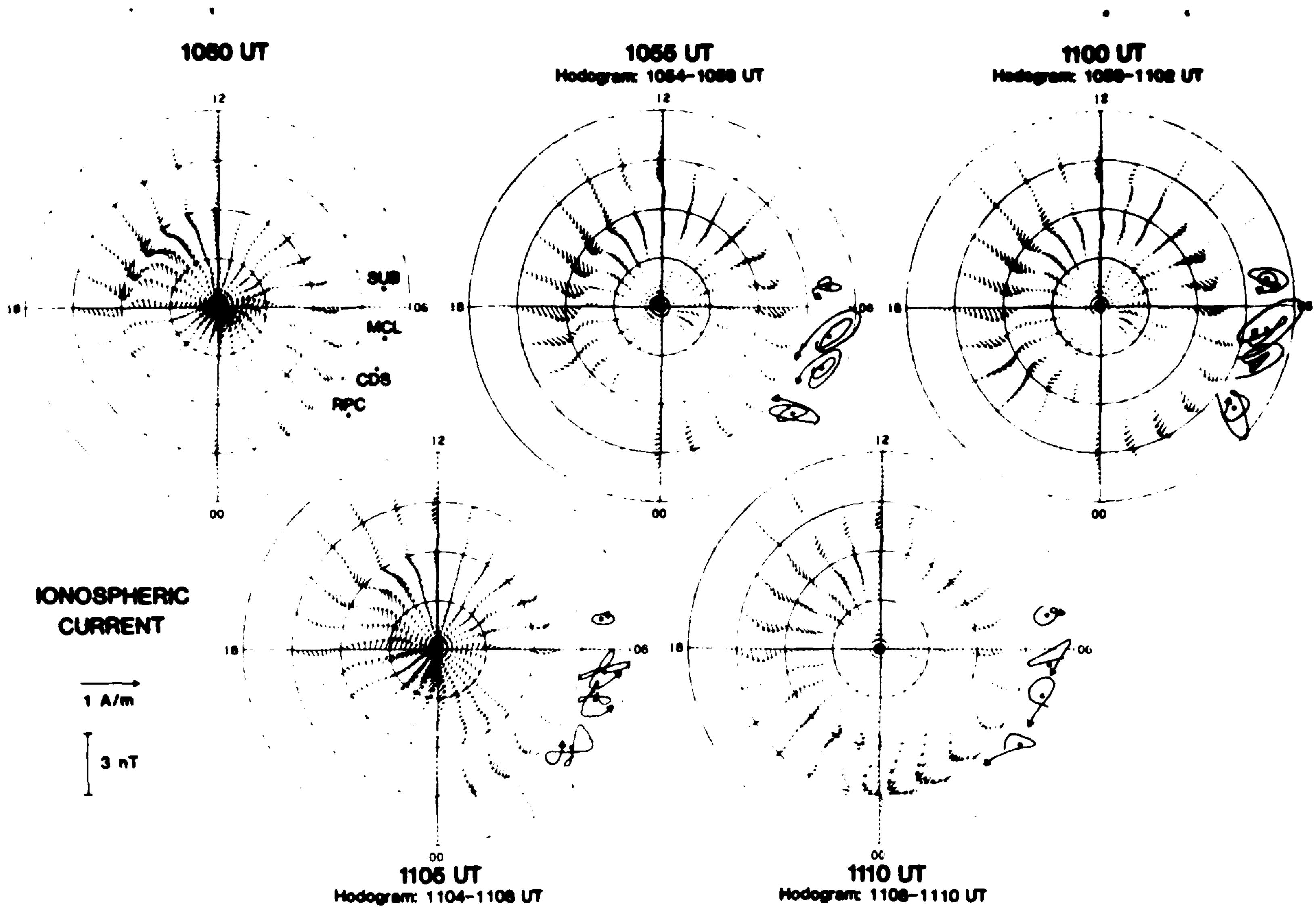

Figure 5: Maps showing the distribution of ionospheric currents at 5 min intervals during the initial stages of a substorm on 22 March, 1979, studied as part of the CDAW 6 effort. The currents were derived by inverting magnetometer data from over 100 observatories with the aid of a semi-empirical ionospheric conductivity model (Kamide et al., 1983). The locations of four of the AFGL Magnetometer Network stations are shown on the earliest map. On subsequent maps we have overlaid the hodograms showing the Pi2 polarization at these stations at the time corresponding to the currents estimates. In each case the polarization pattern is centered on the longitude where the currents are growing fastest. (After Hughes and Singer, 1985)

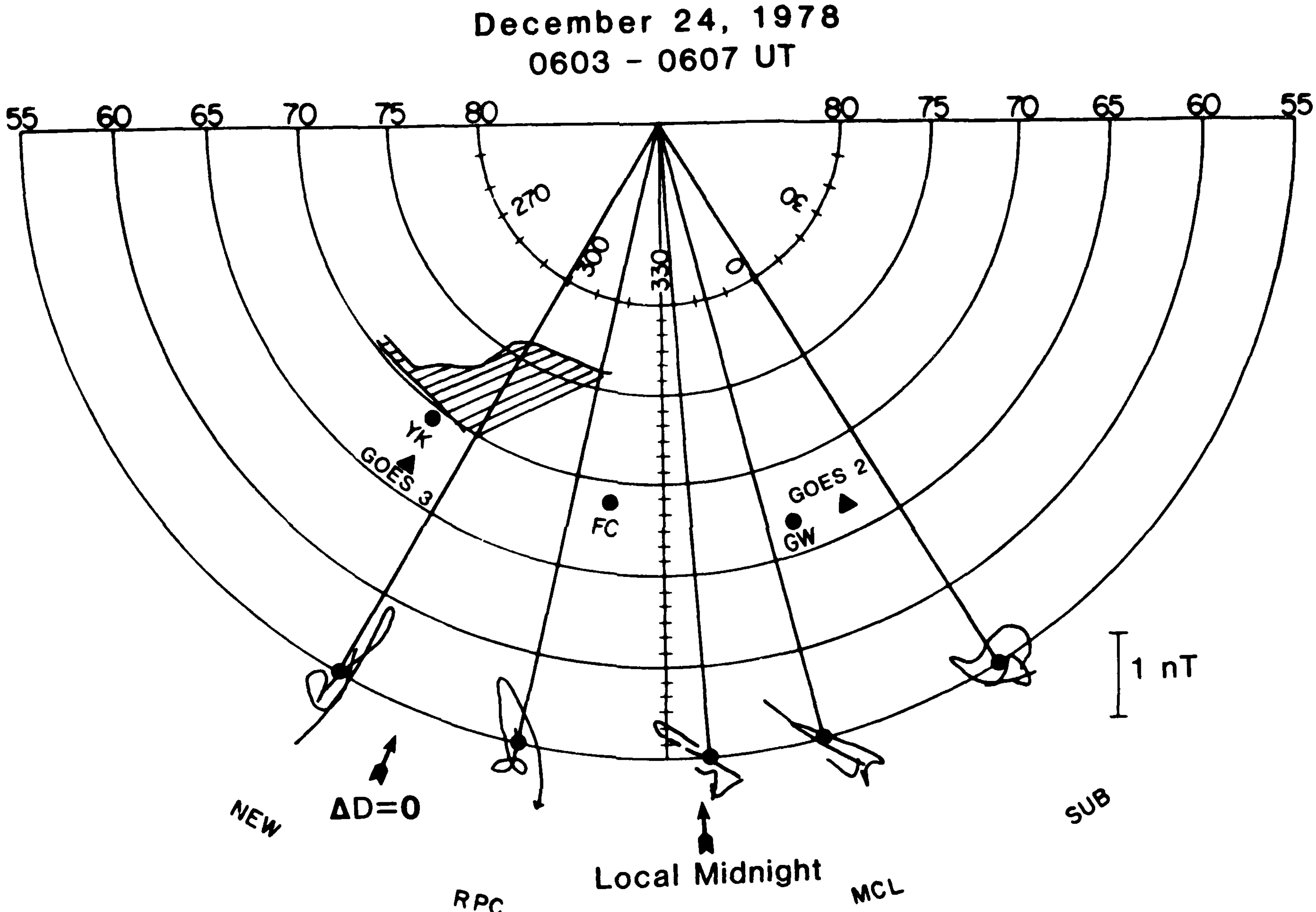

Figure 6: A corrected geomagnetic coordinate map showing the locations of the northern stations of the AFGL Magnetometer Network, three auroral zone observatories and the magnetic footprints of two geosynchronous spacecraft with respect to an auroral surge imaged by a DMSP satellite a few minutes after a Pi2 was recorded by the AFGL stations. The hodograms show the polarization of the Pi2 pulsation. The western edge of the auroral surge is about 1 hour west of the center of the Pi2 polarization pattern. (After Gelpi et al., 1987)

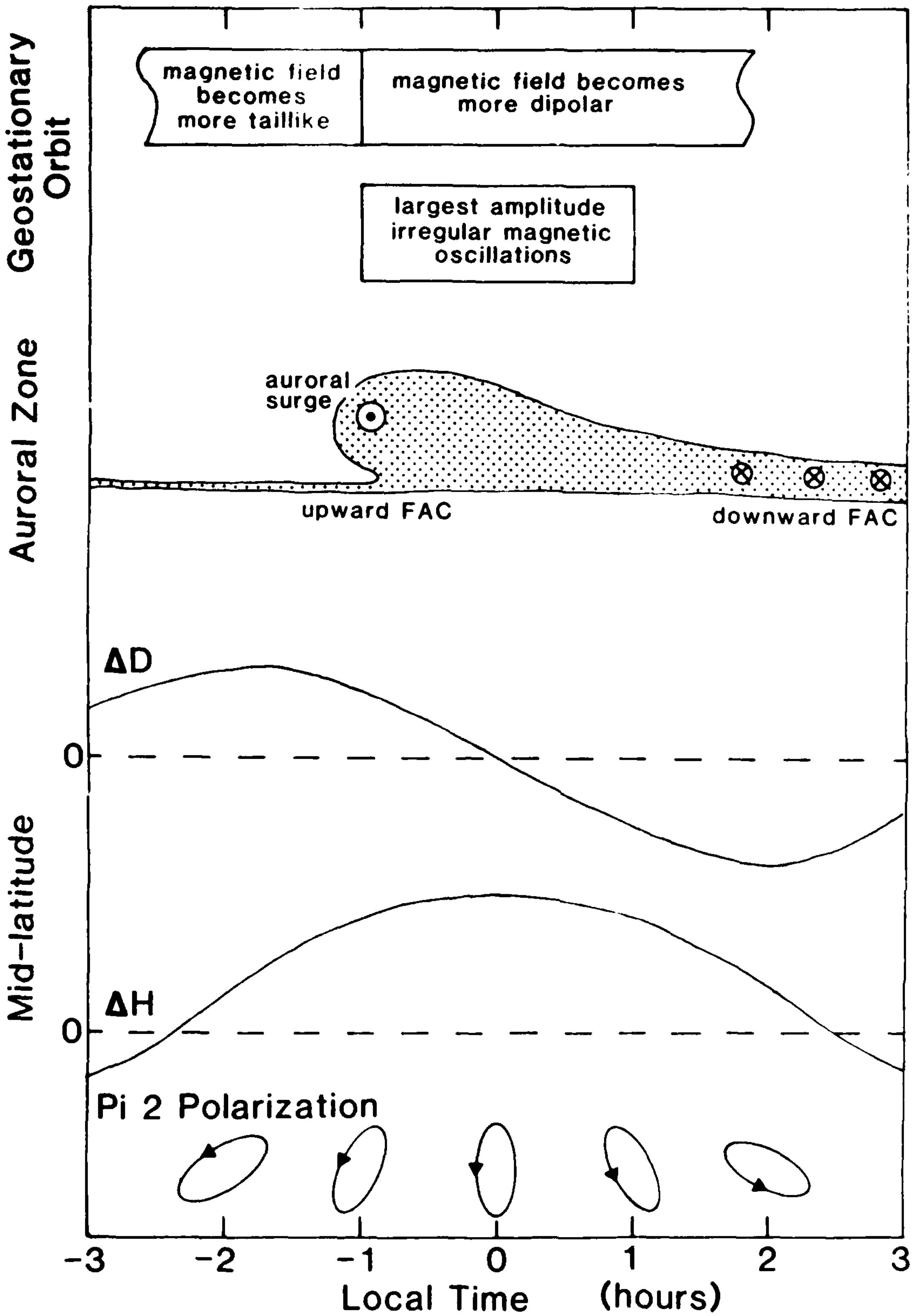

Figure 7: A schematic diagram summarizing our conclusions on the relationship in local time of substorm onset signatures at midlatitudes (lower part of diagram), in the auroral zone (center of diagram) and at geosynchronous orbit (top of diagram). The origin of the local time axis is at the center of the midlatitude patterns. The western edge of the auroral surge forms about an hour west of this point. When mapped to geosynchronous orbit, the western edge of the auroral surge appears to separate the regions of geomagnetic field dipolarization and extension and to form the western boundary of the region where intense magnetic noise bursts occur. (After Gelpi et al., 1897)

III. BUSINESSDATA

A. Contributing Scientists

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J. Behrens (Univ. Munster)
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B. Previous and Related Contracts

F19628-80-C-0025	(12/15/79 11/30/80)
F19628-81-K-0003	(11/15/80 - 11/15/83)
F19628-87-K-0015	(2/27/87 2/27/90)

C. Publications

i. Published Papers

M. Lester, W.J. Hughes, and H. Singer, Longitudinal structure of pi2 pulsations and the substorm current wedge, *J. Geophys. Res.*, *89*, 5489, 1984.

M. Lester, W.J. Hughes and H.J. Singer, Pi2 pulsations and the substorm current wedge ground observations. *Proc. Conf. Achievements of the IMS*. European Space Agency, ESA SP-217, p. 673, Paris, 1984.

H.J. Singer, D.J. Knecht, W.J. Hughes, C. Gelpi and M. Lester, Ground-satellite observations of substorm related pi2 pulsations and current systems. *Proc. Conf. Achievements of the IMS*. European Space Agency, ESA SP-217, p. 679, Paris, 1984.

D.J. Southwood, and W.J. Hughes, Concerning the structure of pi2 pulsations, *J. Geophys. Res.*, *90*, 386, 1985.

W.J. Hughes, and H.J. Singer, Midlatitude pi2 pulsations, geosynchronous substorm onset signatures and auroral zone currents on 22 March 1979: CDAW-6, *J. Geophys. Res.*, *90*, 1297, 1985.

M. Lester, K.H. Glassmeier and J. Behrens, Pi2 pulsations and the eastward electrojet: a case study, *Planet. Space Sci.*, *33*, 351, 1985.

C. Gelpi, W.J. Hughes, H.J. Singer and M. Lester, Mid-latitude Pi2 Polarization Pattern and Synchronous Orbit Magnetic Activity, *J. Geophys. Res.*, *90*, 6451, 1985.

H.J. Singer, W.J. Hughes, C. Gelpi and B.J. Ledley, Magnetic disturbances in the vicinity of synchronous orbit and the substorm current wedge: a case study, *J. Geophys. Res.*, *90*, 9583, 1985.

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P.M. Edwin, B. Roberts and W.J. Hughes, Dispersive Ducting of MHD Waves in the Plasma Sheet: A source of Pi 2 Wave Bursts, *Geophys. Res. Lett.*, *13*, 373, 1986.

C. Gelpi, H.J. Singer and W.J. Hughes, A Comparison of Magnetic Signatures and DMSP Auroral Images at Substorm Onset: 3 Case Studies, *J. Geophys. Res.*, *92*, 2447, 1987.

ii. Papers in Preparation

G.R. Ludlow, C. Gelpi, W.J. Hughes and H.J. Singer, Ground-based Observations of a long duration Pc 1 Event, to be submitted to *J. Geophys. Res.*

C. Gelpi, W.J. Hughes and H.J. Singer, Waves observed simultaneously at synchronous orbit and at midlatitudes in the Pi2 frequency range, to be submitted to *J. Geophys. Res.*

iii. Papers Presented at Meetings

W.J. Hughes and D.J. Southwood, Auroral ionospheric conductivity enhancements and the structure of pi2 pulsation signals. Presented at Fall AGU Meeting, San Francisco, Dec. 1983. (Abstract: *EOS, 64*, 809, 1983.)

H.J. Singer, M. Lester and W.J. Hughes, Pi2 pulsations, the substorm current system and magnetic disturbances at synchronous orbit. Presented at Fall AGU Meeting, San Francisco, Dec. 1983. (Abstract: *EOS, 64*, 808, 1983.)

C. Gelpi, W.J. Hughes and H.J. Singer, A relationship between the midlatitude pi2 polarization pattern and synchronous orbit magnetic signatures. Presented at AGU Spring Meeting, Cincinnati, May 1984. (Abstract: *EOS, 65*, 262, 1984)

M. Lester, W.J. Hughes and H.J. Singer, Pi2 pulsations and the substorm current wedge - ground observations. Symposium on Achievements of the IMS, XXV COSPAR, Graz, Austria, June 1984.

H.J. Singer, W.J. Hughes, D.J. Knecht, M. Lester and C. Gelpi, Ground satellite observations of substorm related pi2 pulsations and current systems. Symposium on Achievements of the IMS, XXV COSPAR, Graz, Austria, June 1984.

C. Gelpi, W.J. Hughes and H.J. Singer, Waves observed simultaneously at synchronous orbit and mid-latitudes in the pi2 frequency regime. Presented at AGU Fall Meeting, San Francisco, Dec. 1984. (Abstract: *EOS, 65*, 1046, 1984)

H.J. Singer, and W.J. Hughes, Midlatitude pi2 pulsations and auroral zone currents. Presented at AGU Fall Meeting, San Francisco, Dec. 1984. (Abstract: *EOS, 65*, 1055, 1984)

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C. Gelpi, H.J. Singer and W.J. Hughes, Auroral Surge forms and Mid-latitude Substorm Signatures. Presented at IAGA 5th Scientific Assembly, Prague, August 1985.

W.J. Hughes, P.M. Edwin and B. Roberts, Dispersive ducting of MHD waves in the plasma sheet: a source of Pi2 wave bursts. Presented at the Chapman Conference on Magnetotail Physics, Laurel, MD, October 1985.

G.R. Ludlow, C. Gelpi, W.J. Hughes and H.J. Singer, Ground-based observations of a long duration Pc 1 Event. Presented at AGU Fall Meeting, San Francisco, Dec. 1986. (Abstract: *EOS*, *67*, 1182, 1986)

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