Radio Science, Volume 4, Number 9, pages 859–868, September 1969

Concurrent equatorial and high-latitude geomagnetic pulsations

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(Received May 6, 1969.)

Examples of various concurrent ULF field fluctuations observed at: Jicamarca (Peru), College (Alaska), and Byrd (Antarctica) are presented to demonstrate the similarity of geomagnetic micropulsations of both Pi and Pc types at equatorial latitudes. The beginning of one Pi 1 event showed as much as 10-sec difference in onset times at a world distribution of stations. The apparent arrival of the signal varied according to the geomagnetic latitudes of the observatories. Magnetospheric sources of geomagnetic pulsations may be observed with equatorial station data.

INTRODUCTION

This paper concerns equatorial rapid variations of the geomagnetic field that have a period range of 10 min to 0.2 sec. Some sample events from the equatorial region will be identified with similar pulsations occurring at high-latitude stations. The purpose is to demonstrate that these equatorial changes are as indicative of magnetospheric sources as are their counterparts in the auroral zones. The fundamental question is how such pulsations are communicated to the equatorial region.

In recent years, geomagnetic micropulsations have been assigned to Pc or Pi categories by separation of their amplitude-time trace. Rather smooth and quasi-sinusoidal pulsations, like those in parts *a* through *d* of Figure 1, are called 'continuous pulsations' or Pc's. Those containing a broader spectral composition, such as examples *e* and *f* of Figure 1, are called 'irregular pulsations' or Pi's. Also in Figure 1, part *g* shows how some variations are not resolvable into the above categories at slow chart speeds, and part *h* shows the effect of local lightning strokes on a typical record. The standard nomenclature is completed with the assignment of a number which represents the predominant period(s) of the pulsations. Figure 2 illustrates this range. Also shown in Figure 2 are field-strength amplitudes typically reported for the micropulsations at high-latitude stations, where all types of Pi and Pc are larger and more frequently observed than at the equator.

Hutton [1965] and *Campbell* [1966, 1968*a*] have presented reviews of the scientific literature concerning equatorial rapid variations. These papers provide the basis for Figure 3, which illustrates the pre-1967 generally assumed relative amplitudes of pulsations reported at a broad latitudinal distribution of observatories. Note the large amplitudes at the auroral zone for all pulsations, and the equatorial enhancement of Pi 2, 3 and Pc 4, 5. The pulsation types that have no low-latitude enhancement on this figure represent the most poorly studied groups before 1967. Recent results indicate that Pi 1, and possibly Pc 2, 3, also may be amplified in the equatorial region [cf. *Roquet,* 1967]. This would leave the Pc 1 as the only pulsation type not affected by that electrojet.

EQUATORIAL-AURORAL SIMILARITIES

There is strong evidence that each natural rapid fluctuation of the geomagnetic field observed in the equatorial region can be identified with an auroral-zone fluctuation. The relative magnitudes of these paired signals would indicate that they either (1) have their principal effect in the high latitudes, or (2) are a worldwide, relatively constant-amplitude event. The irregular distribution of observatories about the globe allows us to assume that when signals of a similar size are discovered at the equator and one high-latitude station, a maximum signal occurred at another longitude region of the auroral zone. In my opinion (1) is the typical nature of all

Pi and Pc. The primary task for equatorial pulsation studies is to determine how the signal is communicated to the lowest latitudes, whether from above, within, or beneath the ionosphere. It seems that all three routes may be used to differing degrees by the various micropulsations.

Table 1 lists the locations of stations presented in this paper. The eccentric dipole, geomagnetic coordinates, as well as the local meridian and geomagnetic (eccentric dipole at equinox) times [*Agy,* 1965] are given. The *L* values [*McIlwain,* 1961; *Campbell and Matsushita,* 1967] are shown for all stations except Jicamarca and Thule where this coordinate loses significance. Local meridan time positions our data with respect to the equatorial electrojet; the geomagnetic time puts the data into perspective for magnetospheric disturbances and the auroral electrojet. Several site features should be noted. Jicamarca is at the dip equator and Thule is near the geomagnetic pole. The fact that Byrd and College, in the auroral zones, are at opposite hemispheres may be overlooked in this study because of the high correlation of activity at conjugate high-latitude stations [*Campbell,* 1968*b*]. Jicamarca is closest to Byrd in geomagnetic longitude. Geomagnetic (eccentric di-

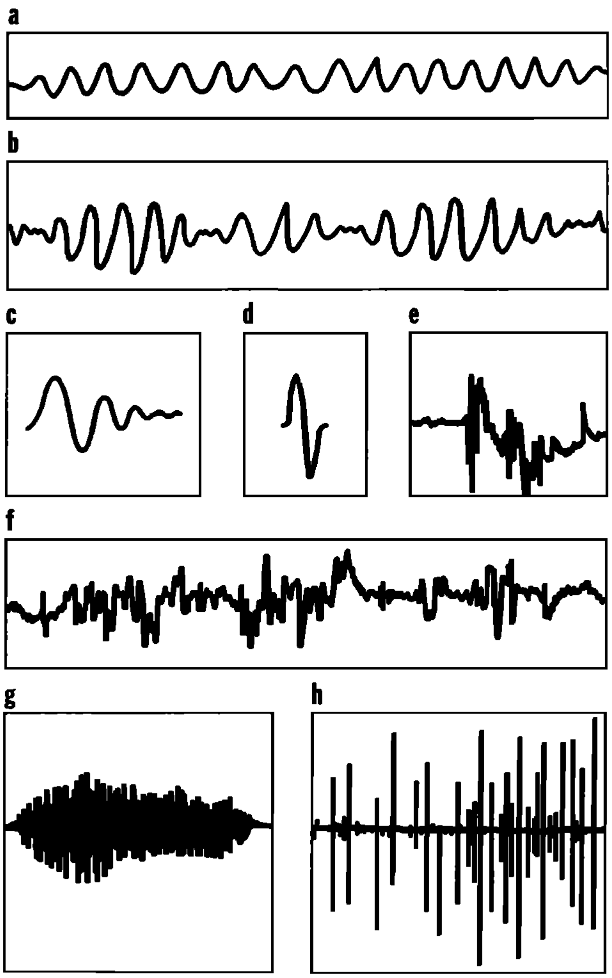

Fig. 1. Catagories of amplitude variations of the magnetic field in the period range of 10 min. to 0.2 sec.

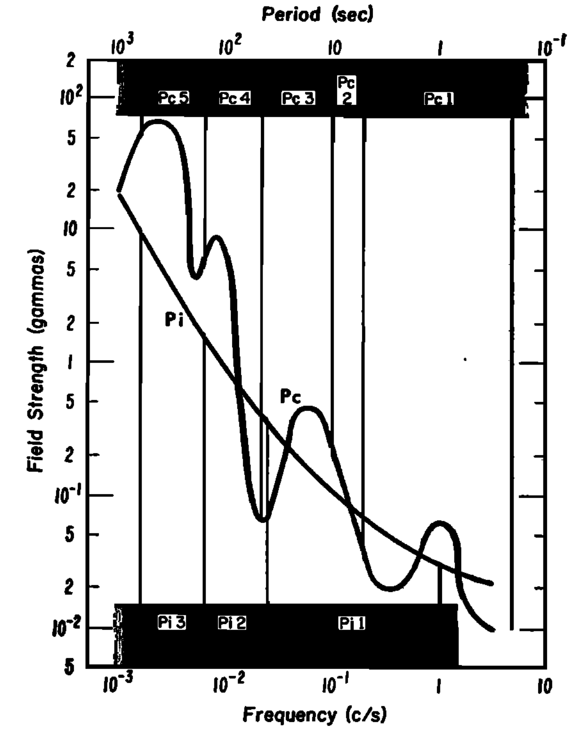

Fig. 2. The Pc and Pi nomenclature and typical high-latitude amplitudes for ULF signals.

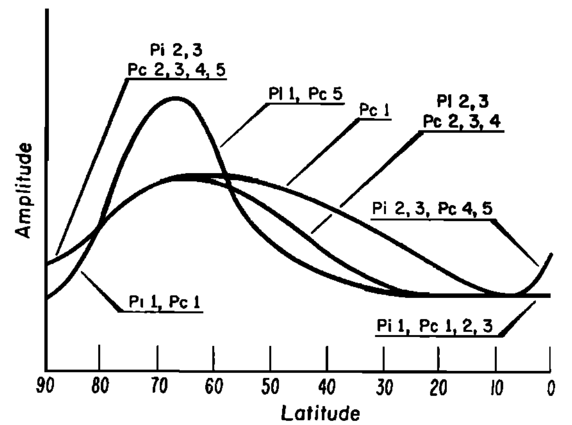

Fig. 3. Schematic latitudinal representation of relative amplitudes for various types of ULF signals according to observers before 1967.

TABLE 1

Station	Geographic Location		Eccentric Dipole Geomagnetic Location		L Value	Local Meridian Time, UT		Equinox Eccentric Dipole Geomagnetic Time, UT	
	Lat.	W. Long.	Lat.	Long.		Noon	Midnight	Noon	Midnight
Jicamarca, Peru	−11.95	76.87	−0.76	136.49	...	1707	0507	1656	0456
Maui, Hawaii	20.7	156.26	21.36	52.91	1.15	2226	1026	2229	1029
Boulder, Colorado	40.14	105.24	48.15	103.61	2.38	1901	0701	1929	0729
College, Alaska	64.86	147.87	67.12	44.00	5.49	2151	0951	2307	1107
Byrd, Antarctica	−79.98	120.02	−68.65	129.95	7.22	2000	0800	1733	0533
Thule, Greenland	76.40	68.32	84.85	168.09	...	1635	0435	1450	0250

pole) midnight, a time of high activity, is at 0533 and 1107 UT for Byrd and College, respectively, whereas local meridian noon at Jicamarca, when an electrojet enhancement occurs, is at 1707 UT. At all these stations identical micropulsation detectors are operated [*Campbell,* 1968*a*]. The antennas are 2-meter-diameter induction loops of 16,000 turns. Records are taken both on magnetic tapes and on ink charts. The amplitude response is flat, and there is no noticeable phase shift in recording between 0.002 and 4.0 c/s. Time simultaneity is maintained to better than 0.1 sec.

Two figures were selected to illustrate times of overhead auroral activity at Byrd station. The luminosity records were obtained from a zenith-axis photometer with a 38° field of view and a 4278-Å filter passing N_2^{+*} emissions. A sample of the total light record and dH/dt, the field change in the north-south direction, is shown for August 23, 1966, in Figure 4. Increasing intensity is downward on this chart. The general rise of background level in the last hour of the record may be disregarded because the early light of dawn scatters into the instrument. Note especially the occasional simultaneous Pi 1, 2 and Pc 2, 3 pulsations and the relative amplitudes on the Jicamarca, College, and Byrd records. The April 24, 1967, auroral event appears in Figure 5. Here a pulsation photometer record is shown, together with dH/dt. The detection instrument used is similar to the above, except that a bandpass filter similar to that used in the geomagnetic micropulsation system is introduced. Again we find simultaneous pulsations, especially Pi 1, 2 and Pc 5.

In the next three figures, examples of concurrent micropulsations at Jicamarca, College, and Byrd are shown for several selected days of March 1968. Note the Pc 2, 3, 4, 5 of Figure 6, and the Pi 1, 2, and Pc 2, 3, 5 of Figure 7. The Figure 8 case has an interesting example near 1400 UT; Jicamarca records show a Pc 5 correspondence with College data and, simultaneously, a Pc 4 correspondence with Byrd.

Amplitudes of the Pc 1 type pulsations drop off quite rapidly from the middle to the equatorial latitudes. We have found that occurrences at the low-latitude site, Maui, Hawaii, are rare in comparison to occurrences at College; the signals do not seem to reach Jicamarca at all. Figure 9 shows the spectral display of one important Pc 1 on October 23, 1967, which was observed throughout most of the Pacific area. Not a trace of this signal was seen at the equatorial site.

Figure 10 summarizes the number of half-hour intervals in which simultaneous micropulsations Pi 1, 2, and Pc 2, 3, 4, 5 were found at Jicamarca and College in the sample period of March–June 1968. Four features are evident. Such events are not rare; they have been observed at all hours of the day; the peak near 1100 UT is approximately geomagnetic midnight at College, a time when the micropulsation activity is typically quite high and the overhead aurora most active; the increased occurrences between 1400 and 2100 UT are during the daylight period at Jicamarca (local meridian noon is at 1707) when the equatorial electrojet is formed. Perhaps we should expect more evidence of concurrent pulsations when the auroral activity peaks and when there is an enhancement of overhead equatorial conductivity. If we could compare data from Jicamarca with data from *all* points along the auroral zone, we would then expect a single smooth maximum corresponding to the time of equatorial electrojet enhancement.

On February 20, 1968, at about 1117 UT an interesting sudden onset of Pi pulsations occurred around the world. We are presently investigating the time and amplitude distribution of this event.

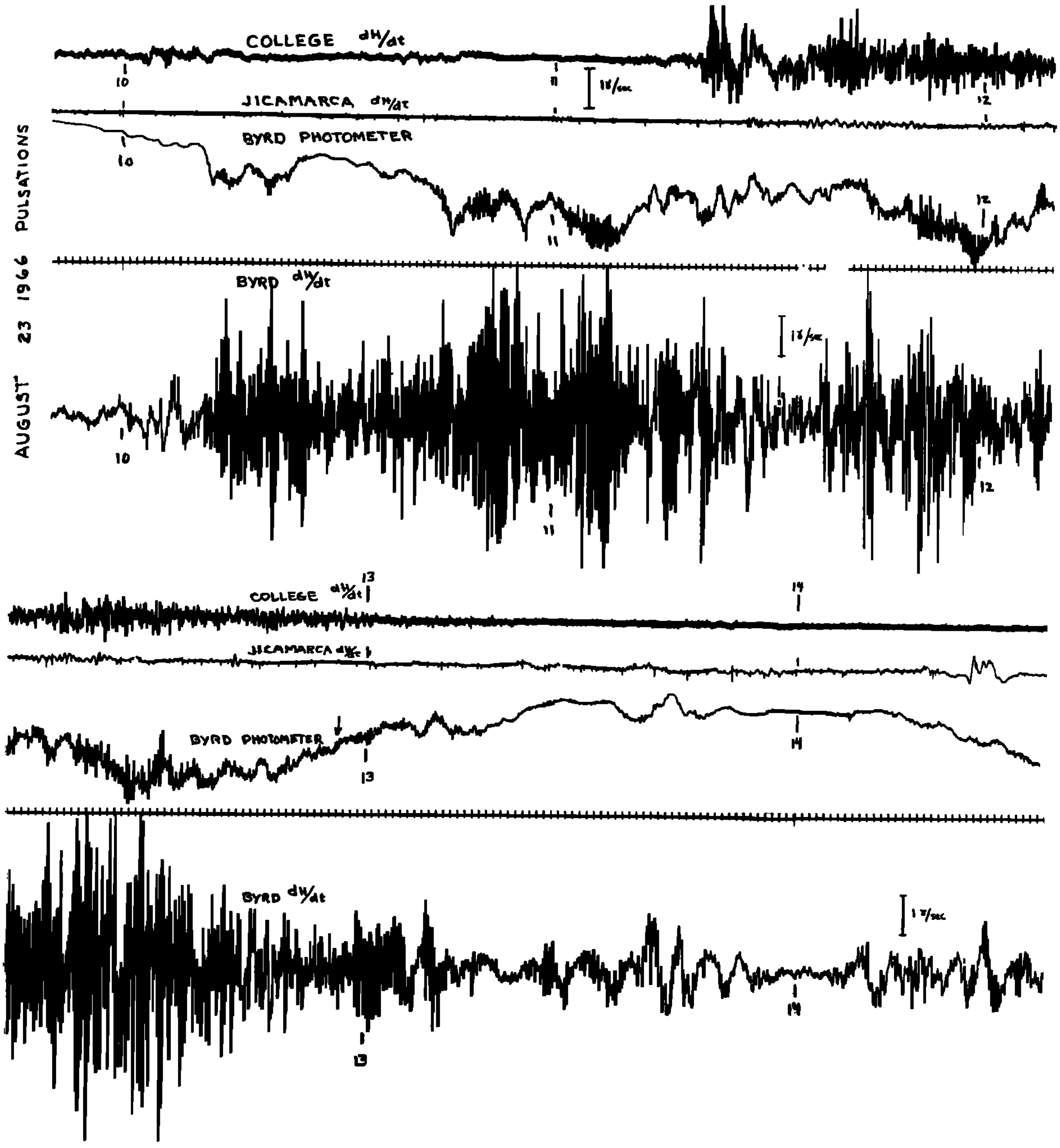

Fig. 4. Sample records of *dH/dt* at College, Jicamarca, and Byrd and a zenith photometer at Byrd for the UT period indicated on August 23, 1966.

The chart records of Thule, College, Boulder, Maui, and Jicamarca shown in Figure 11 illustrate its latitude distribution. The amplitude is highest at the auroral zone, where it is almost geomagnetic midnight.

The lead-lag cross-correlation coefficients between Jicamarca and each of the other stations were determined for 1/2-sec scalings (Figure 12). Table 2 sumarizes the results. A coefficient of approximately 0.6 was obtained for each station. Jicamarca's disturbance preceded those at College, Boulder, and Maui by 7 sec or more. The auroral station event was a full 10 sec later. The time delays order the stations in geomagnetic rather than geographic

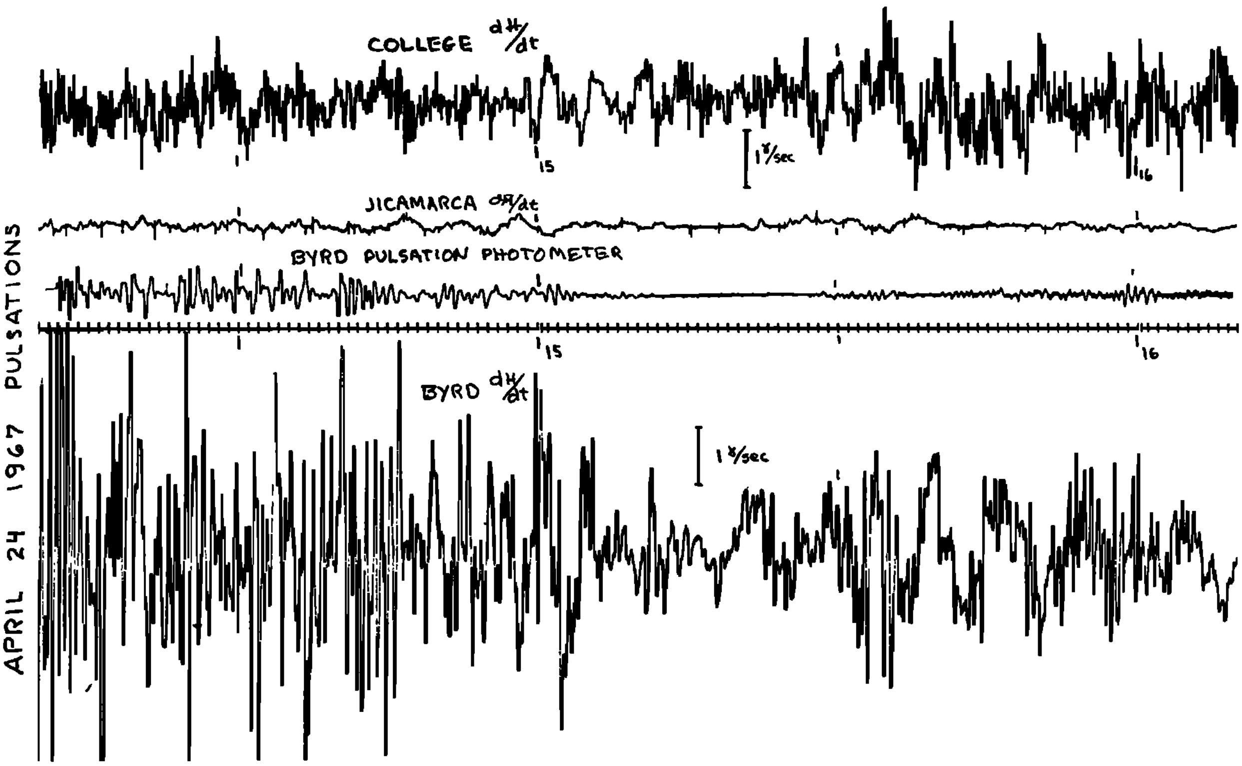

Fig 5. Sample records of *dH/dt* at College, Jicamarca, and Byrd, and a zenith pulsation photometer at Byrd for the UT period indicated on April 24, 1967.

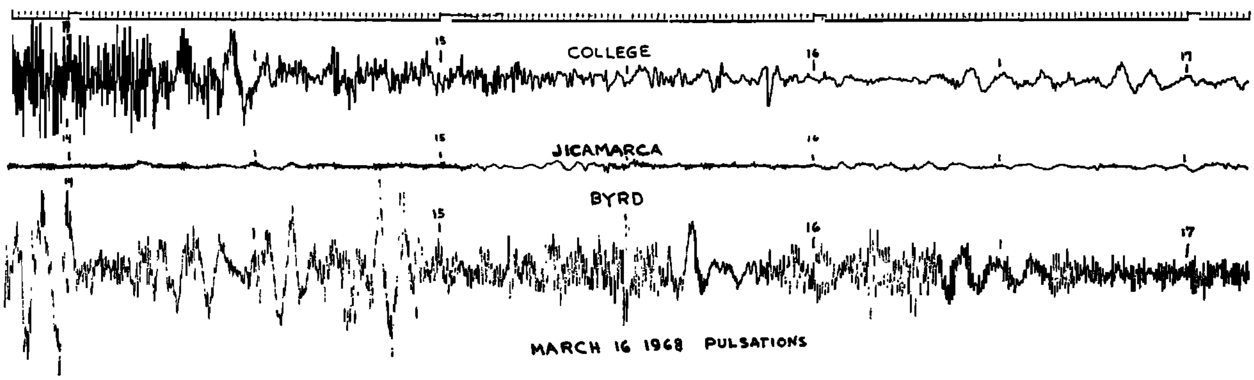

Fig. 6. Sample records of *dH/dt* at College, Jicamarca, and Byrd for the UT period indicated on March 16, 1968.

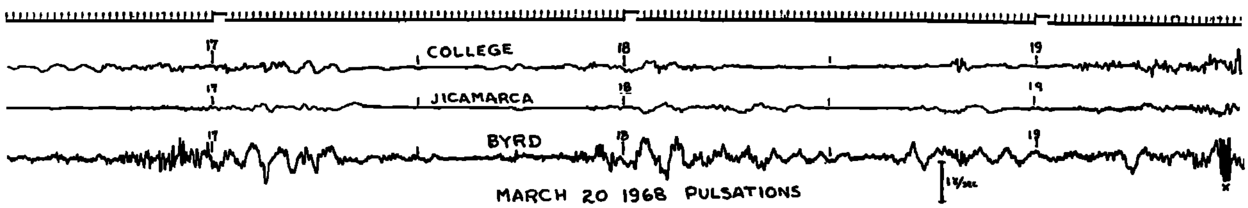

Fig. 7. Sample records of *dH/dt* at College, Jicamarca, and Byrd for the UT period indicated on March 20, 1968.

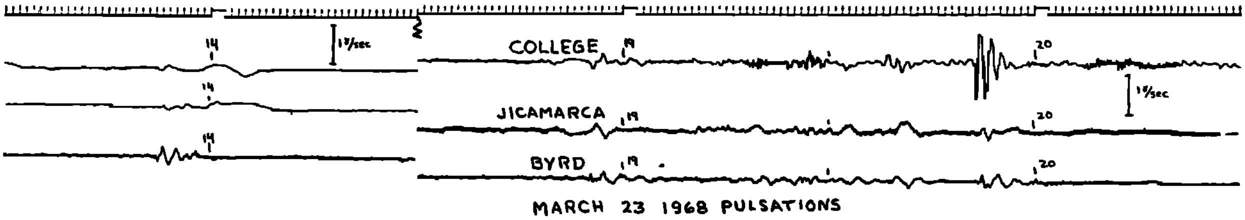

Fig. 8. Sample records of dH/dt at College, Jicamarca, and Byrd for the UT period indicated on March 23, 1968.

longitude. Except for the polar station, the farther westward the station, the later the event occurred, starting on the dawn side and proceeding to the midnight region. This result invites speculation about a similar traveling of the disturbance within the magnetosphere. Although a comparison of the total field, rather than of the single component, would possibly be more useful, those data are not available now.

MAGNETOSPHERIC SOURCES

Our present ability to assign the equatorial rapid variations in the geomagnetic field to magnetospheric sources depends on the joint identification of equatorial and high-latitude micropulsations. The reason for this is that there exists a large number of earlier and current studies that establish the relationship of the high-latitude field fluctuations to charged particle precipitation, the auroral electrojet current, and the magnetospheric parameters.

The Pc 1 travel as hydromagnetic waves in the magnetosphere [cf. *Cornwall,* 1965; *Gendrin,* 1965; *Suguira,* 1965; *Kenney et al.,* 1968; *Sen,* 1968; and *Criswell,* 1969]. The concentrated energy is a field-guided Alfvén wave traveling from its distant magnetospheric excitation region to the high latitudes. These pulsations are absorbed, to some extent, as they arrive at the ionosphere [*Greifinger and Greifinger,* 1965; *Campbell,* 1967]; then, upon coupling to a new propagation mode, they travel equatorward in an ionospheric duct near the F_2-region ionization peak [*Wentworth et al.,* 1966; *Greifinger and Greifinger,* 1968; *Manchester,* 1968]. Two items of importance here are, first, that there have been no reports of an ionospheric manifestation of these pulsations (such as ionization or aurora), and, second, there are no true equatorial detections of such events. The lowest-latitude observation was reported by *Tepley* [1964] for a Canton Island reception at about 8° from the dip equator. The Pc 1 signal traveling a long distance from its high-latitude arrival point must be appreciably attenuated before reaching the equator. The high ionization of the equatorial electrojet region may also be assumed to represent a barrier to this propagation.

The evidence from our figures, as well as from the earlier reports, of the great spatial extent of equatorial Pi 1 to 3 [*Onwumechilli and Ogbuehi,* 1962; *Akasofu and Chapman,* 1963; *Rastogi et al.,* 1966; and *Glangeaud et al.,* 1968] ties together the high- and low-latitude field changes. Auroral intensity, *D*- and *E*-region ionization, particle precipitation, and the auroral electrojet are all interrelated parts of this phenomenon. There is an often reported association of the amplitude of these equatorial Pi 1 and 2 fluctuations with the strength of the equatorial electrojet. This association would imply that such field variations are actually ionospheric currents communicated to the equatorial regions from the higher latitudes. *Nishida* [1968] has shown the Pi 3 to be coherent with variations in the north-south component of the interplanetary magnetic field. He found the time delay between the crossing of an interplanetary magnetic structure across the nose of the bow shock and the associated variation on the ground to be 7 min at the pole and 9 min at the midday equator. It is then a question of how much of the equatorial Pi 3 is a direct magnetospheric effect and how much is again communicated there from the auroral electrojet, which likewise shows such disturbances. If the arrival-time distribution of the Pi 1 in Figures 11 and 12 may be interpreted as the differences in direct arrivals of the signal at the stations from the magnetosphere, then the time scale is considerably shorter and the order of arrival is reversed.

The Pc 2, 3, 4, 5 show many common features. They are often identified over large portions of the earth with some enhancement at the equator [cf. *Matuura,* 1961; *Saito,* 1964; *Roquet,* 1967; *Campbell,* 1968*a*]. Those sinusoidal type pulsations are typically of maximum amplitude in the auroral zone,

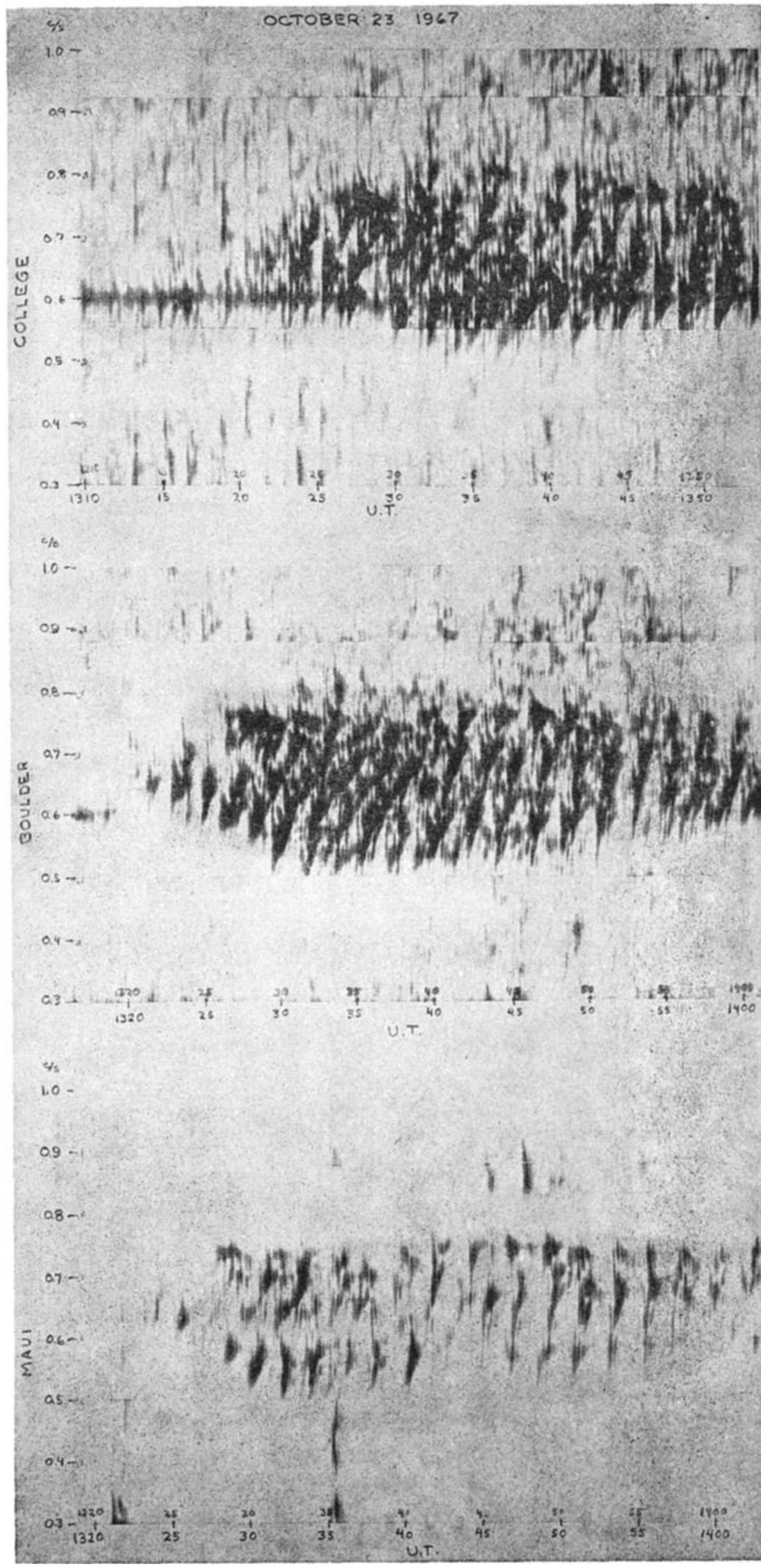

Fig. 9. Frequency-time display of Pc 1 event observed at College, Boulder, and Maui for the UT period indicated on October 23, 1967.

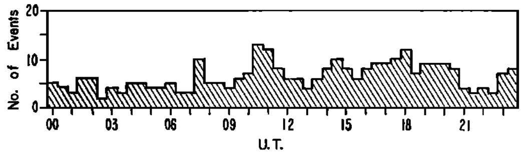

Fig. 10. Numbers of cases of concurrent micropulsations at Jicamarca and College in the period of March to June 1968, for 1/2-hr intervals of UT.

and are at times identifiable, at such high latitudes, with auroral particle precipitation or increased ionospheric radiowave absorption [cf. *Campbell and Leinbach,* 1961; *Kaneda et al.,* 1964; *Sato,* 1964; *Barcus and Rosenberg,* 1965; *Victor,* 1965]. The clear associations with ionospheric phenomena encourage the thought that ionospheric currents bring the disturbance to the lower latitudes. The conjugate station identification of identical signals has excluded the ionosphere as the originating source region or as the effective agent in any selective resonant transmission of the pulsations [*Campbell,* 1968*b*]. It is now generally accepted that the conditions are suitable for the generative hydromagnetic wave resonances within the magnetosphere [*Judge and Coleman,* 1962; *Nagata et al.,* 1963; *Prince et al.,* 1964; *Sugiura and Wilson,* 1964; *Sugiura,* 1965; *Dungey,* 1968].

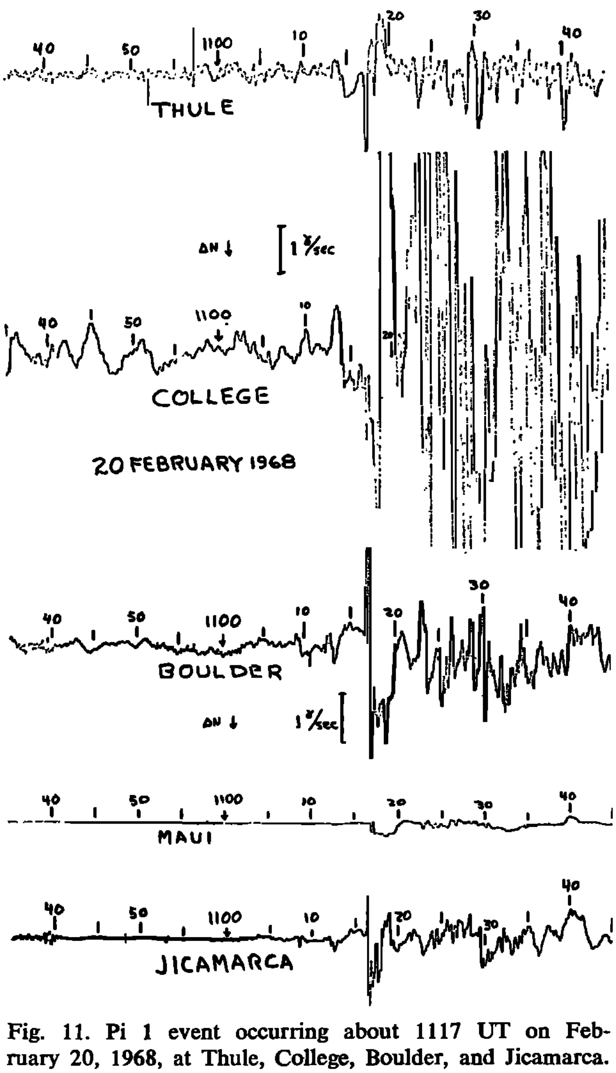

Fig. 11. Pi 1 event occurring about 1117 UT on February 20, 1968, at Thule, College, Boulder, and Jicamarca.

Direct measurements of space phenomena related to surface Pc events have only recently been available. Seasonal increases in Pc 4 and 5 periods with upper atmospheric plasma density variations as reflected by satellite drag, increased VLF whistler dispersion, and enhanced critical frequencies of the E and F_2 ionosphere were demonstrated by *Kato and Saito* [1964]. *Saito* [1964] also reported that the daily, daytime index of Pc 3 activity yielded correlation coefficients of about 0.8 with solar-wind velocity determinations from Mariner 2.

Satellite magnetometers have observed field fluctuations in space about the earth since the first flights of the Pioneer and Explorer series [*Coleman et al.,* 1960; *Sonett et al.,* 1962; *Judge and Coleman,* 1962; *Sonett,* 1963; *Patel and Cahill,* 1964]. The experiments indicate the existence of transverse (Alfvén) hydromagnetic waves with elliptical polarization in a sense consistent with the diurnal pattern of ground observations for waves propagated along the earth field lines. *Patel* [1965] presented Explorer 14 pulsations concurrent with surface field variations at Byrd, Antarctica. Explorer 6 [*Judge and Coleman,* 1962] experimenters found fluctua-

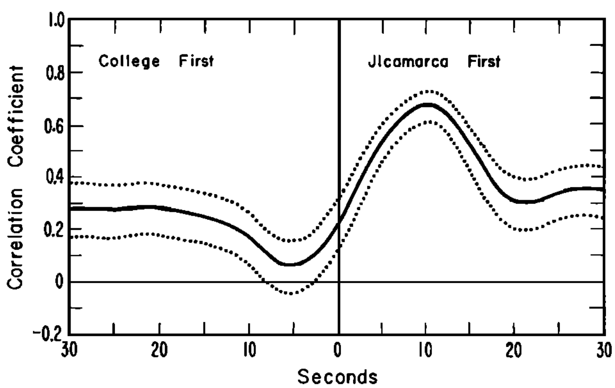

Fig. 12. Lead-lag correlation coefficient for February 20, 1968, Pi 1 event at Jicamarca and College for the period 1116:00 to 1118:30 UT. Dots indicate 90% probability limits.

tions in the intensity of detected particles with relative amplitude variations comparable to the simultaneous field micropulsations. The Explorer 12 [*Patel and Cahill,* 1964] results indicated that the Alfvén waves took about 1½ min to travel from the geomagnetic field boundary at 55,000 km to College, Alaska.

Observation of shorter period Pi and Pc pulsations at satellite altitudes has awaited the advent of geostationary platforms, as well as more sensitive space magnetometers aboard low-noise vehicles. Results from the ATS-1 synchronous satellite by *Cummings and Coleman* [1968] and *Coleman and Cummings* [1968] compared the magnetic field changes measured at 6.6 R_E with Honolulu and College magnetic records. Recent data from the ATS-1 satellite [*Cummings et al.,* 1969] showed transverse oscillations of 2 to 20 γ with 50- to 300-sec period.

CONCLUSION

This paper has presented some evidence for the identification of similar magnetic field micropulsations at equatorial and auroral latitudes. All types except Pi 1 can be observed simultaneously in the two zones. The brief review of some papers on sources of high-latitude micropulsations and on their presence in space was given to show that the equatorial rapid variations in field are manifestations of magnetospheric phenomena.

The ionospheric duct idea for transporting Pc 1 to lower latitudes seems valid. However, more measurements of propagation velocity and attenuation as functions of frequency over long distances are presently needed from the experimenters.

In all the other pulsation types, a daytime equatorial enhancement of amplitudes favors a communication of the disturbance to that region via ionospheric curents of the S_q type. Nevertheless, delays of the occurrence time such as those evidenced in the Table 2 event imply that other processes are transpiring, possibly even a field shock directly from the magnetosphere. What are now required are more exact observations of amplitude and arrival time over the earth during selected characteristic periods of the growth and decay of the equatorial electrojet.

TABLE 2. Time Jicamarca disturbance precedes other stations, 1117 UT, February 20, 1968.

Station	Lead-Lag Correlation Coefficient	90% Confidence Limits	t with respect to Jicamarca, sec	Local Ecc. Dipole Geomagnetic Time
Thule	+0.55	±0.07	+ 7.0	0827
College	+0.68	±0.05	+10.0	0010
Boulder	−0.62	±0.06	+ 7.5	0348
Maui	+0.63	±0.06	+ 8.5	0048
Jicamarca	...	...	0	0621

Acknowledgments. The Jicamarca data were made available through the assistance of Mr. Carlos Romero of the Instituto Geofísico del Peru. The Maui, Hawaii, facility was under the supervision of the Institute of Astronomy of the University of Hawaii. The College, Alaska, observations were conducted by Mr. Jack Townshend of the U. S. Coast and Geodetic Survey. Equipment at Thule, Greenland, is operated for ESSA by the Air Force Cambridge Research Laboratories. Funds for the Byrd, Antarctica, and the Maui, Hawaii, activities were made available through the National Science Foundation under grants AG97 and AG113. I am grateful to all these organizations and wish to express my thanks to the individuals responsible for the cooperative endeavors.

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