Geomagnetic Conjugacy between the Antarctic and the Arctic

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Abstract: Along a tube of force of the geomagnetic field, charged particles such as electrons, electric field and hydromagnetic waves propagate simultaneously from the equatorial region in the magnetosphere to the mutually conjugate areas of the earth's surface.

The auroral electrojets, *SSC*'s, *SI*'s and pc-5 pulsations show remarkable simultaneity and similarity between the conjugate areas. Their time-dependent parameters such as the form of frequency spectra, the dominant period of pulsations, the rise-time of *SSC*'s, etc., are almost exactly the same in the conjugate stations. However, the correlation between amplitudes or magnitudes of these phenomena at the conjugate points is considerably smaller than that for the time-dependent parameters.

The horizontal polarizations of *SSC*'s, *SI*'s and pulsations are the left-hand mode in the morning and right-hand one in the afternoon with an absolutely high statistical significance.

These discussions are mostly based on the data from the conjugate pair of Syowa Station and Reykjavik and that of Macquarie Island and Alaskan stations.

1. Introduction

The geomagnetically conjugate points are defined as the intersection points of a line of geomagnetic force with the earth's surface, one in the northern hemisphere and another in the southern hemisphere. From both observational and theoretical results, it has become known that the geomagnetically conjugate points are generally subjected to simultaneous and similar geomagnetic disturbances (Vestine and Sibley, 1959; Vestine, 1959; Nagata and Kokubun, 1961; Wescott, 1961; Wescott and Mather, 1965 a, b, c). The conjugate phenomena are due to the fact that charged particles such as electrons and ions are closely tied with lines of geomagnetic force by Lorentz's force resulting in their spatial motion around the lines so that they can move freely only along the same lines of force. The geomagnetically conjugate relation, therefore, seems to be especially interesting for high latitude conjugate pairs; for example, a pair of one in the Antarctic and another in the Arctic, because the lines of force linking these pairs pass through the magnetospheric space far distant from the earth, where appreciably great disturbances of the magnetospheric plasma are always taking place.

Some aspects of the conjugate relation for geomagnetic disturbances in high latitudes have already been reviewed by the present writer (Nagata, 1963, 1964).

In a recent review by WESCOTT (1966), the conjugate relations for the cosmic noise absorption, visual aurora, auroral X-rays, geomagnetic variations and VLF phenomena have been summarized and discussed more comprehensively. It seems that the general aspects of simultaneity and similarity of those upper atmospheric disturbances in the conjugate areas in high latitudes have almost been established in a sense of the first approximation. The general aspect of conjugacy in the first approximation is simply interpreted as due to simultaneous transportation of charged particles or propagation of hydromagnetic waves along the lines of geomagnetic force from the equatorial magnetosphere towards the conjugate areas over the earth. This theoretical model would be called the *static conjugacy*.

However, charged particles are reflected at their mirror points, thus making backward and forward motions between the mirror points, and damped particles only precipitate to the lower ionosphere. A considerable portion of hydromagnetic waves is also reflected by the ionosphere, a kind of standing hydromagnetic waves being possibly generated along the lines of geomagnetic force. Furthermore, charged particles should be subjected to the drift motion owing to the gradient and curvature of magnetic field. Thus, the *dynamic conjugacy*, in which the above-mentioned dynamic behaviour is taken into account, will become more complicated than the static conjugacy. Taking the dynamic behaviour mentioned above into consideration, NAGATA, KOKUBUN and IIJIMA (1966) have studied, in fair detail, the magnetic conjugacy for polar magnetic storms, magnetic bays, *SSC*'s, *SI*'s and pc-5 pulsations between the Antarctic and the Arctic. WILSON (1966) also has studied the conjugacy of pc-5 pulsations in detail. The geomagnetic conjugacy could be divided into two categories; namely, (a) motions of plasma particles strongly subjected to the lines of geomagnetic force and (b) anisotropic hydromagnetic waves propagating along the direction of geomagnetic field. However, the results of category (a) conjugacy could further be classified into two groups; namely, (A) effects of ionization, excitation, etc., of the earth's upper atmosphere caused by precipitating plasma (such as auroral displays, increase of cosmic noise absorption, etc.), and (B) effects of transference of excess electric charge by precipitating plasma particles; in other words, transference of an electric field to the ionosphere.

2. Conjugate Stations of Antactic Magnetic Observatories

The geomagnetically conjugate points of Antarctic magnetic stations can be computed by refering to the spatial distribution of the geomagnetic field which is customarily expressed in terms of spherical harmonic series.

VESTINE (1960) reported a number of conjugate points for existing stations. WESCOTT and MATHER (1964) and ROEDERER *et al.* (1965) have published extensive lists of conjugate pairs based on more precise data of the geomagnetic field distribution. On the other hand, HAKURA (1964) has proposed a convenient orthogonal coordinate system for representing any location on the earth's surface based on the geomagnetic field distribution. In the HAKURA's coordinates, called corrected geomagnetic coordinates, the conjugate point P′ of a point P is expressed, with a high precision, as a point symmetric with P with respect to the equater of the new coordinates. In Table 1, the corrected geomagnetic latitudes and longitudes of Antarctic stations and those of the Arctic stations nearest to the formers' conjugate points are listed. Among those approximately conjugate pair stations, the conjugacy is comparatively well held for those of Syowa Station-Reykjavik and Macquarie Island-Kotzebue.

Table 1. Corrected geomagnetic coordinates of Antarctic stations and those of Arctic stations nearest their conjugate points.

Antarctic stations	Corrected geomagnetic Lat.	Long.	Approximate conjugate stations	Corrected geomagnetic Lat.	Long.
Kergulen	−57.8	122.5	Nurmijurvi	56.6	103.6
Campbell Is.	−60.5	255.2	Anchorage	60.8	261.3
			Cape Wellen	62.6	243.0
Macquarie Is.	−64.4	244.0	Kotzebue	63.4	247.8
			Healy	63.7	260.2
			College	64.9	260.2
Halley Bay	−61.4	28.5	Lervick	58.9	84.3
Syowa Station	−66.7	72.5	Reykjavik	66.6	71.2
Byrd	−68.7	352.0	Churchill	70.0	326.0
Mowson	−70.6	93.1	——	—	—
Little America	−74.3	332.8	Baker Lake	75.1	320.4
Dumon d'Urville	−80.1	228.7	——	—	—
Mirny	−76.6	127.4	Spitzbergen	74.7	114.8
Wilkes	−79.7	157.6	——	—	—
South Pole	−74.7	17.3	——	—	—
Scott Base	−80.5	323.4	——	—	—
Vostok	−87.9	66.7	——	—	—

3. Auroral Electrojet

Magnetic bays can be represented by auroral electrojets of a rather short duration, whereas polar substorms can be considered as a sequence of successive occurrences of bay-type variations.

3-1. *Cross correlation coefficients for magnetic bays and polar substorms*

The simplest possible measure for the degree of coherence of geomagnetic variations between two separate stations will be their cross correlation coefficients. Using this method, NAGATA and KOKUBUN (1961), NAGATA *et al.* (1962), ONDOH and MAEDA (1962), BOYD (1963), KOKUBUN (1965) and WESCOTT and MATHER (1965 a, b, c) have studied the problem of conjugacy for magnetic bays and polar substorms. Generally speaking, the conjugacy between approximately conjugate stations is comparatively good (the cross correlation coefficient $\gamma > 0.7$) for sharp negative bays which have been proved to be associated with electron precipitation of a fairly large flux (*i. e.* 10^7-10^9 electrons/cm^2, sec). The degree of coherence in conjugate areas ought to depend on the lateral dimensions of electron beams precipitating to the conjugate areas. The aerial dimensions of coherent magnetic variations have been estimated by FELDSTEIN and KURDINA (1958), NAGATA (1962), WESCOTT and MATHER (1966) and others. The coherent area increases with increasing magnetic activity, in particular, along the geomagnetic latitude cycle, as pointed out by ONDOH and MAEDA (1962) and NAGATA (1962). For comparatively weak auroral electrojets, the dimension of coherent area, defined by the cross correlation (γ) which is larger than 0.9, are 125–180 km and 300 -350 km in N-S and E-W directions respectively. In the case of severe magnetic storms, the area becomes enlarged, the dimensions of coherence of $\gamma \geqq 0.8$ reaching about 400 km and 2000 km respectively in N-S and E-W directions.

Table 2. Average cross correlation coefficients between the auroral zone stations and their approximate or nearly conjugate stations.

Station pairs	Corrected geomagnetic Lat.	Corrected geomagnetic Long.	N-S deviation	E-W deviation	Correlation coefficient	Remark
Syowa	−66.7	72.5	− 0.1	1.3	0.86	H*
Reykjavik	66.6	71.2				
Macquarie Is.	−64.4	244.0	+ 0.5	16.3	0.85	K**
College	64.9	260.3				
Macquarie Is.	−64.4	244.0	− 1.8	1.0	0.75	Q***
Cape Wellen	62.6	243.0				
Halley Bay	−61.4	28.5	− 2.5	55.8	0.55	H**
Lerwick	58.9	84.3				
Little America	−74.3	332.8	+ 9.8	70.3	0.49	H**
Big Delta	64.5	262.5				
Mirny	−76.6	127.4	+11.7	12.6	0.38	K**
Murmansk	64.7	114.8				

Remarks H : Correlation for geomagnetic horizontal force. (*) NAGATA *et al.* (1966)
K : Correlation for K-indies. (**) ONDOH and MAEDA (1962).
Q : Correlation for Q-indices (***) NAGATA *et al.* (1962).

Table 2 summarizes the average cross correlation coefficients between the auroral zone stations and their approximately or nearly conjugate stations. Either one or both stations in these pairs are located within the auroral zone, defined as a zone of 61°–67° in the corrected geomagnetic latitude. The N-S deviation in the table indicates a poleward deviation from the reference station of the conjugate points of pair station, where a station nearer to the central latitude of the auroral zone (±65°) is chosen as the reference station. Since different measures are used in evaluating the correlation, their quantitative comparison in detail will not be permissible. However, it will be clear at a glance that the correlation coefficient decreases sharply with increasing difference, whereas the high correlation persists for larger difference in longitude.

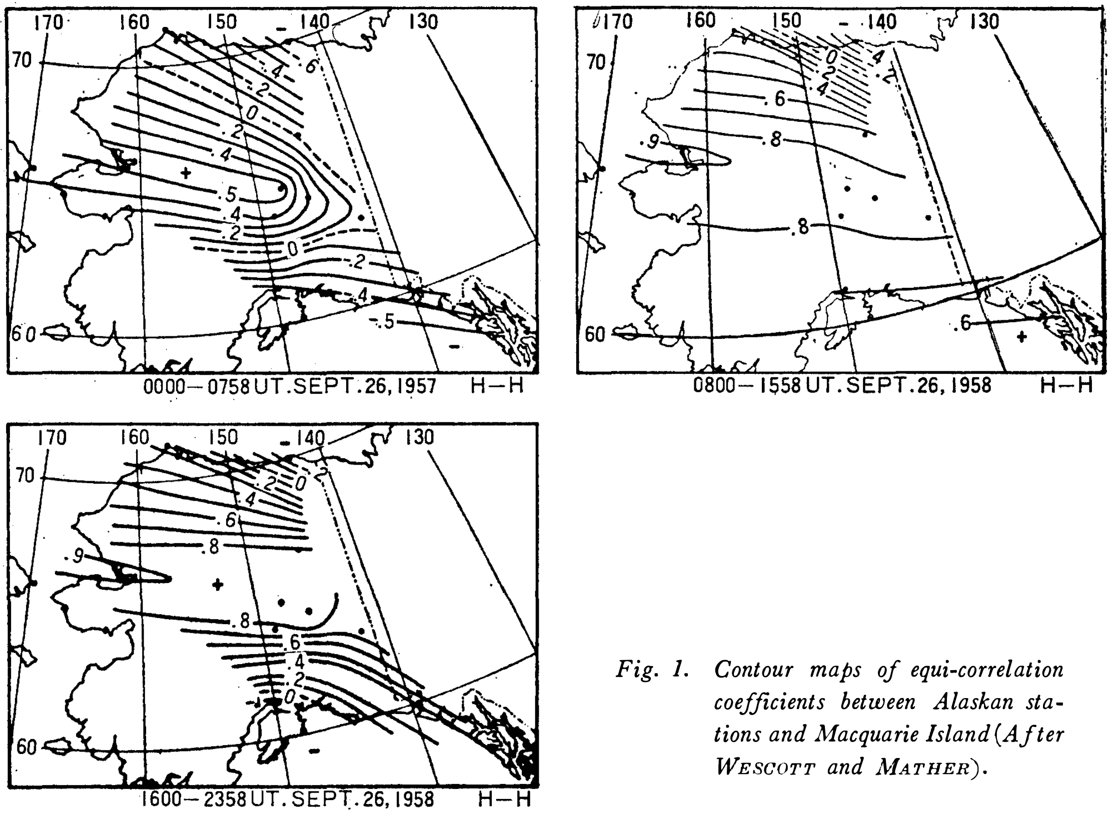


Fig. 1. Contour maps of equi-correlation coefficients between Alaskan stations and Macquarie Island (After Wescott and Mather).

Extensive studies based on the cross correlation method have been made by Wescott and Mather (1965 a, b, c) for selected individual events, using magnetograms of Macquarie Island and from eleven stations in the neighbourhood of its conjugate point. Figure 1 shows an example of contour map of equi-correlation coefficient. Although the geometrical shape of contours differs from case to case, it has been generally concluded that the contours are always elongated along a line of constant L value, *i.e.*, a line of constant corrected geomagnetic latitude.

3–2. *Similarity and simultaneity of auroral electrojets in conjugate areas*

The correlation coefficient between approximately conjugate stations takes the maximum value for cross correlation of simultaneous values (Nagata *et al.*, 1962), indicating that the major variations of auroral electrojets take place simultaneously at conjugate stations. For all typical bay events, the magnetically north components (ΔH) have the same sense, either positive or negative, but the magnetically east components ($H\Delta D$) have the opposite sense between conjugate

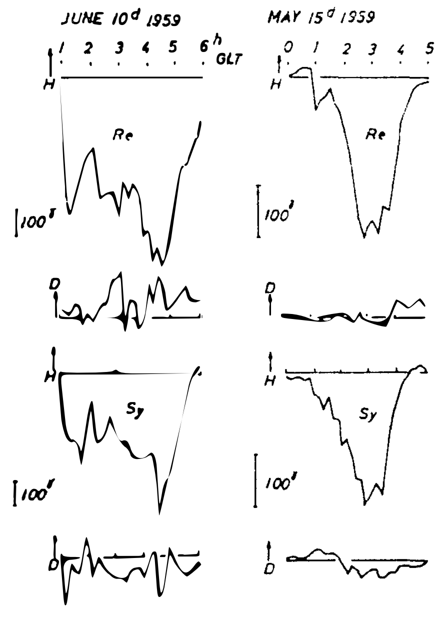


Fig. 2. Examples of negative bays observed simultaneously at Syowa Station (Sy) and Reykjavik (Re).

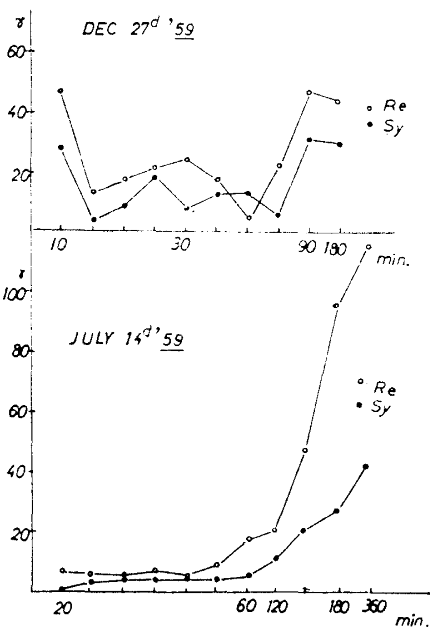


Fig. 3. Examples of period spectrum of geomagnetic bays observed simultaneously at Syowa Station (Sy) and Reykjavik (Re).

stations as illustrated in Fig. 2. This result indicates that the auroral electrojets are located and oriented with a conjugate relationship (see Fig. 4). In other words, all points on the electrojet on one side are conjugate with those on the other corresponding electrojet.

Figure 3 shows examples of the frequency spectra of simultaneous bays at Syowa Station and Reykjavik. The main peaks in the spectra are in a good mutual agreement between the conjugate stations. However, the intensities of spectra are considerably different between the two stations. Throughout all other examples so far examined, it is true that the time-dependent parameters, such as times of peaks of variations and shapes of frequency spectra, are in a good agreement, but the magnitudes or intensities as a whole are considerably different between the conjugate stations.

3–3. *Comparison of current patterns*

Direct comparison of time sequence of the simultaneous ionospheric current patterns over the both polar regions will be one of the ideal approaches to solve the problem of conjugate relationship. Owing to a limited number of magnetic stations, particularly in the Antactic, satisfactory research along this line will meet various kinds of difficulties. NAGATA, KOKUBUN and IIJIMA (1966) have tried to make preliminary studies along this line, using simultaneous magnetograms during the IGY at eleven and nine stations respectively in the Arctic and Antarctic regions. Figure 5 shows the average current patterns over the north and south polar regions for

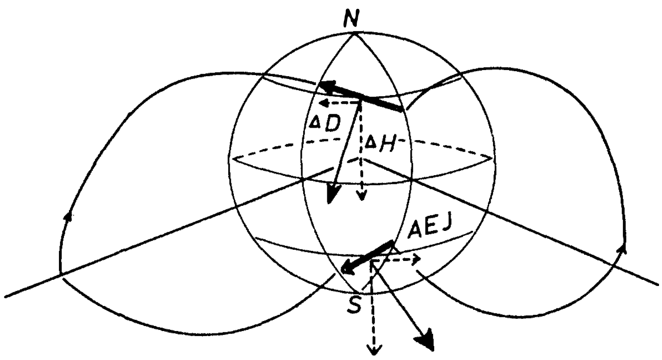


Fig. 4. Conjugacy of the auroral electrojet.

Table 3. Characteristic measures of the average ionospheric current patterns of polar magnetic storms simultaneously observed in the north and south polar region.

Measures	Severe storm $(\overline{K}_p=7.4)$		Moderate storm $(\overline{K}_p=4.3)$	
	North	South	North	South
Direction of current at the pole	09^h	09^h	09^h	08^h
Center of current vortices				
Morning side	70°, 2.2^h	-70°, 2.2^h	72°, 2.5^h	-72°, 2.4^h
Afternoon side	71°, 15.7^h	-71°, 14.3^h	72°, 14.4^h	-72°, 13.9^h
Total polar cap intensity	85×10^4 Amp.	85×10^4 Amp.	45×19^4 Amp.	45×10^4 Amp.
Westward *AEJ*	40×10^4 Amp.	35×10^4 Amp.	25×10^4 Amp.	20×10^4 Amp.
Eastward *AEJ*	30×10^4 Amp.	25×10^4 Amp.	10×10^4 Amp.	10×10^4 Amp.

the most developed stage of 6 hours in the duration of 14 severe magnetic storms ($K_p>6$, $\overline{K}_p=7.4$) during the IGY. The ionospheric current patterns in the two polar regions are almost exactly symmetric with respect to the equator of corrected geomagnetic coordinates, consisting of latitude and magnetic time. As the key parameters of the polar ionospheric current patterns, the direction of polar cap parallel currents, the total current over the polar cap, the intensities of westward and eastward auroral electrojets (*AEJ*) and the locations of centers of polar double vortices are summarized in Table 3. The results of a similar analysis for 14 moderate storms ($K_p\leqq5$, $\overline{K}_p=4.3$) are also shown in the table. In Table 3 as well as in Fig. 5, we may conclude that the polar magnetic storms at conjugate points in the Antarctic and Arctic regions are almost identical to each other, in regard not only to their modes of variation with time and space, but also to their

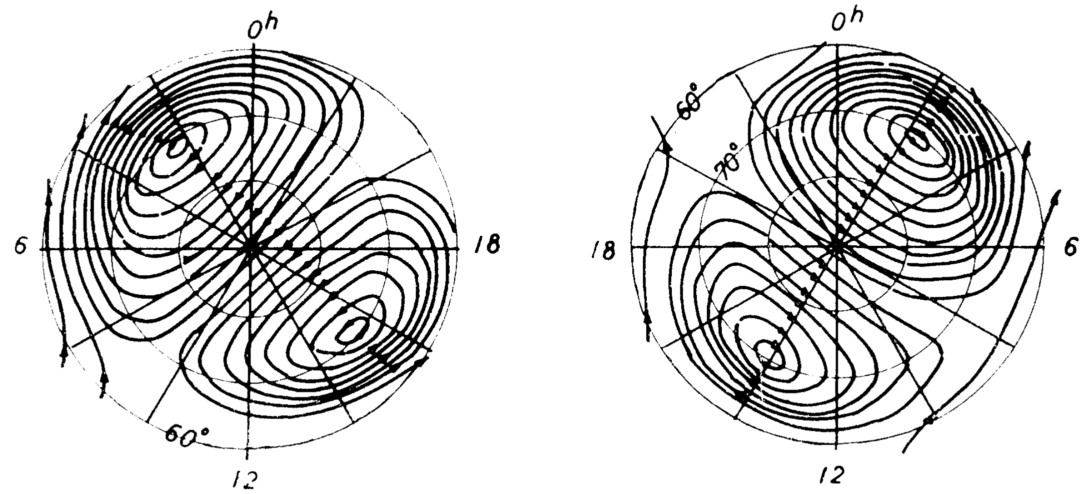


Fig. 5. Ionospheric current pattern of D_p field for average severe storm ($\overline{K_p}=7.4$) in the northern (left) and southern (right) polar regions. Electric current between adjacent current lines is 5×10^4 amperes.

magnitude. However, the magnitude of geomagnetic bays at polar conjugate points seem to be subjected to a seasonal variation effect. For instance, the average total polar cap current for 24 selected magnetic bays is about 2.3×10^5Amp. for the sunlit condition (summer), whereas that for 17 bays for the dark condition amounts only to 1.5×10^5Amp. It seems likely that the marked seasonal change in electric conductivity of the polar ionosphere is essentially involved in the ionospheric current for geomagnetic bays. This is also the case of S^p_q field (Nagata and Kokubun, 1962).

4. Magnetic Pulsations, *SSC*'s and *SI*'s

The conjugate relationship for polar magnetic pulsations of pc-4 and pc-5 categories and storm sudden commencements (*SSC*'s) have been studied by Sugiura (1961), Wilson and Sugiura (1961), Nagata *et al.* (1963, 1966), Wilson (1966) and others. As shown by Kokubun and Nagata (1965) and Nagata (1964), the amplitude of pc-5 pulsation dependent on geomagnetic latitude takes the maximum value in the auroral zone, decreasing toward both equatorial and polar sides. This fact may indicate that the energy of magnetic pulsations ascribed to hydromagnetic waves is confined mostly to the lines of geomagnetic force passing through the both auroral zones.

Sugiura's suggestion (1961) that the *SSC* phenomenon observed on the earth's surface can be interpreted as an arrival of the front of a hydromagnetic shock wave has been widely accepted (*e.g.* Nagata, 1963), and this idea has been extended to interpret the sudden impulse (*SI*) phenomenon also (Nagata *et al.*, 1966). One of the marked characteristics which are common to pc-5 pulsations, *SSC*'s and *SI*'s observed at conjugate stations in the auroral zones is a conjugate relationship of their polarization.

Table 4. Polarization characteristics (in the horizontal plane) of pc-5 pulsations, SSC's and SI's simultaneously observed at Syowa Station and Reykjavik.

Type of variation	Morning side (23ʰ—11ʰ LT) Syowa Station	Reykjavik	Afternoon side (11ʰ—23ʰ LT) Syowa Station	Reykjavik
(1) pc-5				
L-mode	81%	100%	37%	32%
R-mode	19	0	63	68
(2) *SSC*				
L-mode	92	89	20	34
R-mode	8	11	80	66
(3) *SI*				
L-mode	89	89	19	19
R-mode	11	11	81	81

Ramarks L-mode: Left-hand sense polarization.
R-mode: Right-hand sense polarization.

4–1. *Polarization characteristics*

Pc-5 pulsations and *SSC*'s observed in high latitudes are, in general, elliptically polarized and the sense of rotation of polarization in a horizontal plane in the afternoon is opposite to that in the morning (SUGIURA, 1961; WILSON and SUGIURA, 1961; NAGATA *et al.* 1963; WILSON, 1966). Results of analyses of the polarization characteristics for pc-5 pulsations, *SSC*'s and *SI*'s observed simultaneously at a conjugate pair, Syowa Station and Reykjavik, are summarized in Table 4 (NAGATA *et al.*, 1966), where L-mode means the left-hand rotation along the direction of a line of force and R-mode the right-hand rotation. The L-mode polarization corresponds to the counterclockwise rotation in the north and the clockwise rotation in the south when looked down from the above toward the earth's surface. It will be statistically confirmed in Table 4 that the polarization in the morning is the left-hand sense whereas that in the afternoon is the right-hand one. Exactly the same results have been obtained from the data of pc-5 pulsations and *SSC*'s at the approximately conjugate stations, Macquarie Island and Alaskan stations. The invariant characteristic of the polarization of pc-5 pulsations along a line of force has been proved by satellite-borne measurements also. Thus, pc-5 pulsations, *SSC*'s and *SI*'s are ascribed to transverse hydromagnetic waves of either L-or R-mode. The tendency that the morning events are of the L-mode is statistically more significant than the afternoon tendency of the R-mode. It has been pointed out further in the data from College, Alaska (KOKUBUN and NAGATA, 1965) that the range of L-mode pulsations is generally larger than that of R-mode ones. It seems likely, therefore, that the L-mode is more easily generated and maintained than the R-mode.

4–2. *Similarity and simultaneity at conjugate points*

Figure 6 shows an example of correlation diagram of the period of pc-5 pulsations observed simultaneously at Syowa Station and Reykjavik. Figure 7 shows that of rise-time of *SSC*'s simultaneously observed at the two stations. Figures 8 and 9 show examples of frequency spectra of *SSC*'s and pc-5 pulsations respec-

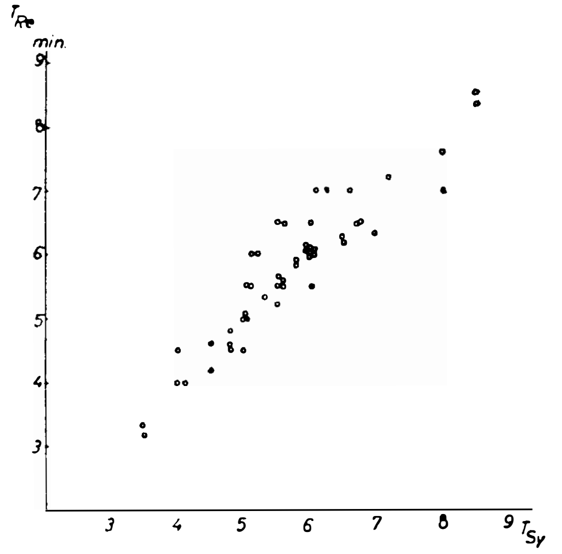


Fig. 6. Correlation diagram of period of pc-5 pulsations observed simultaneously at Syowa Station (T_{Sy}) and Reykjavik (T_{Re}).

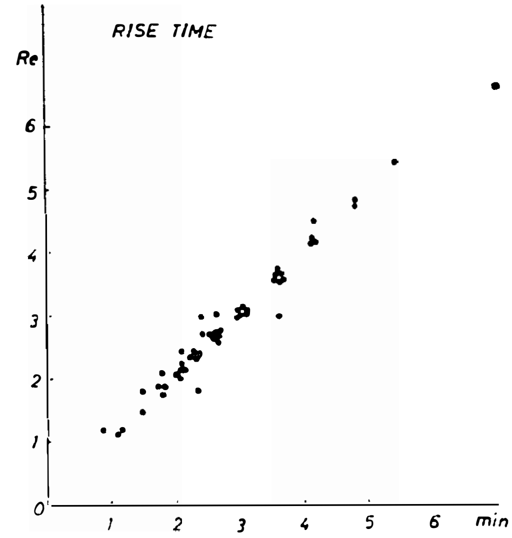
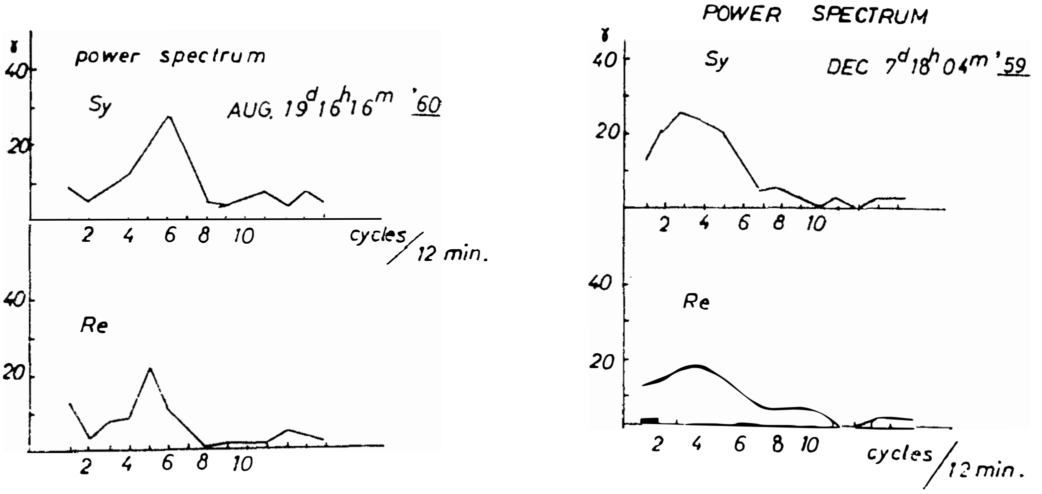
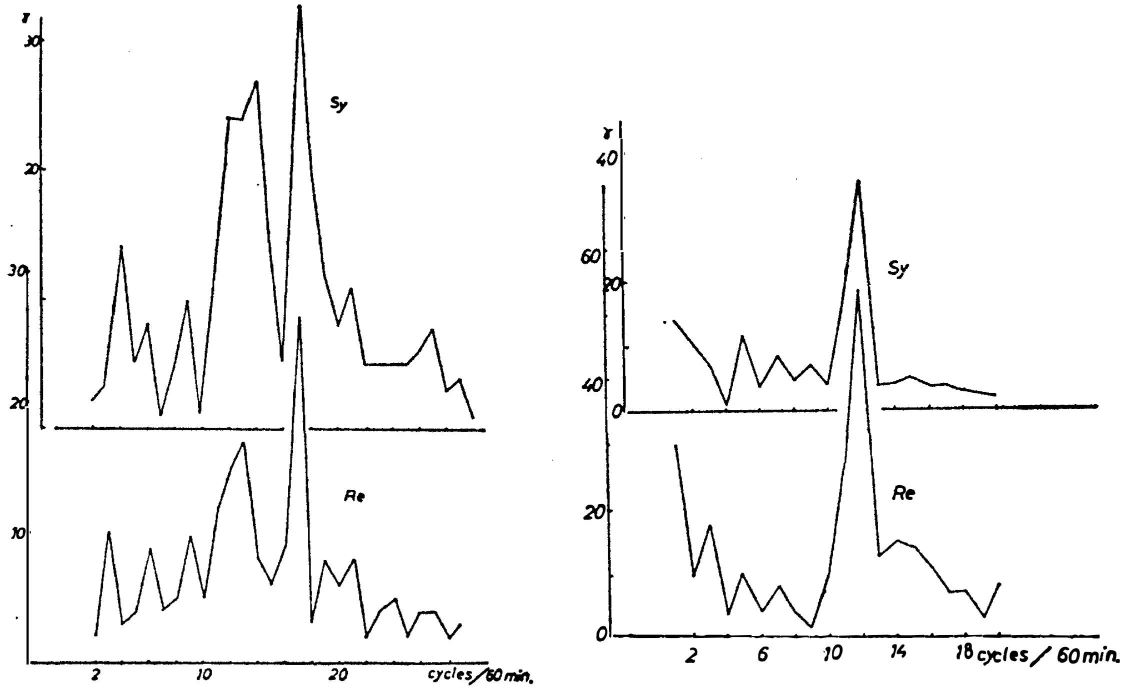


Fig. 7. Correlation diagram of the rise-time of SSC observed simultaneously at Syowa Station (Sy) and Reykjavik (Re).

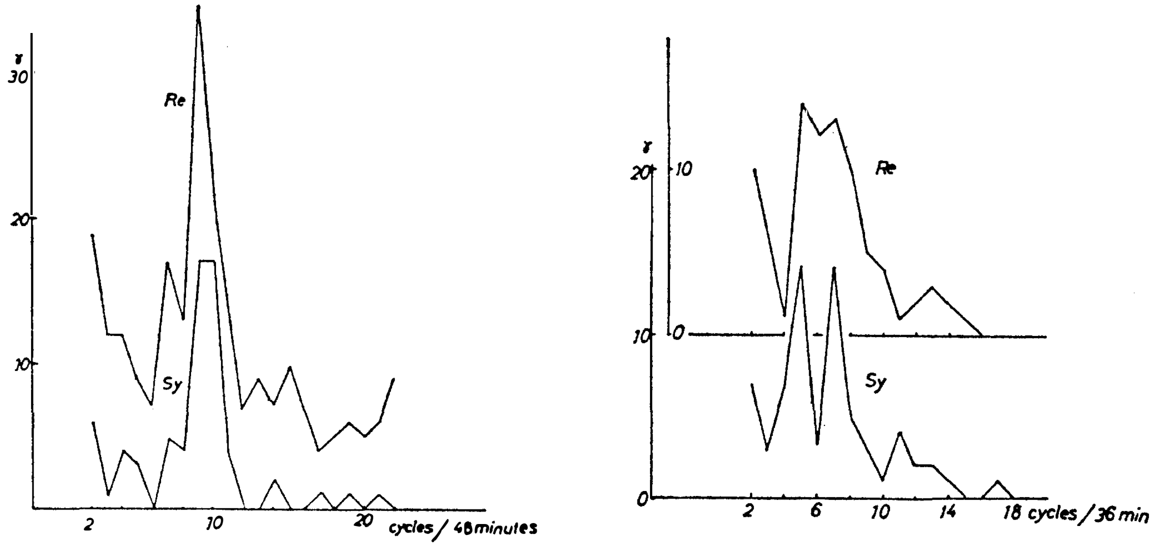


(a) (b)

Fig. 8. Frequency spectra of pulsation following SSC observed simultaneously at Syowa Station (Sy) and Reykjavik (Re).



(*a*). *July 21, 06ʰ00ᵐ–07ʰ00ᵐ, 1959.* (*b*). *Sept. 18, 06ʰ30ᵐ–07ʰ30ᵐ, 1959.*



(*c*). *Sept. 5, 06ʰ00ᵐ–06ʰ48ᵐ, 1959.* (*d*). *May 9, 03ʰ00ᵐ–03ʰ36ᵐ, 1959.*

Fig. 9. Frequency spectra of pc-5 pulsations observed simultaneously at Syowa Station (Sy) and Reykjavik (Re).

tively observed simultaneously at these stations. Throughout all these results it will certainly be concluded that the time-dependent parameters, such as the period of pulsations, the rise-time of sudden changes and the shape of frequency spectra of the simultaneous magnetic variations, are almost the same at the two conjugate stations.

On the other hand, Figures 10, 11 and 12 show examples of correlation diagrams of magnitude or amplitude of pc-5 pulsations, *SSC*'s and *SI*'s observed

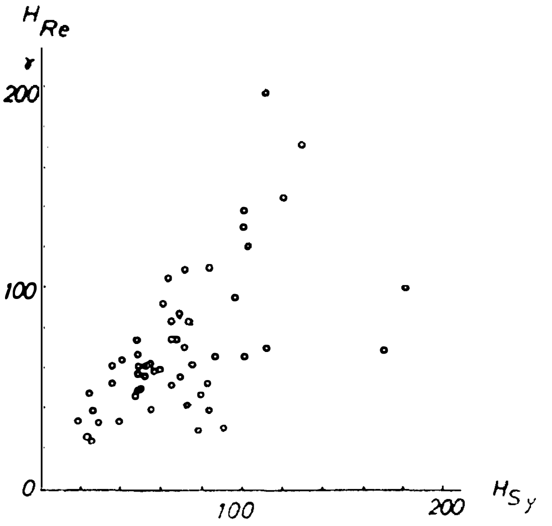


Fig. 10. Correlation diagram of amplitude of pc-5 pulsation observed simultaneously at Syowa Station (H_{Sy}) and Reykjavik (H_{Re}).

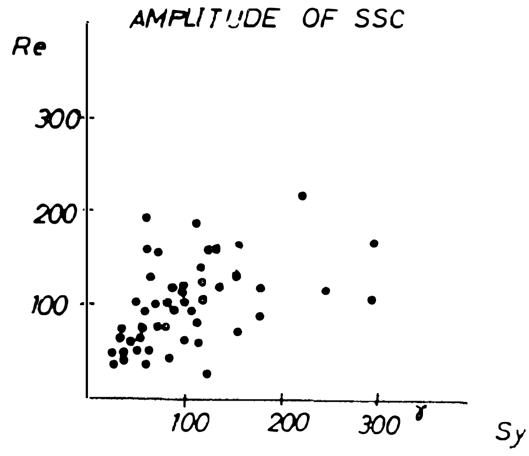


Fig. 11. Correlation diagram of amplitude of SSC's between Syowa Station (Sy) and Reykjavik (Re).

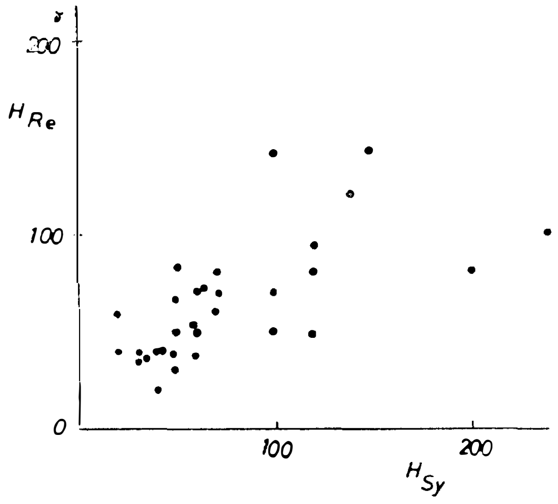


Fig. 12. Correlation diagram of amplitude of SI's observed sumultaneously at Syowa Station (H_{Sy}) and Reykjavik (H_{Re}).

simultaneously at the two stations. The correlation of amplitudes of these phenomena is considerably worse than that of the time-dependent parameters, though the average values of amplitude ratio of these phenomena at the two conjugate stations are approximately uniform, as seen in these diagrams.

Summarizing all observed facts represented by Figs. 6–12, one may conclude that the deriving mechanism is almost the same at the auroral zone conjugate stations for any event of pc-5 pulsations, *SSC*'s and *SI*'s, but the magnitude of the events may be affected by the local ionospheric condition and difference in the mirroring height for charged particles and hydromagnetic waves*.

4–3. *Coherent area for pc-5 pulsations*

As is the case with magnetic bays, the area of coherent variation is essentially related to the conjugate relation of magnetic pulsations and other hydromagnetic wave phenomena. Figures 13 and 14 show respectively examples of simultaneous horizontal polarization diagrams and frequency spectra of pc-5 pulsations obtained at Point Barrow, College, Big Delta, Healy and Sitka. In all examined cases (Kokubun and Nagata, 1965), the mode and intensity of pulsations observed at College, Healy and Big Delta are approximately the same. The simultaneous pulsations at Sitka, about 5° south from these stations, are still in the same mode of variation as those of the auroral zone variations, but their intensity at Sitka is much smaller than those at the other stations. Thus, the coherency of pc-5 pulsations is well extended equatorward from the auroral zone by about 5 degrees in latitude angle, but their amplitude decreases sharply with decreasing latitude as illustrated in Fig. 15. On the contrary, the wave form and frequency spectra on the poleward side are considerably different from those in the auroral zone,

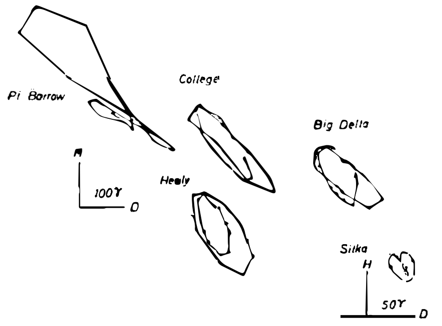


Fig. 13(a). Loci of rotating polarization vectors for a morning type pc-5.

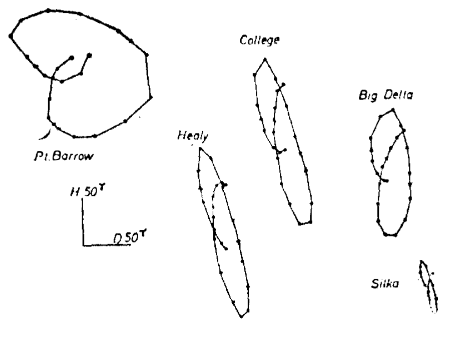


Fig. 13(b). Loci of rotating polarization vectors for an afternoon type pc-5.

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* The hydromagnetic waves in the magnetospheric plasma of finite temperature in an inhomogeneous magnetic field also are subjected to the mirror effect. (See Y. Inoue and T. Nagata: Macroscopic plasmadynamics of a teneous, hot and fully ionized gas in an Inhomogeneous Magnetic Field. University of Pittsburgh, SMUP-Report No. 1, October 1966).

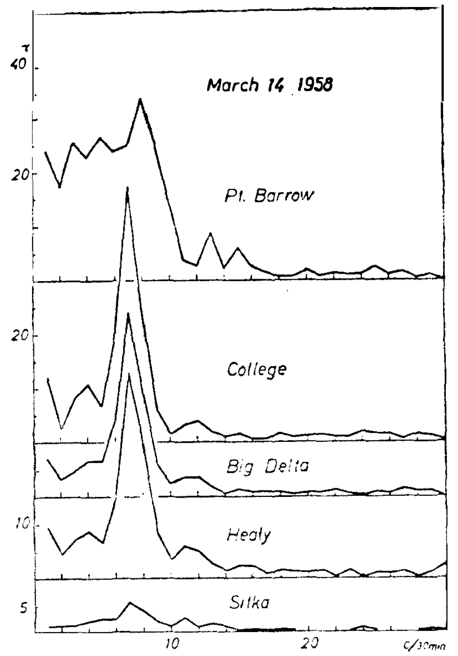

Fig. 14. Fourier spectra of a pc-5 (morning type) observed on March 14, 20^h 15^m–45^m *U. T., 1958.*

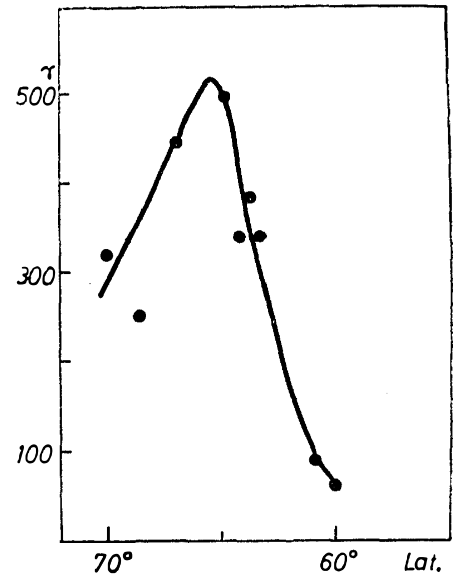

Fig. 15. Latitude dependence of the mean range of the horizontal component of a pc-5 observed on March 19, 1958.

indicating that the coherent range for pc-5 pulsations is not much extended toward the pole from the auroral zone.

No exact estimate of longitudinal extent of the coherent area has yet been made. OGUTI (1963) and KOKUBUN and NAGATA (1965) statistically evaluated the longitudinal coherent range as about 30° or more in angle.

The sharp change of amplitude with latitude near the auroral zone may suggest that a slight difference in relative distance between an observing station and the central line of pc-5 activity also may result in an appreciable difference in the amplitude.

5. Concluding Remarks

As discussed in the introduction of the present review, the conjugate phenomenon is certainly due to transportation of plasma energy along a tube of force which connects its both ends, called the conjugate areas. The carriers of the energy will be either plasma particles or hydromagnetic waves.

The generation of auroral electrojets (*AEJ*) may be subjected at least to two factors, *i.e.* (i) a local increase of ionization produced by precipitating plasma particles and (ii) a transfer of a local electric field. Only when the distributions of these two factors are the same in the conjugate ionospheric regions of the same original condition, the produced *AEJ* can become purely conjugate. Physical mechanism in detail of production of *AEJ* has not yet been satisfactorily understood, though the fact that sharp negative bays are always associated with electron precipitation has been confirmed observationally. The obsearved approximate conjugacy of *AEJ* phenomena, however, may strongly suggest that the energy spectrum, the flux and the amount of excess charge of plasma particles precipitating simultaneously to the conjugate ionospheric regions are approximately equal. This would indicate that the source of these precipitating particles is not located near either side of the conjugate ionospheric regions, but in a deep part of the magnetosphere, presumably in the neighbourhood of the magnetic equatorial plane. It would be suggested that the source of sharp negative bays is located in the neighbourhood of the earthward edge of neutral sheet, where the magnetospheric plasma is inevitably forced to become unstable.

The observed inequality of magnitude of bays at the conjugate stations may be caused partly by a difference in density and height of the ambient ionospheric plasma. The ionospheric effect may stand for the seasonal variation of bay's magnitude. As pointed out by VESTINE and SIBLEY (1959), a considerable difference of height of the mirror point at conjugate stations should result in an appreciable difference of bay's magnitude. In this case, the resultant difference should be permanent insofar as the geomagnetic secular variation is ignored. As for the conjugacy of pc-5 pulsations, *SSC*'s and *SI*'s which can be attributed to hydromagnetic waves or hydromagnetic shock waves, possible reflection of these waves by the top-side of the ionosphere should always be taken into consideration. Only the refracted parts of waves can reach the earth's surface. The results of WILSON's studies (1966) on the three dimensional polarization of pc-5 pulsations at conjugate stations have indicated that the reflection, refraction and attenuation of hydromagnetic waves by the ionosphere are playing an important role in the characteristics of pc-5 pulsations observed on the earth's surface. From this viewpoint, the observed facts of the extremely good conjugacy of the time-dependent parameters and the considerably less conjugacy of magnitude in these hydromagnetic wave phenomena could be understood.

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