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Geomagnetic Secular Variation Over and Near the Antarctic Continent

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南極大陸周辺における地球磁場永年変化

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要　　旨

南極大陸近辺における地球磁場の永年変化は著しくはげしいことが，IGY 南極観測の結果明らかになった．特に，昭和基地近傍はその変化量がはげしく，鉛直磁力の変化量は約 $2\times10\gamma$/年 にも達する．第4図と第5図とを比較すれば，南半球，特に南極大陸近辺の地球磁場永年変化が北半球のそれに比していかに著しいものであるか一見して明らかであろう．

特に昭和基地とHeard島の間は 2800 km の距離であるにかかわらず，前者では $\dot{Z}=181\gamma$/年，後者では $\dot{Z}=-98\gamma$/年 である．このきわめて顕著な永年変化局部異常は第6図に示す如く，地核表面附近の磁気双極子対の変動によって代表せしめ得るが，物理的に見て，このような磁気双極子対を実現する電流渦対は極めて強烈なものであって，未だその発生機構について物理的に合理的な解釈は得られていない．

1. Introduction

It may be noticed in geomagnetic isopor charts that geomagnetic secular variations in the southern hemisphere are much more complicated in pattern and intense in magnitude than in the northern hemisphere. It seems that this aspect can be ascertained in Figs. 1 and 2 which show the world isoporic chart for 1950–55[1].

Remarkable regional anomaly in the geomagnetic secular variation in the region of some hundreds kilometers south of the southern west coast of South Africa has been studied by BULLARD[2] in connection with dynamo-theory of the geomagnetic non-dipole field. On the other hand, foci of geomagnetic secular variation in and near South America, a focus of minus in $\dot{Z}$ inland and another focus of plus in $\dot{Z}$ south of the continental coast, have long been investigated by SLAUCITAJS[3]. However, the behaviour of the southern parts of these intense foci of geomagnetic secular variations has not yet been clarified.

In the Japanese Antarctic Research Expedition (JARE) programs, therefore, research of geomagnetic secular variation in the vicinity of the Antarctic Continent has been taken up as one of main purposes of the expedition. Geomagnetic works in JARE may be classified into three categories, namely (a) continuous recording of geomagnetic three compoment variations by means of an ordidary magnetograph and a direct vision magnetograph, with repeated absolute measurements for the base-line

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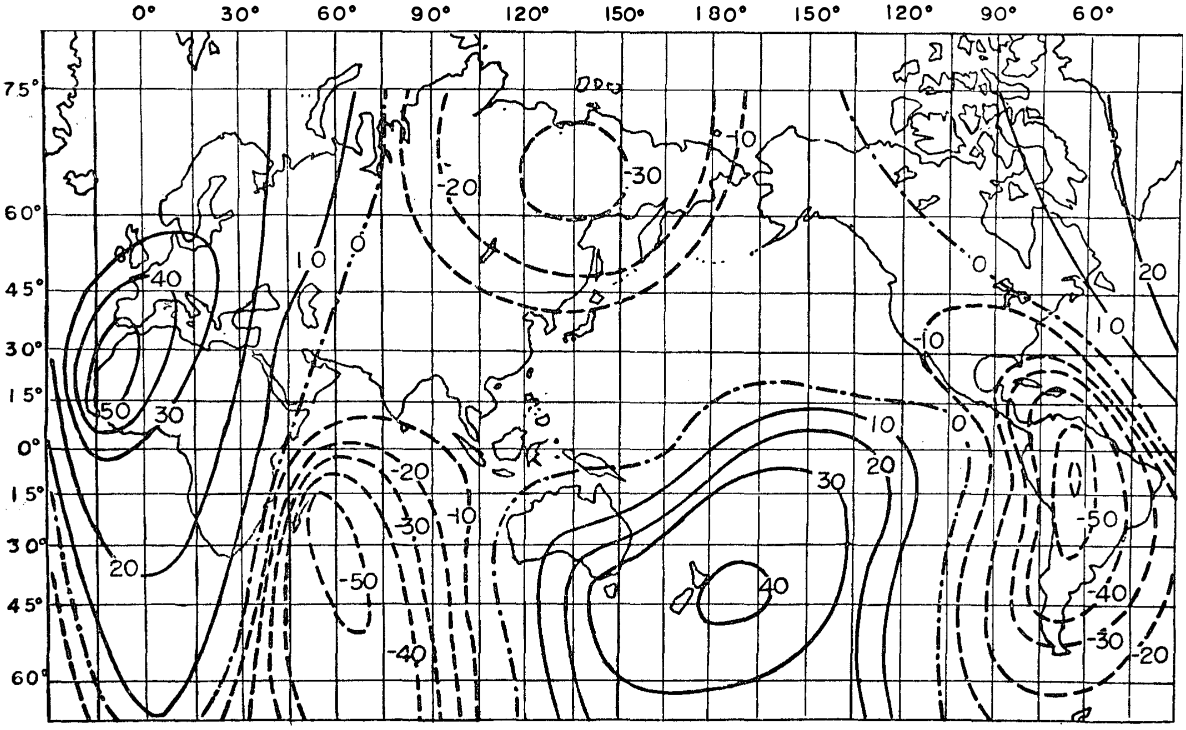

Fig. 1. Secular variation for the period 1950–55, east component, contour interval 10 gammas per year.

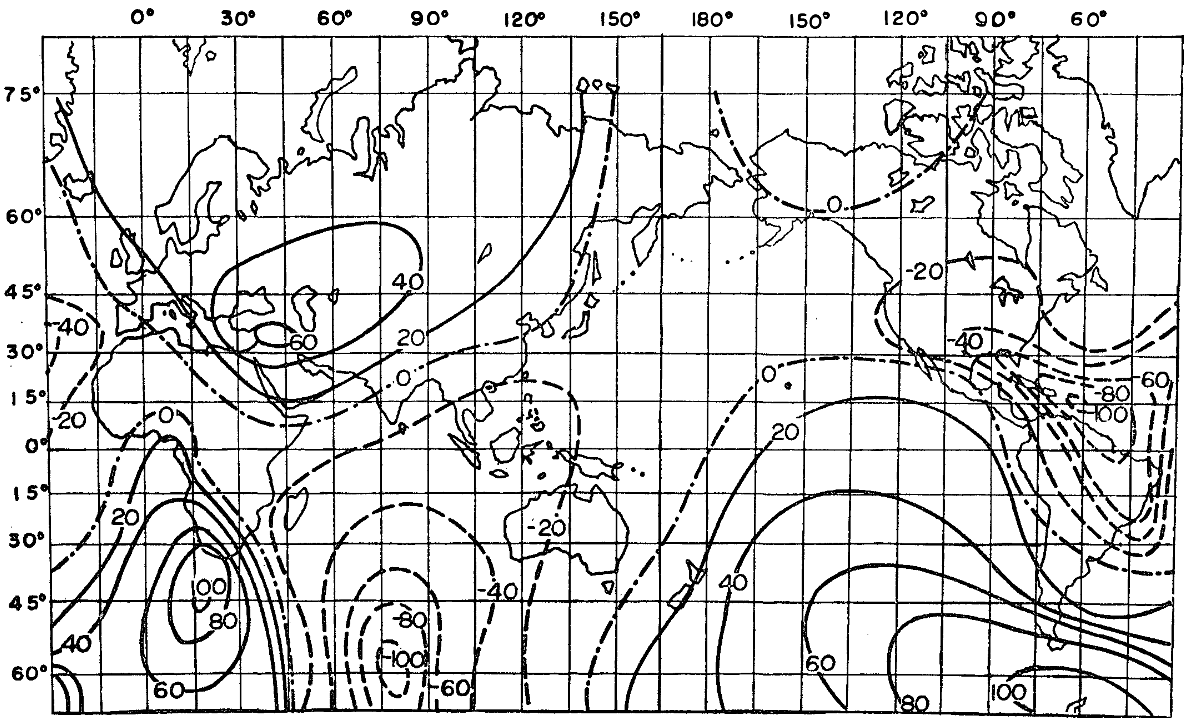

Fig. 2. Secular variation for the period 1950–55, vertical component, contour interval 20 gammas per year.

determination at a magnetic observatory at Syowa Station, (b) repeating of magnetic surveys on land and on fast ice, and (c) total force surveys by means of a proton precession magnetometer throughout the whole voyage of the expedition ship M/S "Soya". Results of these observations seem to show that secular variation in the geomagnetic field at Syowa Station and its neighbourhood has been extremery large.

2. Geomagnetic secular variation at Syowa Station and its neighbourhood

Regular routine observation of the geomagnetic field has been continued since February 1959 at Syowa Station (69°00′S in latitude and 39°35′E in longitude) on East Ongul Island. Change in the base-line values (i. e. value excluding daily variation and disturbances) of D, H and Z at the station during period from February 1959 to January 1960 is shown in Fig. 3. On the other hand, the first geomagnetic absolute

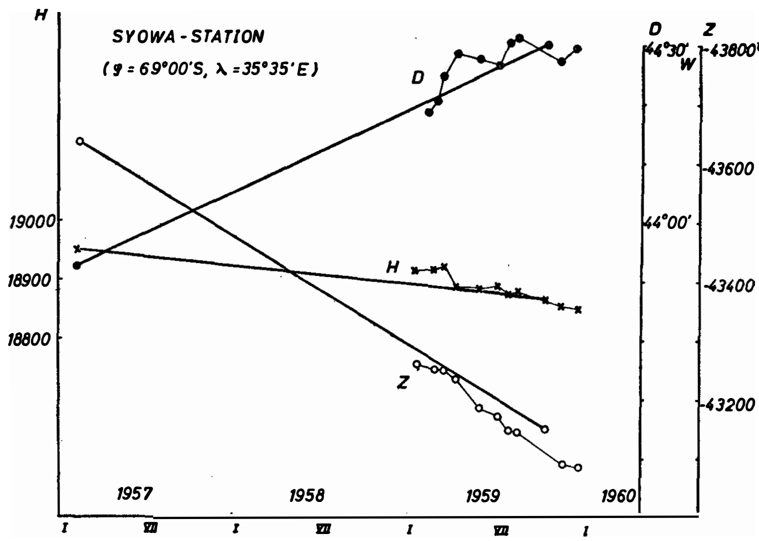

Fig. 3. Secular variation of D, H and Z of Syowa station.

measurements were carried out in February 1957 at 8 regulation points on East Ongul Island, and continuous recording of geomagnetic variation was also made during two weeks in the early half of the month. In October 1959, re-measurements at the 8 points were made in order to find the secular variation. Disturbances and daily variations being eliminated for February 1957 and for October 1959 from these observed values, average values of D, H and Z at these 8 points for the two epochs are plotted in Fig. 3. The changes in the three components during the two epochs may give the amount of secular variation during the period, namely for 2.67 years. From all data given in Fig. 3, average secular variations at Syowa Station for the period of 1957–60 are obtained as follows.

$$\dot{X} = -\ 79\,\gamma/\text{year}, \qquad \dot{D} = -\ 14.1\ \text{minutes/year},$$
$$\dot{Y} = -\ 40\,\gamma/\text{year}, \qquad \dot{H} = -\ 28\,\gamma/\text{year}.$$
$$\dot{Z} = +\ 181\,\gamma/\text{year},$$

It may be noticed in the above result that geomagnetic secular variation, especially in Z-component, around Syowa Station is markedly large.

The existence of the large secular variation in this area was presumed when results of magnetic surveys on land and on fast sea-ice in Lützow-Holm Bay in 1956–57[4] were compared with the magnetic chart for 1945, compiled by VESTINE et al[5]. Differences, 1956 values minus VESTINE's 1945 values amount to about $+5\times10^3\gamma$ in Z, $-2\times10^3\gamma$ in H and less than one degree in D. Although it seems that some part of this big difference might be due to scarcity of data so far observed in this area, large part of the difference might be attributed to accumulation of a certain large amount of secular variation since several tens years ago when geomagnetic measurements were carried out at several points upon rare occasion. Actually, sense of the differences in Z, H and D here is in agreement with those corresponding values during 1957–60, if the differences are assumed to be due to the secular variation.

3. Geomagnetic secular variation over the Antarctic region

In the vicinity of the Antarctic continent, there have been two permanent magnetic observatories, namely,

a) Macquarie Island Observatory (54°30′S in latitude and 158°57′E in longitude),

b) Orcadas del Sur Observatory (60°44′S in latitude and 44°44′W in longitude).

Further geomagnetic observation was continued from 1955 at Mawson (φ=67°35′S, λ=62°55′E) and was continued during three years 1952–54 at Heard Island (φ=53°02′S, λ=73°22′E). Just before IGY, a number of scientific stations were set up on the Antarctic continent, and geomagnetic data at these stations are now available. Through the courtesy of scientists and organizations in charge of magnetic observations at these stations, as many geomagnetic data as possible have been collected by the author. Names and localities of stations, from where geomagnetic data were obtained anyway, are listed in Table 1.

Table 1.

Name of station	Latitude	Longitude	Period of data	$\dot{X}$	$\dot{Y}$ (γ/year)	$\dot{Z}$
1. Byrd Station	79°-59′S	120°-01′E	IGY			
2. Little America	78 -18	199 -50	IGY	+ 7	+45	+132
3. Scott Base	77 -51	166 -47	IGY	−38	+15	+ 36
4. Halley Bay	75 -31	333 -24	IGY	(−13	−39	+ 70)
5. Charcot	69 -22	139 -01	1957			
6. Syowa	69 -00	35 -35	1957-9	−79	−40	+181
7. Mawson	67 -35	62 -55	1955-8	−71	−57	+ 51
8. Dumont d'Urville	66 -40	141 -01	1957			
9. Mirny	66 -33	93 -00	1956-8	−94	−39	+ 45
10. Wilkes	66 -15	110 -31	IGY	(−87	− 1	+ 21)
11. Argentine Is.	65 -15	295 -44	1956-8	−34	−48	+131
12. Orcadas del Sur	60 -44	315 -06	1933-59	−67	−14	+ 93
13. Macquarie Is.	54 -30	158 -57	1952-9	−18	+47	+ 16
14. Heard Is.	53 -02	73 -22	1952-4	−37	−44	− 98

Generally speaking, it is rather difficult to extract the secular variation component from geomagnetic data observed only during the one and a half year of IGY period, or during a shorter period such as in French stations, Charcot and Dumont d'Urville, because monthly mean values or even annual mean values of the geomagnetic three components in the polar region are appreciably affected by geomagnetic activity originating in the upper atmosphere and the outer space. For example, remarkable depression in absolute value of Z component was noticed for about half a year from the end of 1957 through the early half of 1958 at Wilkes, Little America, Dumont d'Urville, Charcot, Scott Base, and may be at Byrd Station also. Therefore it is hardly possible to determine the secular variation rate for Dumont d'Urville, Charcot, and Byrd Station, because of the shortness of the observation period and of the largeness of the variation due to disturbances, and for Wilkes estimated rates seem to give only the order of their magnitude owing to the same reasons but less seriously, while the rates at Little America and Scott Base seem to be reliable at least for their first figure, though geomagnetic variations there were also subject to a fair amount of disturbances. A remark must be made about the values at Halley Bay. It has been reported that the Halley Bay Station on the ice-shelf has been drifting slowly so that it can not be determined at present whether the observed values of secular variations are due to real change with time in the geomagnetic field at a point or partly due to change with place caused by the drifting. Therefore the secular variation rates given in Table 1 are more or less doubtful.

Throughout all the data tabulated in Table 1, it may be said that annual rates of geomagnetic secular variations at Halley Bay and Wilkes are a little doubtful owing to the above-mentioned reasons, while reliability of the rates at the other stations seem to be sufficient for the purpose of the present work, estimated errors being less than 15%.

On the other hand, data of geomagnetic secular variations for 1956–58 at repeated stations, obtained by an Argentinian group, are reproduced in Table 2.

Table 2.

Name of station	Latitude	Longitude	Period of data	$\dot{X}$	$\dot{Y}$ (γ/year)	$\dot{Z}$
Ushuaia	54°-49′ S	251°-42′ E	1956-8	−64	−29	+120
Esperanza	63 -22	303 -00	1956-8	−57	−26	+107
Merchior	64 -19	257 -00	1956-8	−49	−30	+132

Argentinian data, which were put in the writer's hands by the courtesy of Prof. L. SLAUCITAJS, include values at five other points near the latter two points in the above Table, but they are not reproduced here, because the values at these stations are nearly the same as at the above-listed near points.

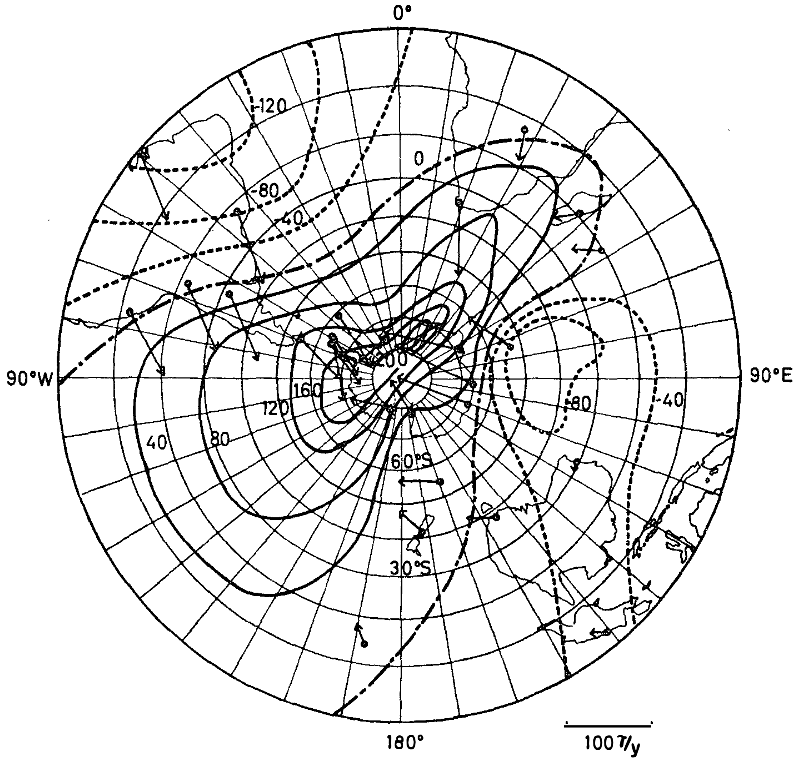

Fig. 4. Isoporic chart for Z for 1955–60 in unit of γ/year in the southern hemisphere. Arrows represent $\dot{\boldsymbol{H}}=(\dot{X},\dot{Y})$.

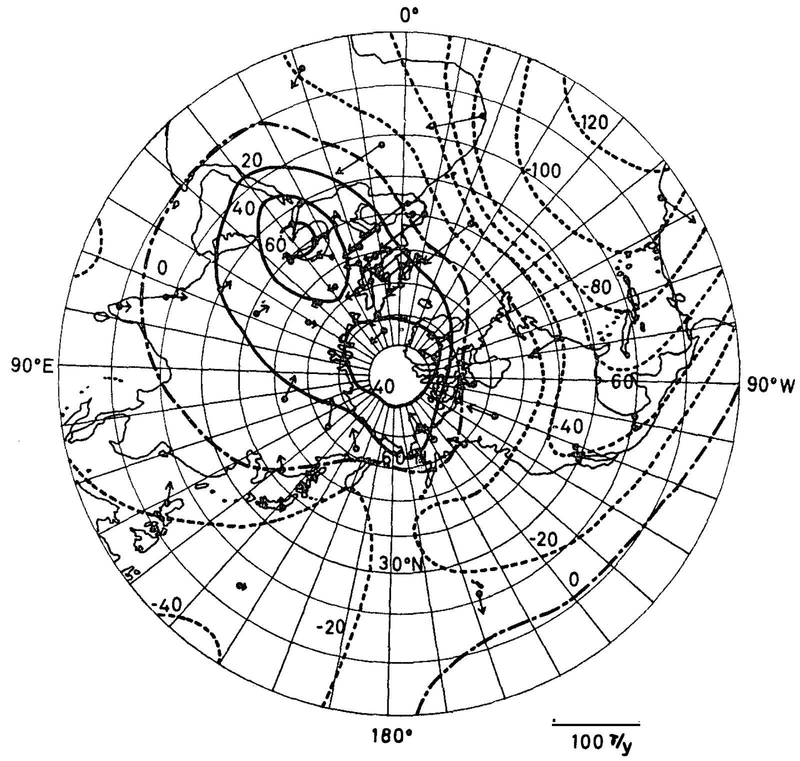

Fig. 5. Isoporic chart for Z for 1955–60 in unit of γ/year in the northern hemisphere. Arrow represents $\dot{\boldsymbol{H}}=(\dot{X},\dot{Y})$.

4. Geomagnetic secular variations in the southern hemisphere and their remarkable characteristics

Distribution of $(\dot{X}, \dot{Y}, \dot{Z})$ values in the Antarctic area thus estimated are illustrated in Fig. 4, together with those at the other magnetic observatories in the southern hemisphere. In this figure, Z value at an individual point is given by a numeral, while $\dot{\boldsymbol{H}}=(\dot{X}, \dot{Y})$ is illustrated by a vector arrow. Lines of equal $\dot{Z}$ value in the figure are drawn by assuming that curl $(\dot{X}, \dot{Y}, \dot{Z})=0$ and div $(\dot{X}, \dot{Y}, \dot{Z})=0$, *i. e.* $\nabla^2(\dot{H}, \dot{Y}, \dot{Z})=0$, on the earth's surface and the origins of $(\dot{X}, \dot{Y}, \dot{Z})$ are situated beneath the earth's surface.

In Fig. 5, distribution of $(\dot{X}, \dot{Y}, \dot{Z})$ in the northern hemisphere is illustrated for comparison. By comparing Fig. 4 with Fig. 5, it will be clearly noticed that geomagnetic secular variation in the southern hemisphere, especially around the Antarctic continent, is rematkably larger than in the northern hemisphere. We may point out four main foci of $(\dot{X}, \dot{Y}, \dot{Z})$ vectors in the southern hemisphere, namely, positive ones in East Antarctica station and near Marie Byrd Land, and negative ones around Heard Island and in the middle of South America. Amount of $|\dot{Z}|$ at each one of these foci exceeds 100γ/year, and especially that in East Antarctica is nearly 200γ/year. This may be remarkable contrast with the feature in the northetn hemisphere that a focus of $\dot{Z}$ is situated around Central Asia, its amount being only about 50γ/year or a little more. Corresponding to the above-mentioned characteristics of $\dot{Z}$ distribution, those of $\dot{\boldsymbol{H}}$ are also intense and complicated in the southern hemisphere. It may be concluded thus that secular variation in the geomagnetic field is much more active in the southern hemisphere than in the northern hemisphere with respect to both of number of foci and their intensity.

As has already been shown by VESTINE[5] for geomagnetic secular variation for 1940–45, three foci, one in the northern hemisphere, one in South America, and one between South America and Marie Byrd Land of Antarctica, could be interpreted reasonably as due to changes in electric current vortices near the surface of the earth's core. However, there are two neighbouring foci near the coast of East Antarctica, a positive $\dot{Z}$ focus on inland of East Antarctica and a negative $\dot{Z}$ focus near Heard Island, distance between them along the great circle and difference between their intensities being about 25° and 300γ/year respectively. It seems unlikely that such a pair of intense geomagnetic secular variation foci very near to each other can easily be understood as the effect of a local dynamo just beneath the surface of the earth's core, as suggested by BULLARD[2] in the case of the northern part of the positive $\dot{Z}$ area dealt with here, even if the primary magnetic field affecting the dynamo is assumed to be a strong toroidal one within the core. However, it is proved to be possible that the origin of the pair can almost be attributed to a pair of radial magnetic dipoles on the earth's core surface, as illustrated in Fig. 6, which shows a cross section of the earth along the great circle passing through Syowa and Heard

Island. As shown in this figure, the upward magnetic dipole has to have about 3.5×10^{22} emu/year in its annual rate of change in moment, while the downward of 15° degree apart is about 2/3 in its change in moment. The diagram of the upper half of the figure illustrates distribution curves $\dot{Z}$ and $\dot{H}$ on the earth's surface in the great circle plane, derived from the pair of dipoles, and circles in the diagram represent observed annual rates $\dot{Z}$ and $\dot{H}$, at four stations, the direction of the latter being nearly parallel to the great circle plane. A fairly good agreement between observed and calculated values will be seen in the diagram.

Now, if the above-mentioned model of a pair of radial magnetic dipoles on the earth's core surface is accepted, problem will be what is real physical mechanism for producing such a change of the form of pair of dipoles. This will be a problem to be solved in the future.

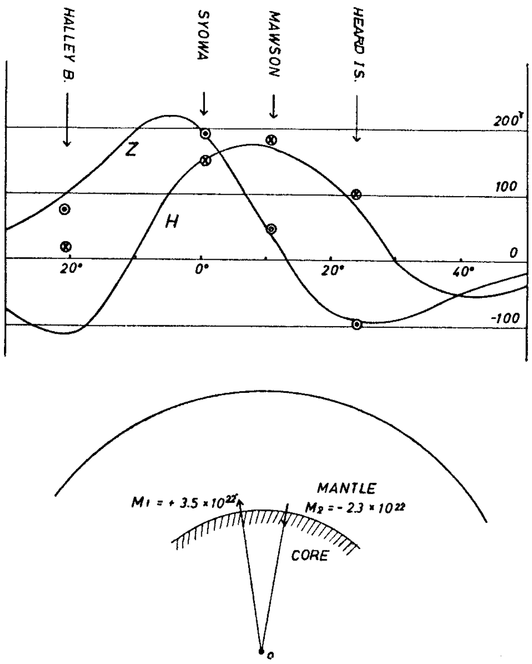

Fig. 6. Distribution of $\dot{Z}$ and $\dot{H}$ along the great circle plane passing through Syowa and Heard Island in Antarctica.

Above: Observed values of $\dot{Z}$ and $\dot{H}$ and those produced by a pair of magnetic dipoles illustrated below.

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