SUB | NIEDERSÄCHSISCHE STAATS- UND UNIVERSITÄTSBIBLIOTHEK GÖTTINGEN

Werk

Jahr: 1974
Kollektion: fid.geo
Signatur: 8 Z NAT 2148:40
Digitalisiert: Niedersächsische Staats- und Universitätsbibliothek Göttingen
Werk Id: PPN1015067948_0040
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948_0040

LOG Id: LOG_0038
LOG Titel: Spherical harmonic analysis of the DS-field during magnetic storms
LOG Typ: article

Übergeordnetes Werk

Werk Id: PPN1015067948
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948
OPAC: http://opac.sub.uni-goettingen.de/DB=1/PPN?PPN=1015067948

Terms and Conditions

The Goettingen State and University Library provides access to digitized documents strictly for noncommercial educational, research and private purposes and makes no warranty with regard to their use for other purposes. Some of our collections are protected by copyright. Publication and/or broadcast in any form (including electronic) requires prior written permission from the Goettingen State- and University Library.
Each copy of any part of this document must contain there Terms and Conditions. With the usage of the library's online system to access or download a digitized document you accept the Terms and Conditions.
Reproductions of material on the web site may not be made for or donated to other repositories, nor may be further reproduced without written permission from the Goettingen State- and University Library.

For reproduction requests and permissions, please contact us. If citing materials, please give proper attribution of the source.

Contact

Niedersächsische Staats- und Universitätsbibliothek Göttingen
Georg-August-Universität Göttingen
Platz der Göttinger Sieben 1
37073 Göttingen
Germany
Email: gdz@sub.uni-goettingen.de

J. Geophys. 40, 239–253, 1974

Spherical Harmonic Analysis of the DS-Field during Magnetic Storms

H. Schreiber

Institut für Geophysik der Universität Göttingen

Received January 7, 1974

Abstract. A spherical harmonic analysis of the average DS-field during great magnetic storms is presented using data taken from Sugiura and Chapman (1960). Eight coefficients for the diurnal terms (in geomagnetic LT) and three for the semi-diurnal terms give a sufficient approximation of the DS-field during the first two storm-days. Differences between the H and D component analyses are due to limited and uncertain data. The DS-field in low latitudes is well approximated by the P_2^1-term. This term shows a phase shift from the first to the second storm-day that resembles the phase drift of the asymmetric ring current. The ratio of the internal to the external part of this term is 0.32 for the first and 0.25 for the second storm-day. Equivalent current systems of the external field and of the internal plus external field show nearly the same structure.

Key words: DS-Field — Magnetic Storms — Spherical Harmonic Analysis — Asymmetric Ring Current — Polar Electrojet — Internal and External Parts.

1. Introduction

During the main phase of geomagnetic storms the horizontal component H of the earth's magnetic field is decreased in middle and low latitudes as a result of the magnetospheric ring current. This current arises from motions of charged particles (mainly protons with energies of the order 10 KeV) in the magnetosphere. The particle distribution, as well as the ring current and the depression of H at the earth, is not symmetric with respect to longitude. From the analyses of world-wide observations, it has been suggested that ionospheric return currents of the auroral electrojet are the source of the asymmetry in low latitudes. In recent years, current models of the Birkeland type have been discussed with field aligned currents connecting the auroral electrojets with magnetospheric currents (Bonnevier *et al.*, 1970; Akasofu and Meng, 1969a, 1969b).

Magnetometer measurements on the satellite Ogo 2 (Langel and Sweeney, 1971) during magnetic storms showed that the asymmetry in low latitudes is caused by currents at altitudes beyond the ionosphere. For the comparison of the nonsymmetric part DS of the variation field at the satellite and at the ground the ratio of the internal to the external part of the disturbance field was taken to be $i/e = 0.38$. This ratio had been found by Rikitake and Sato (1957) for the symmetric field D_{st}. However, the ratio i/e may not be the same for D_{st} and DS.

This investigation tries to separate, by means of a spherical harmonic expansion, the internal and external parts of the DS-field. The data for the analysis were taken from Sugiura and Chapman (1960).

2. *Computation of the Spherical Harmonic Coefficients*

The disturbance field D of any component of the disturbance field at the ground may be separated into a symmetric part (with respect to longitude) D_{st} and a nonsymmetric part DS by means of a Fourier harmonic analysis

$$D(\theta, \lambda, T) = D_{st}(\theta, T) + \sum_{n=1}^{\infty} C_n(\theta, T) \cos(n\lambda - \varepsilon_n(\theta, T)) \tag{1}$$

D_{st} is the disturbance field averaged over circles of geomagnetic colatitude θ; it is a function of only θ and the storm time T (beginning with the ssc). The sum describes the dependence on geomagnetic longitude λ (or geomagnetic local time ϕ) using harmonic components with amplitudes C_n and

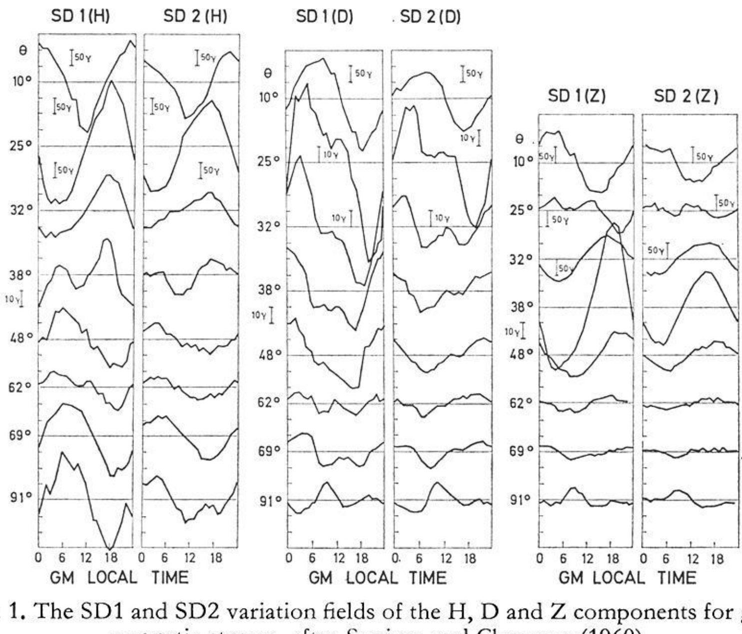

Fig. 1. The SD1 and SD2 variation fields of the H, D and Z components for great magnetic storms, after Sugiura and Chapman (1960)

phases ε_n. This part of the disturbance field is denoted DS, and the average of DS over the first (second) storm day is denoted SD1 (SD2). In Fig. 1, SD1 and SD2 are shown for the components H, D, Z after Chapman and Sugiura (1960) who analysed hourly values of 74 great storms at 29 observatories divided into 8 groups according to geomagnetic latitude. Thus SD1 and SD2 are the average longitudinal variations of great storms. In all three components, the diurnal mode in geomagnetic local time predominates. In the following, symmetry of SD1 and SD2 with respect to the equator is assumed because data are available only for the northern hemisphere.

DS may be considered as the negative gradient of a potential V; then the spherical harmonic expansion of V in spherical coordinates r, θ, ϕ with a as radius of the earth is given by

$$V = a \sum_{n=1}^{\infty} \sum_{m=1}^{n} \left\{ \left[\left(\frac{r}{a}\right)^n e_{na}^m + \left(\frac{a}{r}\right)^{n+1} i_{na}^m \right] \cos m\phi \right. \tag{2}$$

$$\left. + \left[\left(\frac{r}{a}\right)^n e_{nb}^m + \left(\frac{a}{r}\right)^{n+1} i_{nb}^m \right] \sin m\phi \right\} P_n^m(\cos\theta)$$

Using the following identities

$$a_n^m = e_{na}^m + i_{na}^m \qquad b_n^m = e_{nb}^m + i_{nb}^m \tag{3a}$$

$$\tilde{a}_n^m = n e_{na}^m - (n+1) i_{na}^m \qquad \tilde{b}_n^m = n e_{nb}^m - (n+1) e_{nb}^m \tag{3b}$$

$$\overset{0}{a}{}_n^m = -m(e_{nb}^m + i_{nb}^m) \qquad \overset{0}{b}{}_n^m = m(e_{na}^m + i_{na}^m) \tag{3c}$$

the components H, D and Z of DS are

$$\mathrm{DS(H)} = \sum_{n=1}^{\infty} \sum_{m=1}^{n} [a_n^m \cos m\phi + b_n^m \sin m\phi] \, dP_n^m/d\theta \tag{4}$$

$$\mathrm{DS(Z)} = \sum_{n=1}^{\infty} \sum_{m=1}^{n} [\tilde{a}_n^m \cos m\phi + \tilde{b}_n^m \sin m\phi] \, P_n^m \tag{5}$$

$$\mathrm{DS(D)} \sin\theta = \sum_{n=1}^{\infty} \sum_{m=1}^{n} [\overset{0}{a}{}_n^m \cos m\phi + \overset{0}{b}{}_n^m \sin m\phi] \, P_n^m \tag{6}$$

The practical computation of the coefficients a_n^m, e_n^m, $\tilde{a}_n^m$, $\tilde{b}_n^m$, $\overset{0}{a}{}_n^m$, $\overset{0}{b}{}_n^m$ was carried out by calculating first the harmonic Fourier coefficients with respect to ϕ

$$\left.\begin{matrix} A^m(\theta) \\ B^m(\theta) \end{matrix}\right\} = \frac{1}{\pi} \int_0^{2\pi} \mathrm{f}(\theta, \phi) \begin{Bmatrix} \cos \\ \sin \end{Bmatrix} m\phi \, \mathrm{d}\phi. \tag{7}$$

Table 1. The computed coefficients of SD1 and SD2 for the expansions in Eqs. (4), (5), (6)

	m n	1 2	1 4	1 6	1 8	1 10	2 3	2 5	2 7
SD1	a	4.20	0.74	0.57	0.057	-0.328	-0.070	0.094	0.083
	b	-7.49	3.01	3.34	2.71	1.390	-0.063	-0.053	0.017
	å	5.76	-1.95	-1.34	-2.17	0.630	0.425	0.141	-0.024
	b̊	5.07	1.72	2.75	0.095	0.671	0.359	0.062	0.229
	ã	1.88	-1.41	1.18	3.33	4.01	-0.072	0.150	0.143
	b̃	6.82	1.75	7.78	8.32	4.22	0.120	0.180	0.236
SD2	a	-1.85	1.04	1.31	1.04	0.438	0.082	0.034	0.032
	b	-4.06	2.34	2.44	2.02	1.36	-0.082	-0.027	-0.004
	å	3.95	-1.06	-0.286	-1.10	0.267	0.254	0.076	0.027
	b̊	-1.27	2.69	1.82	1.19	0.290	0.302	0.390	0.124
	ã	1.29	-0.424	3.05	4.25	3.48	0.174	0.136	0.163
	b̃	-4.44	0.110	4.42	4.35	2.32	0.162	0.105	0.170

Here $f(\theta, \phi)$ denotes the H-, D- or Z components of SD1 or SD2. The coefficients of Eqs. (4) to (6) are then calculated numerically with known formulae (e.g. Chapman and Bartels, 1940, chapt. XVII). As pointed out in Fig. 1, the evaluation of the coefficients $A^m(\theta)$ and $B^m(\theta)$ shows that the diurnal term A^1 and B^1 predominate in all components. At some latitudes a distinct semidiurnal part (with $m = 2$) is also seen; for example at $\theta = 38°$ in the H-component. Beside these terms it is questionable whether meaningful coefficients with $m > 2$ can be determined from the given data, and therefore, only coefficients for $m = 1$ and $m = 2$ were calculated. From the assumption of symmetry of the SD-field with respect to the geomagnetic equator, it follows that only coefficients with $n = 2, 4, 6, 8, 10 \ldots$ for $m = 1$, and $n = 3, 5, 7 \ldots$ for $m = 2$ are nonzero. For these combinations of n and m, 8 values for the coefficients a_n^m, b_n^m, $\tilde{a}_n^m$, $\tilde{b}_n^m$, $\mathring{a}_n^m$, $\mathring{b}_n^m$ were computed from the data for SD1 and SD2 (see Table 1). Fig. 2 shows the approximation obtained by the five terms of the diurnal ($m = 1$) mode. The full lines, A^1 and B^1, are the interpolated curves for the 8 points computed after Eq. (7). The broken lines, A_s^1 and B_s^1, represent the synthesis using the five diurnal coefficients calculated by numerical integration:

$$A_s^1(\mathrm{H}) = \sum_{n=1}^{5} a_{2n}^1 \, dP_{2n}^1/d\theta$$

$$A_s^1(\mathrm{D}) = \sum_{n=1}^{5} \tilde{a}_{2n}^1 \, P_{2n}^1 \tag{8}$$

$$A_s^1(\mathrm{Z}) = \sum_{n=1}^{5} \mathring{a}_{2n}^1 \, P_{2n}^1/\sin\theta$$

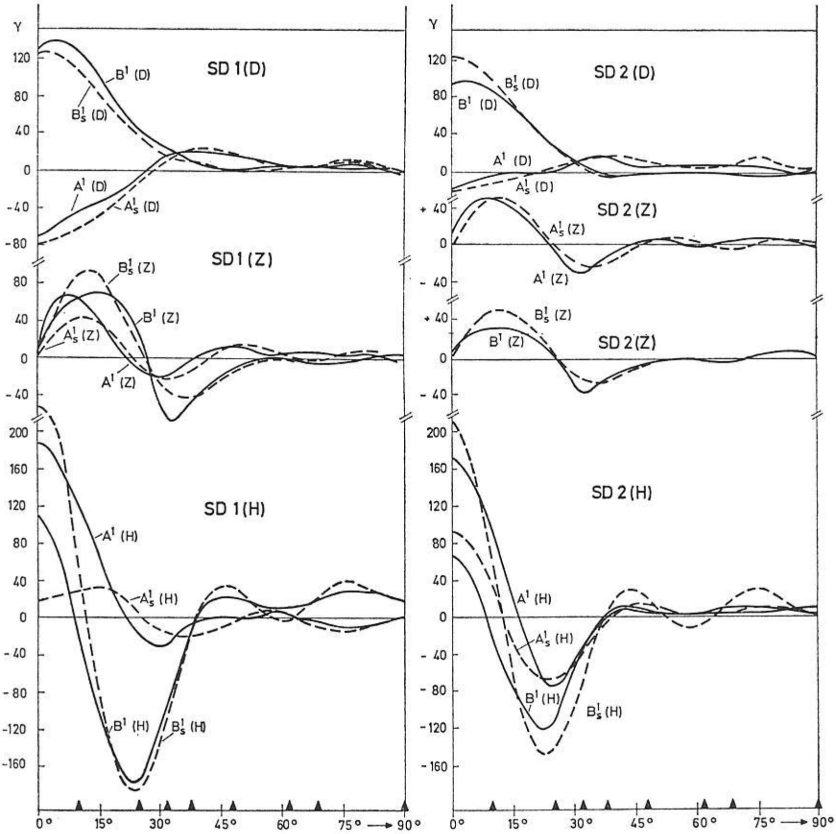

Fig. 2. The interpolated curves A^1 and B^1 of SD1 and SD2 for the H, D and Z component (full lines) and the syntheses with five coefficients A_s^1 and B_s^1 (dashed lines). The triangles on the abscissa indicate the eight colatitudes of the available data

The curves illustrate the principal difficulty arising when functions like these having great amplitudes in high latitudes ($\theta = 25°$) and comparatively small amplitudes in low latitudes ($\theta = 91°$) are subjected to spherical harmonic analysis. Such cases generally require a greater number of terms for a good approximation. Nevertheless, as seen in Fig. 2, five terms are sufficient for at least the D and Z components. The H component approximation breaks down in higher latitudes. In Fig. 3, the original data and the syntheses calculated after Eqs. (4), (5), (6) with 8 coefficients are plotted. The D and Z components are well approximated by the synthesis; the H component, however, shows considerable differences in high latitudes.

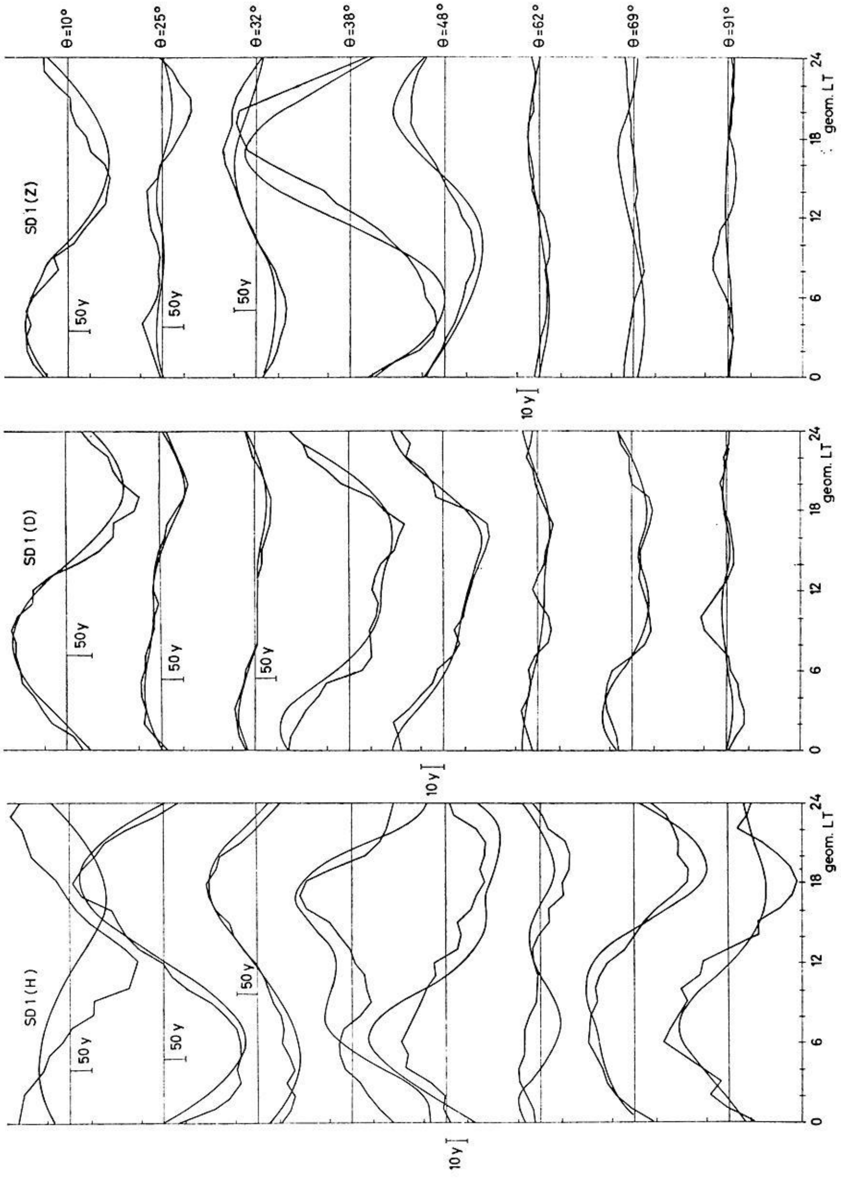

Fig. 3. The original data curves and the approximations after Eqs. (4), (5), (6) with five coefficients for the diurnal and three for the semidiurnal terms

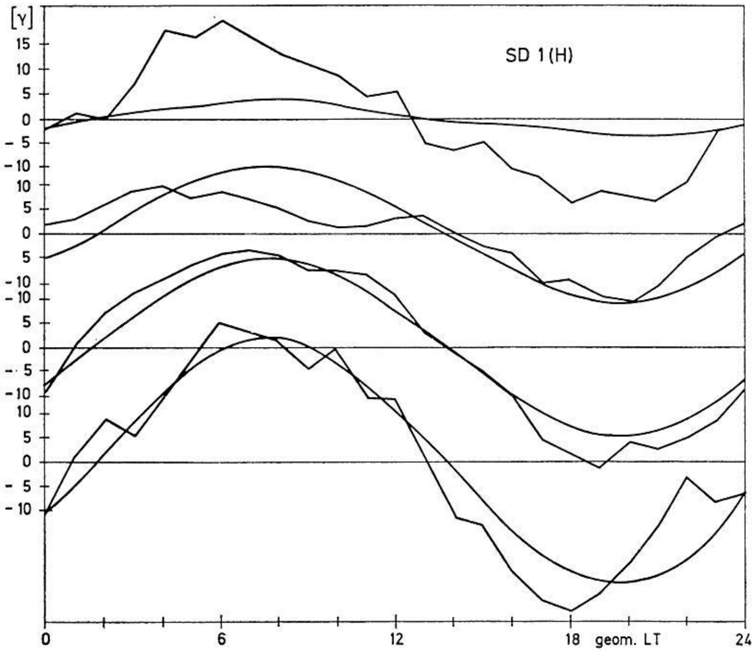

Fig. 4. SD1 (H) in low latitudes and the synthesis with only the P_2^1 term

In low latitudes, the SD-field is adequately approximated by only the first term with the coefficients a_2^1 and b_2^1 as is shown in Fig. 4, where the H component of SD1 and the first approximation are drawn for low latitudes. There is satisfactory agreement between the observed field and the first approximation in colatitudes 91°, 69° and 62°. The same is true for the other components and for SD2.

3. The Internal and External Parts of DS

The main purpose of this spherical harmonic analysis is to separate the part of the disturbance field which is induced in the earth by the variation of the external field. The coefficients e_n^m of the external and i_n^m of the internal parts are calculated with Eqs. (3) from the coefficients listed in Table 1. Using Eqs. (3a) and (3b), e_n^m and i_n^m are calculated from the H and Z components, or alternatively, with Eqs. (3b) and (3c) from the D and Z components. Both results should be the same, if the SD-field is a potential field; for example, the equalities $a_n^1 = \overset{0}{b}{}_n^1$ and $\overset{0}{a}{}_n^1 = -b_n^1$ should hold. From Table 1, we see that only for $n = 2$ are these conditions roughly satisfied. For greater n, there are considerable differences between the coefficients calculated from the D and H components. These differences might lead

Table 2. The coefficients for the internal and external parts of SD1 and SD2, the amplitudes c and phases η derived from the values of Table 1

	m n	1 2	1 4	1 6	1 8	1 10	2 3	2 5	2 7
SD1 (H, Z)	e_a [γ]	2.90	0.252	0.396	0.226	0.019	-0.050	0.065	0.054
	e_b [γ]	-5.86	1.87	2.40	1.92	0.927	-0.019	-0.013	0.025
	i_a [γ]	1.30	0.483	0.172	-0.169	-0.347	-0.019	0.029	0.029
	i_b [γ]	-1.63	1.14	0.943	0.786	0.458	-0.044	-0.041	-0.008
	c_e [γ]	6.54	1.88	2.43	1.94	0.927	0.054	0.066	0.059
	c_i [γ]	2.09	1.24	0.958	0.804	0.575	0.048	0.050	0.030
	c_i/c_e	0.320	0.659	0.394	0.415	0.621	0.905	0.754	0.509
	η_e [°]	-63.7	82.3	80.6	83.3	88.8	-159.1	-11.0	24.8
	η_i [°]	-51.4	67.1	79.7	102.1	127.2	-113.7	-54.3	-14.9
SD2 (H, Z)	e_a [γ]	-1.37	0.531	0.940	0.798	0.395	0.072	0.031	0.028
	e_b [γ]	-3.33	1.31	1.65	1.33	0.820	-0.024	-0.005	0.009
	i_a [γ]	-0.480	0.509	0.370	0.237	0.043	0.011	0.003	0.004
	i_b [γ]	-0.737	1.028	0.786	0.697	0.535	-0.058	-0.022	-0.013
	c_e [γ]	3.60	1.42	1.90	1.55	0.910	0.076	0.031	0.029
	c_i [γ]	0.880	1.147	0.869	0.736	0.536	0.059	0.022	0.014
	c_i/c_e	0.245	0.810	0.457	0.475	0.589	0.781	0.694	0.476
	η_e [°]	-112.4	68.0	60.4	59.0	64.3	-18.2	-9.1	17.8
	η_i [°]	-123.1	63.6	64.8	71.2	85.4	-79.8	-81.6	-72.5

to the conclusion that the DS-field is not derivable from a potential V and that electric currents flow normal to the surface of the earth during DS-variations. This case is not concluded here, and the differences mentioned are thought to be caused by incomplete and inaccurate data. Conclusions drawn from the analysis in the following sections are valid for the analysis of H and Z as well as of D and Z.

In Table 2, the coefficients e_a, e_b, i_a, i_b, amplitudes $c_e = (e_a^2 + e_b^2)^{1/2}$, $c_i = (i_a^2 + i_b^2)^{1/2}$, ratios c_i/c_e, and the phase angles η_e, η_i are listed. With these values, the external part of SD is

$$\mathrm{SD(H)}_e = \sum_{n=1}^{\infty} \sum_{m=1}^{n} c_{ne}^m \cos(m\phi - \eta_{ne}^m)\, dP_n^m/d\theta$$

$$\mathrm{SD(D)}_e = \sum_{n=1}^{\infty} \sum_{m=1}^{n} c_{ne}^m \sin(m\phi - \eta_{ne}^m)\, P_n^m/\sin\theta \tag{9}$$

$$\mathrm{SD(Z)}_e = \sum_{n=1}^{\infty} \sum_{m=1}^{n} \mathrm{n}\, c_{ne}^m \cos(m\phi - \eta_{ne}^m)\, P_n^m$$

From the numerical values of Table 2 it follows that:
a) The decrease of the amplitudes c_e from the first to the second storm day is greater for c^1_{2e}, which approximates the SD-field in lower latitudes, and less for amplitudes c^1_{ne} with $n > 2$, which describe mainly the SD-field in high latitudes.
b) The ratio c^1_{2i}/c^1_{2e} decreases from 0.32 during the first to 0.25 during the second storm day. For the terms with $n > 2$, the internal part compared to the external one, is greater, and the ratios increase from the first to the second storm day.
c) The phase η^1_{2e} shifts by about 50 degrees from the first to the second storm day (that is, two degrees per hour). This agrees approximately with the known westward drift of the asymmetric ring current during magnetic storms. Cummings (1966) estimates a value of 3 degrees per hour westward shift during the maximum main phase. For the other diurnal terms mainly caused by the SD-variations in high latitudes, the phase shift from SD1 to SD2 is comparatively small.

To what extend the ratios c_i/c_e and phase differences $\eta_i - \eta_e$ can be used for investigations of the conductivity within the earth is not discussed here.

In studying the external magnetic field DS-variations, the internal part is often not separated. The deviation of such non-separated fields from those with a separated internal part is illustrated in Fig. 5. For the 8 latitudes of the data, the curves represent the external part of SD1 (broken lines) and the external plus internal parts (solid lines). Differences in the phase and structure between the two fields are negligible, and only Z component amplitudes show significant deviations.

4. Equivalent Current Systems of the DS-Field

Differences between internal and external parts of the DS-field or between SD1 and SD2 may be clearly illustrated by equivalent current systems, which can be calculated from the spherical harmonic coefficients (e.g. Chapman and Bartels, 1940).

In the following figures, contours of the current function are drawn, which, in effect, are streamlines of the electric current. The radius R of the spherical surface on which the external currents flow is taken to be $R = a +$ 100 km. In early studies it was believed, that such current systems represent real ionospheric currents. However, in recent years, it has been established that at least the low latitude DS-variation is mainly caused by the asymmetric magnetospheric ring current. Therefore, the following current systems should not be regarded as real current systems.

Fig. 6 shows (as a completion of Fig. 5) streamlines for the external part (upper diagram) and the internal plus external parts (lower diagram) of the SD1 current system computed with the five terms of the diurnal

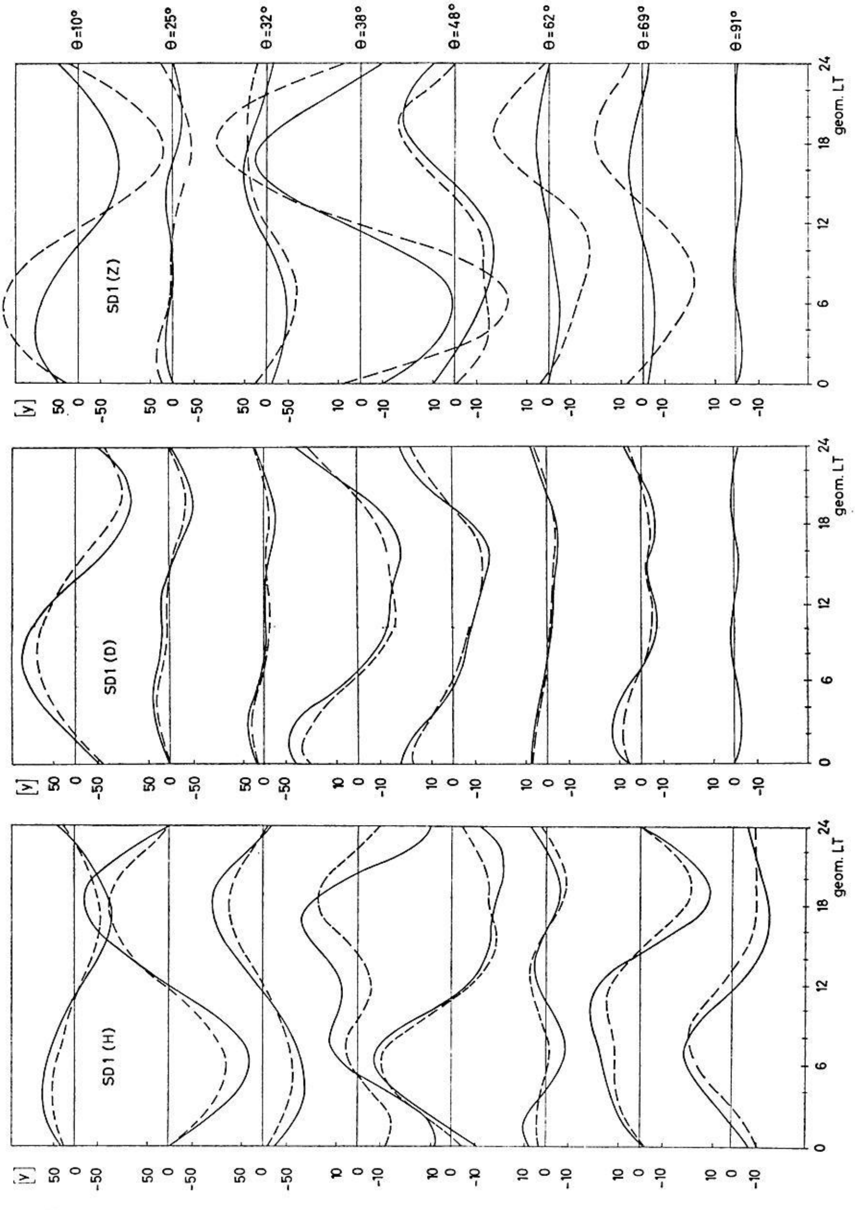

Fig. 5. The external part of SD1 (dashed lines) and internal plus external part (full lines)

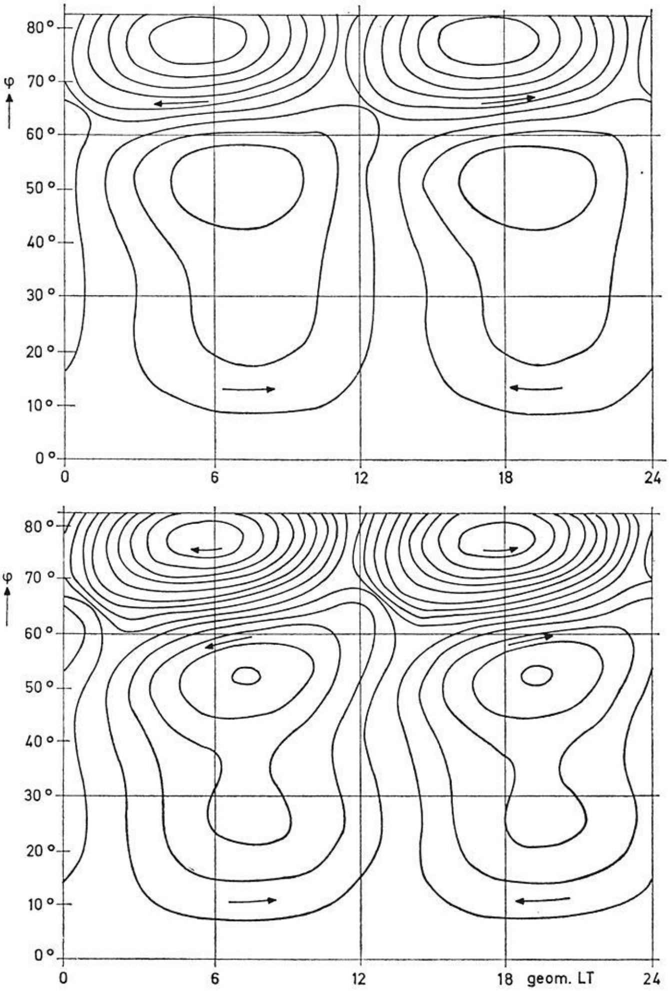

Fig. 6. The external equivalent current system of the average SD1 (upper diagram) and the internal plus external parts (lower diagram) computed with five coefficients (evaluated from H and Z component) for the diurnal terms. The current flow between two lines is $4 \cdot 10^4$ Amp. The null-lines are not drawn

mode; the latter is derived under the assumption that SD-variations have only external sources. Both systems are very similar in their structure; for example, the location of the westward electrojets which here flow from higher latitudes at about 8.00 geomagnetic LT to lower latitudes at about 2.00 geomagnetic LT. Thus calculating equivalent current systems without separating the internal part does not alter the structure of the system. Only the equivalent current strength of the inner part must be taken into consideration.

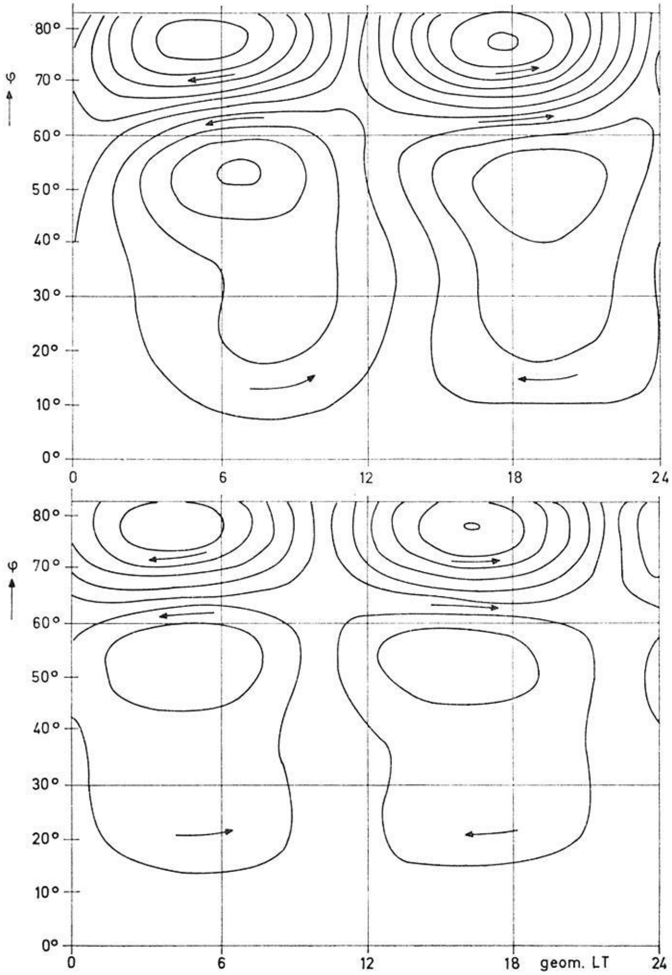

Fig. 7. Equivalent external current systems of SD1 (upper diagram) and SD2 (lower diagram) with the eight coefficients computed from H and Z components. The current flow between two lines is $4 \cdot 10^4$ Amp. Null-lines are not drawn

Equivalent current systems of the internal and external parts of SD1 and SD2 are compared in Figs. 7 and 8. These streamlines contain also the three terms of the semidiurnal mode ($m = 2$) which leads to a slight asymmetry of the current loops in the morning- and evening-sector. The phase shift of the external part in low latitudes from the first to the second storm day, as well as a shift of the polar loops to higher latitudes during the storms can be recognized in Fig. 7. In the calculation of the internal current systems of Fig. 8, a depth of 100 km for the spherical current surface was assumed.

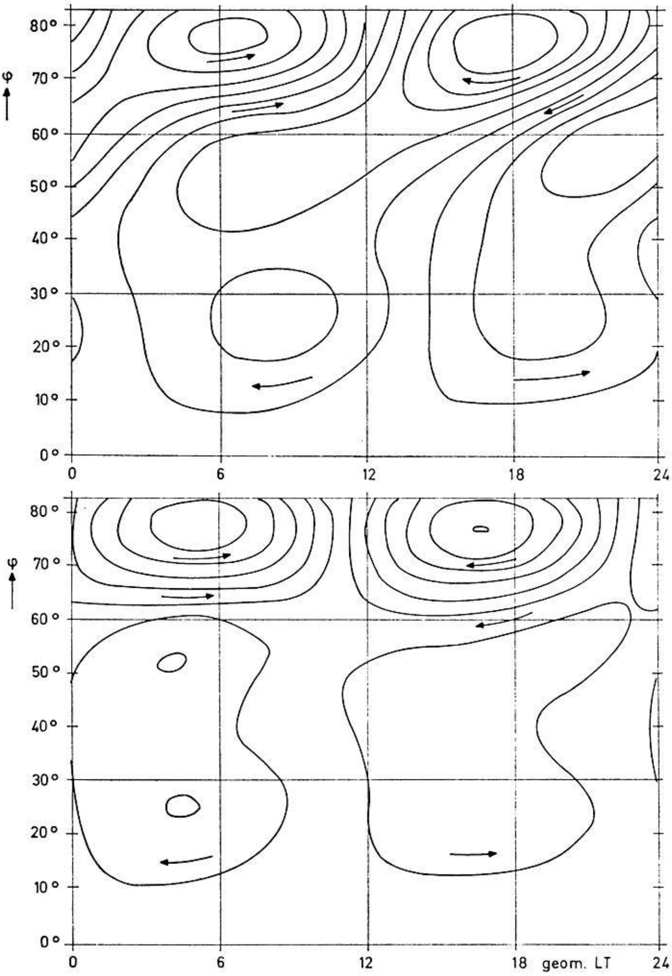

Fig. 8. Internal equivalent current systems of SD1 (upper diagram) and SD2 (lower diagram) computed with the eight internal terms from H and Z. The current flow between two lines is $2 \cdot 10^4$ Amp. Null-lines are not drawn

5. Conclusions

A spherical harmonic analysis of the DS-field during great magnetic storms has been carried out using averaged data taken from Sugiura and Chapman (1960). Since these data were limited to eight latitudes of the northern hemisphere, symmetry with respect to the equator had to be assumed. However, the data used seem to be the best average data presently available. An adequate approximation required five terms of the diurnal and three of the semidiurnal harmonics to be calculated.

The considerable differences found between the coefficients computed from the H component and D component were attributed to limited data and the ambiguities introduced by averaging. The differences increase for terms with greater n; these terms mainly describe the DS-field in high latitudes which generally varies more for individual storms than the DS-field in low latitudes. Thus in averaging several storms, there may arise differences between the averaged high latitude DS-field and the actual field of individual storms.

The separation of the internal and external parts reveals no appreciable differences between the structure of the external DS-field and the total DS-field regarded as a field of anly external origin. The ratios of the internal to external part c_{2i}^1/c_{2e}^1 have lower values than those obtained for the same term from the analysis of the Sq-variation (e. g. Chapman and Bartels, 1940). The ratios c_{2i}^1/c_{2e}^1, especially for SD2, are also lower than the corresponding ratio within the first term in the analysis of D_{st} (Rikitake and Sato, 1957; Schreiber, 1968).

In geomagnetic latitudes lower than 30 degrees, the average DS-field is adequately represented by the first term of the expansion. The phase shift of this part from the first to the second storm day approximates the phase shift of the asymmetric ring current which thus may be described roughly by the P_2^1-term. The phases of the higher order terms ($n = 6$, 8, 10), influenced mainly by the DS-variations in high latitudes and the polar electrojets, are nearly constant during the first and second storm days, suggesting that the asymmetric ring current, the field aligned currents, and the polar electrojets do not always form a closed current system.

An estimate of error for the coefficients listed in Tables 1 and 2 is not possible here because the averaged values of the data used are subject to undetermined scatter. An indication of the reliability of the calculated coefficients can be provided by a comparison of the coefficient values computed from the horizontal component H and the declination D. The considerable differences found here, suggest that appreciable errors are present and that the results should be used with care for investigations of the conductivity within the earth.

Acknowledgements. The author thanks Prof. M. Siebert and Drs. H. Drägert and P. Weidelt for their assistance in preparing this paper. The numerical calculations of the investigation were carried out on the UNIVAC-1108 computer of the Gesellschaft für wissenschaftliche Datenverarbeitung, Göttingen.

References

Akasofu, S.-I., Meng, C.-I.: Nonuniform growth of the ring current belt. Planetary Space Sci. *17*, 707–714, 1969a

Akasofu, S.-I., Meng, G.-I.: A study of polar magnetic substorms. J. Geophys. Res. *64*, 293–313, 1969b

Bonnevier, B., Boström, R. Rostoker, G.: A three dimensional model current system for polar magnetic substorms. J. Geophys. Res. *75*, 107–122, 1970
Chapman, S., Bartels, J.: Geomagnetism. Oxford: Clarendon Press 1940
Cummings, W. D.: Asymmetric ring currents and the low latitude disturbance daily variation. J. Geophys. Res. *71*, 4495–4503, 1966
Langel, R. A., Sweney, R. E.: Asymmetric ring current at twilight local time, J. Geophys. Res. *76*, 4420–4427, 1971
Rikitake, T., Sato, S.: The geomagnetic D_{st} field of the magnetic storm on June 18–19, 1936, Bull. Earthquake Res. Inst., Tokyo Univ. *35*, 7–21, 1957
Schreiber, H.: Das Magnetfeld des Ringstroms während der Hauptphase erdmagnetischer Stürme und ein Vergleich mit dem beobachteten D_{st}-Anteil des Störfeldes. Mitteil. Max-Planck-Inst. f. Aeronomie *35*, 1–57, 1968
Sugiura, M., Chapman, S.: The average morphology of geomagnetic storms with sudden commencement. Abh. Akad. Wiss. Göttingen, Math.-Phys. Kl., Sonderheft Nr. 4, 1960

Dr. Hermann Schreiber
Institut für Geophysik
der Universität
D-3400 Göttingen
Herzberger Landstraße 180
Federal Republic of Germany