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National Aeronautics and
Space Administration

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ABSTRACT

Magsat data from the magnetically quiet days of November 5-6, 1979, were used to derive a thirteenth degree and order spherical harmonic geomagnetic field model, MGST(3/80). The model utilized both scalar and vector data and fit that data with standard deviations of 8, 52, 55 and 97 nT for the scalar magnitude, B_r, B_θ, and B_ϕ, respectively. When compared with earlier models, the earth's dipole moment continues to decrease at a rate of about 26 nT/yr. Evaluation of earlier models with Magsat data shows that the scalar field at the Magsat epoch is best predicted by the POGO(2/72) model but that the AWC/75 and IGS/75 are better for predicting vector fields.

INTRODUCTION

The NASA spacecraft Magsat (NASA/GSFC, 1979) was successfully launched into a low-altitude, near-polar orbit on October 30, 1979. Intended specifically to map the magnetic field near the Earth (Langel et al., 1977; Langel, 1979), Magsat's instrumentation includes a Cesium vapor scalar magnetometer of accuracy ±1 nT (nanotesla) and a fluxgate magnetometer of accuracy better than 3 nT rms (Acuna et al., 1978). The scalar magnetometer has been successfully utilized to calibrate the vector magnetometer to an rms difference in field magnitude of less than 1 nT for the data reported herein. Initial attitude determination utilized an Earth horizon scanner and a precision sun sensor. The resulting accuracy is estimated to be somewhat better than 20 arc-minutes rms, which is equivalent to a component accuracy of 290 nT in a 50000 nT field or 175 nT in a 30000 nT field. Later data processing (Langel and Berbert, 1979) will utilize on-board star cameras and an optical system to measure the attitude of the vector magnetometer relative to the star cameras. This is expected to improve the attitude accuracy to about 20 arc-seconds rms, with corresponding component accuracies of 3-6 nT. The accuracy of orbit determination is better than the 60 m radial and 300 m horizontal accuracy required for a 3 nT rms overall accuracy of the scalar data (Langel, 1976). For the initial attitude accuracy, orbital error has negligible effect on the vector data.

The anticipated lifetime at launch was five months. However, it now appears that orbital decay is considerably less than predicted and we expect a seven to seven-and-a-half month lifetime before reentry.

Initial orbital parameters for Magsat are:

Apogee:	561.2 km
Perigee:	352.4 km
Inclination:	96.76°.

Several magnetically quiet days of Magsat data have now become available and are suitable for deriving a preliminary field model and for evaluating existing geomagnetic field models for the epoch of November 1979.

THE MAGSAT MODEL

Of the data currently available to us for analysis, November 5 and 6 have the lowest Kp indices. The highest three-hourly Kp value is 1+, which occurred only once. Plots of Dst and of the data itself also indicated that these days were indeed very quiet. Accordingly, a selection of 7468 data points from these days was used to derive an initial Magsat model whose spherical harmonic coefficients are given in Table 1. This included 2414 scalar points whose distribution is depicted in Figure 1. Global coverage was excellent; all but 10 of 648 $10^{\circ} \times 10^{\circ}$ blocks contained at least one data point. Also included were 1679 values of B_r, 1681 values of B_θ, and 1694 values of B_ϕ, where B_r, B_θ and B_ϕ are the field components measured in spherical coordinates, for latitudes below 50°. Their distribution for those latitudes is similar to that of the scalar data shown in Figure 1. Vector data above 50° latitude were not included because of non-curl-free fields from field-aligned currents. Such fields are transverse to the main field and, as shown by Langel (1974), have little or no effect on the amplitude of the scalar measurements. All data are at twilight local times because of the orientation of the Magsat orbit.

The fitting method was essentially that described by Cain et al. (1967). A degree and order thirteen model was chosen because it was justified by the density of the data and because studies by Phillips (unpublished, personal communication), and Cain (1976) indicate that a thirteenth degree and order representation is sufficient to represent the main field of the Earth. Any such choice is, of course, somewhat subjective.

This model fits the selected data with the mean and standard deviations shown in the following table.

COMPONENTS	MEAN DEVIATION (nT)	STANDARD DEVIATION (nT)
Scalar Magnitude	0	8
B_r	22	52
B_θ	10	55
B_ϕ	84	97

The source of the non-zero means for the vector data appears to be a bias of 4-7 arc-minutes in the initial attitude solution. The standard deviation of the scalar data is mainly due to a combination of fields from external and crustal sources, neither of which is modeled. The standard deviation of the vector data is due to current lack of precision in spacecraft attitude.

Evaluation of such a model is best done by comparison with independent data. Although a global set of independent data is not now available to us, comparisons have been made with a set of 44 repeat station measurements obtained by the U.S. Geological Survey in 1978 and 1979. The root mean square (rms) of residuals of total intensity at these stations was determined to be of the order of 170 nT, which may be considered as a good fit to the surface data. We have also plotted residuals of several additional days of Magsat data relative to this model. These plots indicate that the model is a good representation of the quiet-time field at the spacecraft.

The model was used to compute the field magnitude B, declination D, horizontal field H and vertical field Z at 400 km altitude. Contour plots are shown in Figure 2.

No secular variation terms are included in the model. However, the usefulness of the model could be extended in time by including secular variation terms from models such as IGS/75, AWC/75, or IGRF 1975 (whose terms consist of averages of IGS/75 and AWC/75).

STRENGTH OF THE CENTERED DIPOLE

The first approximation of the geomagnetic field is that of the field of a dipole located at the Earth's center and inclined to its axis of rotation. The strength of that dipole is measured by MR^{-3}, where M is the dipole moment computed from the first three harmonic coefficients and R is the mean radius of the Earth. MR^{-3} has been decreasing for some years (Harwood and Malin, 1976; Barraclough et al., 1978), resulting in speculation that we may be observing a reversal of the Earth's field. We have computed MR^{-3} from the new model and compared it to earlier models, as summarized in Table 2 and Figure 3. The Magsat results show a continuing decrease of MR^{-3}, consistent with earlier results. A comparison of the dipole moment measured by Magsat with that measured by POGO around 1968 indicates a rate of decrease of 26 nT/year. The slope of the line in Figure 3 is -27 nT/year. These rates are somewhat larger than the 10-20 nT/year rates measured in the 1940-1960 time frame (Harwood and Malin, 1976). If the higher rates continue, the Earth's field would reverse in about 1200 years.

EVALUATION OF EARLIER MODELS

The availability of Magsat data makes it convenient to evaluate the predictive capability of those field models currently in common use in the scientific community (see also Mead, 1979). For this evaluation 4825 scalar points and 6637 vector points at all latitudes were selected from November 5 and 6, 1979. The best known and perhaps most widely used of the current models is the IGRF (International Geomagnetic Reference Field, Zmuda, 1971; updated for use from 1975, IAGA, 1976). Other models chosen for evaluation were IGS/75 (Barraclough et al., 1975), AWC/75 (Peddie and Fabiano, 1976) and POGO(2/72) (Langel et al., 1980). Table 3 shows the mean and standard deviation of the selected Magsat data with respect to each of these models.

The POGO(2/72) model was derived from satellite scalar field data only. Its predictive capability for the scalar field at the Magsat epoch is, as might be expected, better than the other models shown in Table 3. For component prediction the AWC/75 and IGS/75 models are very close in capability, with perhaps a slight edge to IGS/75. The IGRF 1975 model is significantly poorer in its predictions of the vector field at the Magsat epoch.

SUMMARY

A global set of scalar and vector data from Magsat was used to construct a thirteenth degree and order geomagnetic field model at epoch 1979.85. The model fits the Magsat scalar data with a standard deviation of 8 nT, and also provides a good fit to 44 recent repeat station measurements. Comparison with previous models indicates that the Earth's dipole moment continues to decrease, at a rate of 26 nT/year. Evaluation of earlier models with Magsat data shows that the POGO(2/72) model gave the best predictions of the scalar field, but that the IGS/75 and AWC/75 models were better at predicting the vector components.

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Table 1. The MGST(3/80) field model. The mean radius of the Earth was assumed to be 6371.2 km. Mean epoch is 1979.85.

n	m	g_n^m, nT	h_n^m, nT
1	0	-29990.1	0.0
1	1	-1958.1	5609.5
2	0	-1993.2	0.0
2	1	3027.7	-2129.5
2	2	1662.4	-192.3
3	0	1269.6	0.0
3	1	-2180.1	-331.4
3	2	1251.7	270.6
3	3	833.3	-250.6
4	0	937.2	0.0
4	1	782.7	211.9
4	2	399.2	-257.6
4	3	-419.8	51.3
4	4	198.7	-297.6
5	0	-213.7	0.0
5	1	357.1	42.9
5	2	261.0	148.8
5	3	-73.3	-150.5
5	4	-162.8	-78.8
5	5	-46.5	90.6
6	0	48.9	0.0
6	1	65.3	-14.4
6	2	41.1	93.8
6	3	-192.2	70.9
6	4	3.9	-43.2
6	5	14.1	-2.7
6	6	-107.8	17.2
7	0	70.6	0.0
7	1	-58.6	-81.2
7	2	1.9	-27.2
7	3	20.5	-5.1
7	4	-12.3	16.4
7	5	-0.2	18.6
7	6	10.9	-22.9
7	7	-2.1	-9.2
8	0	18.1	0.0
8	1	6.7	6.7
8	2	-0.2	-17.8
8	3	-10.8	4.2
8	4	-7.1	-22.1
8	5	4.4	9.3
8	6	2.4	16.0
8	7	6.0	-13.1
8	8	-1.8	-15.8
9	0	5.7	0.0
9	1	10.1	-21.3
9	2	1.0	15.0
9	3	-12.8	9.0
9	4	9.3	-4.9
9	5	-3.1	-6.7
9	6	-1.3	8.7
9	7	6.6	9.5
9	8	1.5	-6.7
9	9	-4.5	3.5
10	0	-3.1	0.0
10	1	-3.6	1.3
10	2	2.4	0.6
10	3	-5.2	2.5
10	4	-2.0	5.5
10	5	4.6	-4.3
10	6	3.2	-0.1
10	7	0.6	-1.4
10	8	2.1	3.5
10	9	3.5	-0.4
10	10	-1.0	-6.5
11	0	2.2	0.0
11	1	-1.3	0.7
11	2	-1.8	1.9
11	3	2.2	-1.1
11	4	0.2	-2.7
11	5	-0.5	0.7
11	6	-0.3	-0.1
11	7	1.9	-2.3
11	8	1.9	0.0
11	9	-0.3	-1.6
11	10	2.1	-0.8
11	11	2.4	0.8
12	0	-1.7	0.0
12	1	0.6	0.9
12	2	-0.1	0.3
12	3	-0.1	2.2
12	4	0.3	-1.5
12	5	0.6	0.6
12	6	-0.6	0.3
12	7	-0.4	-0.3
12	8	-0.0	0.3
12	9	-0.7	-0.3
12	10	0.0	-1.5
12	11	0.1	-0.5
12	12	1.4	-0.3
13	0	0.1	0.0
13	1	-0.4	-0.2
13	2	0.3	0.4
13	3	-0.5	1.7
13	4	-0.1	0.1
13	5	1.2	-0.6
13	6	-0.5	-0.1
13	7	0.1	1.0
13	8	-0.4	0.1
13	9	-0.0	0.9
13	10	0.0	0.4
13	11	-0.1	-0.4
13	12	0.7	-1.1
13	13	0.4	0.5

TABLE 2. STRENGTH OF CENTERED DIPOLE AND RATES OF CHANGE FOR THE PERIOD 1960 TO 1980

Model	Epoch	MR^{-3}, nT	$\dot{M}R^{-3}$, nT/yr
Cain et al., 1965	1960	31043	-19
GSFC(12/66) (Cain et al., 1967)	1960	31021	-15
Malin, 1969	1960	31152	-17
Leaton et al., 1965	1965	30987	-16
Barraclough et al., 1978	1965	30955	-22
POGO(2/72) (Langel et al., 1980)	1968	30879	-26
IGS/75 (Barraclough et al., 1975)	1975	30701	-29
AWC/75 (Peddie and Fabiano, 1976)	1975	30652	-26
MGST(3/80)	1979.85	30573	-26*

*by comparison with POGO(2/72), Epoch 1968

Table 3: Residuals of selected MAGSAT data to some published field models. Units are nT.

	IGRF 1975	AWC/75	IGS/75	POGO(2/72)	MGST(3/80)
Scalar:mean deviation	-90	61	23	9	0
:standard deviation	125	127	120	107	8
B_r:mean deviation	29	46	40	25	21
:standard deviation	204	153	137	211	44
B_θ:mean deviation	44	-10	8	12	12
:standard deviation	146	115	114	145	107
B_ϕ:mean deviation	62	62	61	61	62
:standard deviation	181	157	155	208	129

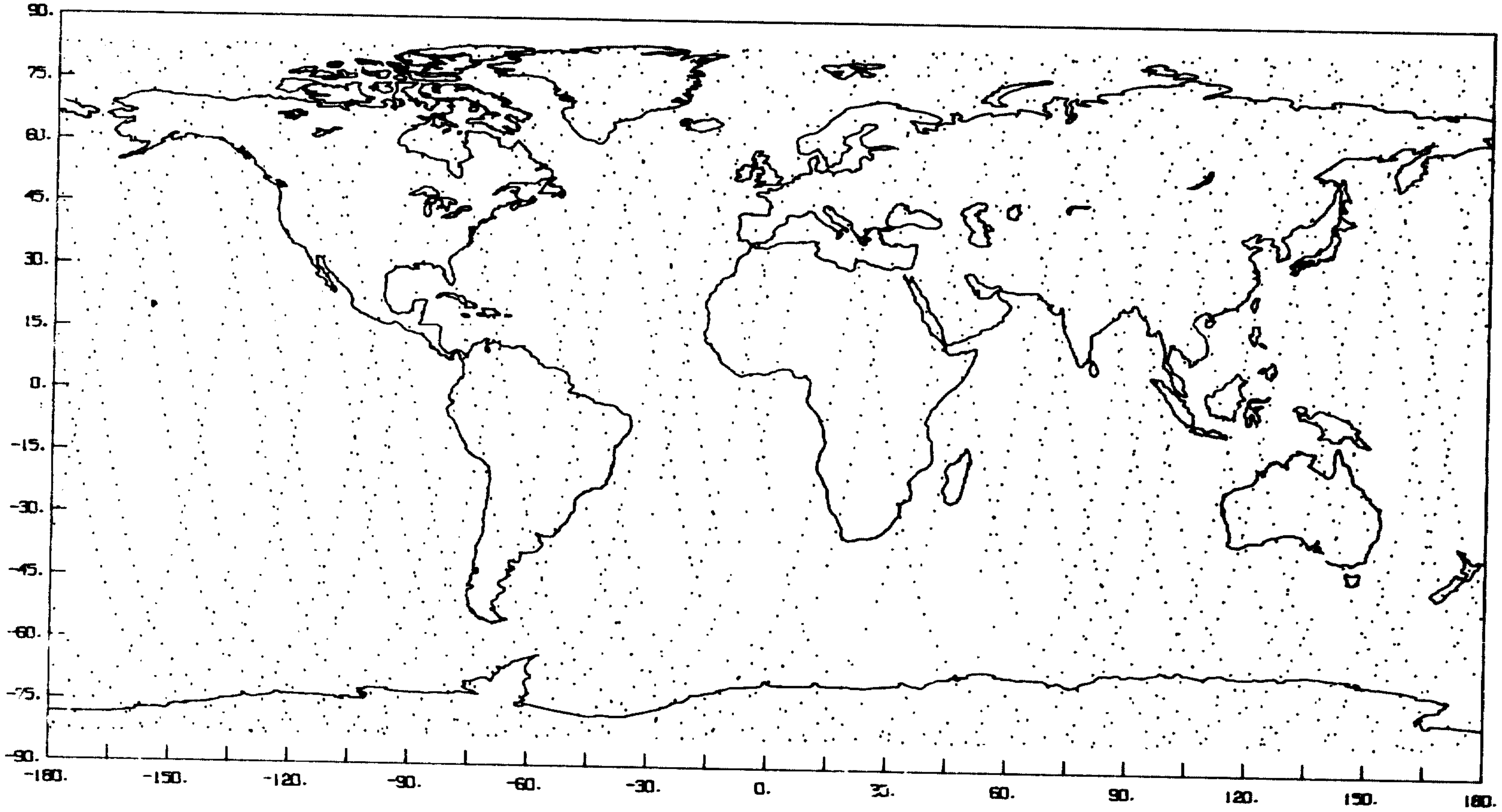

Figure 1. Distribution of scalar field data used to derive model. Vector data was limited to ± 50° latitude.

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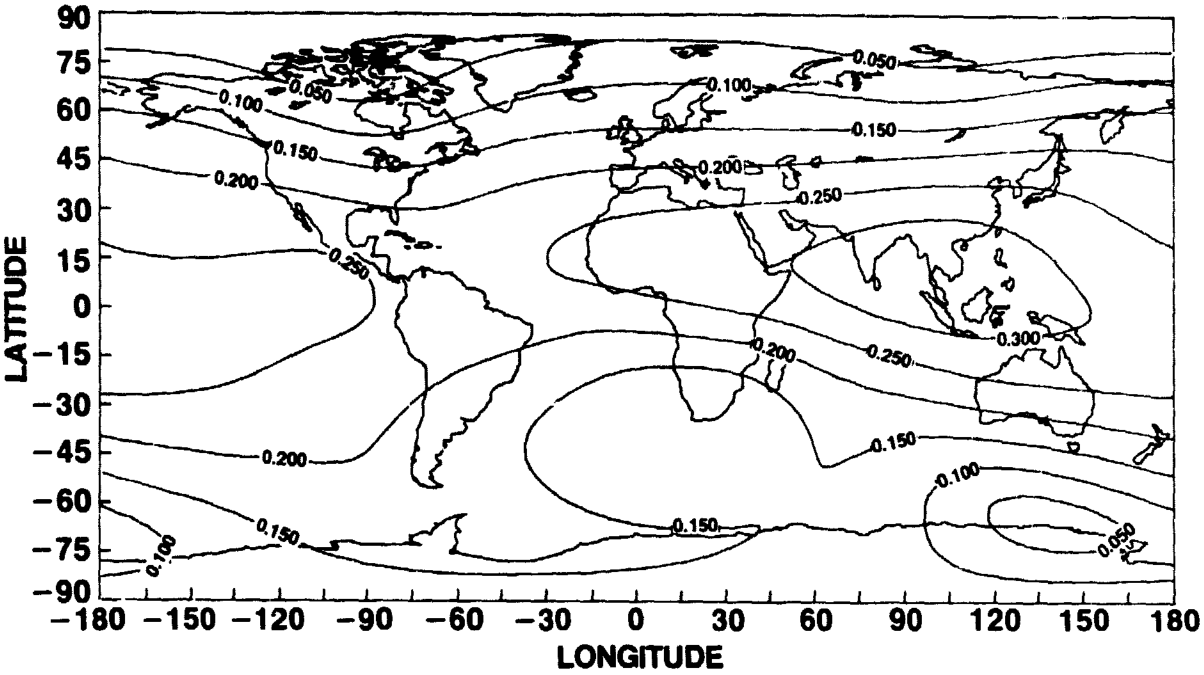
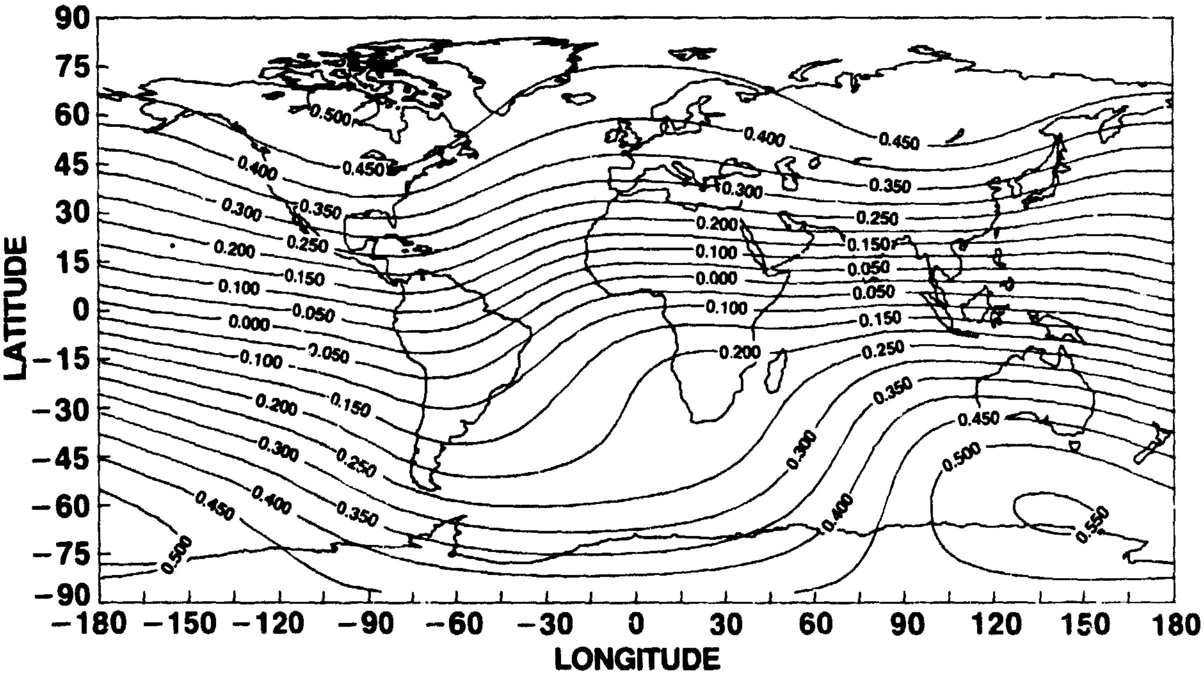


C) HORIZONTAL FIELD, H, GAUSS.



D) VERTICAL FIELD, Z, GAUSS

Figure 2(c) and 2(d). Horizontal field (c) and vertical field (d) at 400 km altitude, as computed from the MGST(3/80) model.

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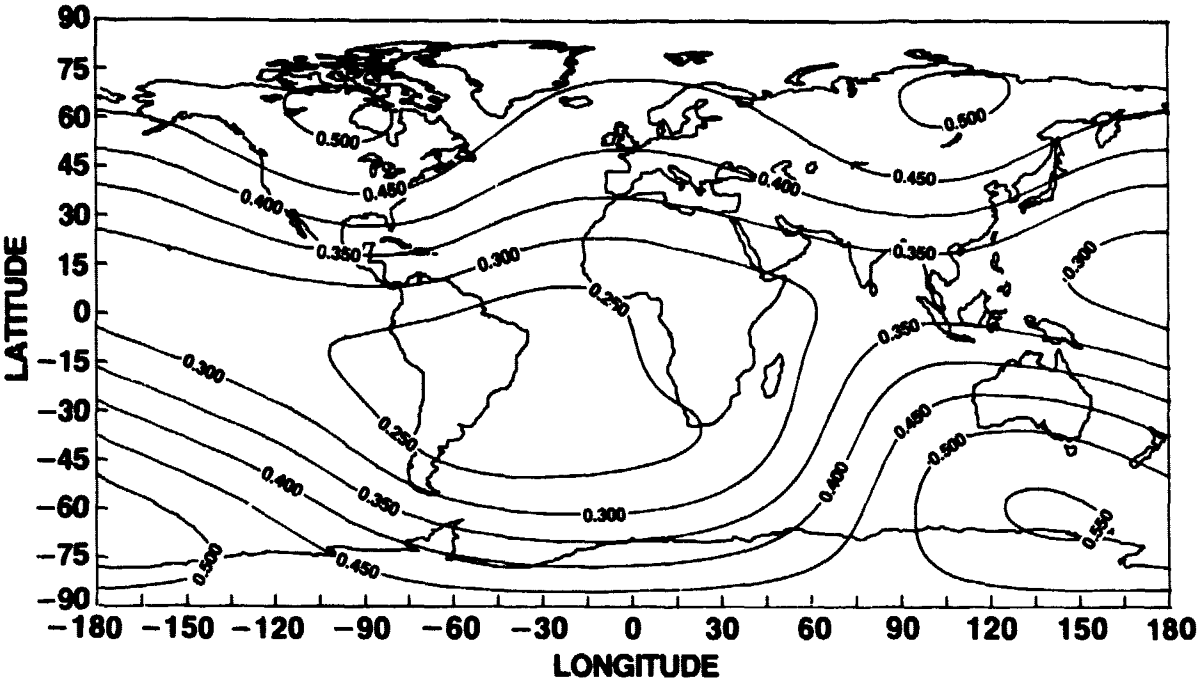
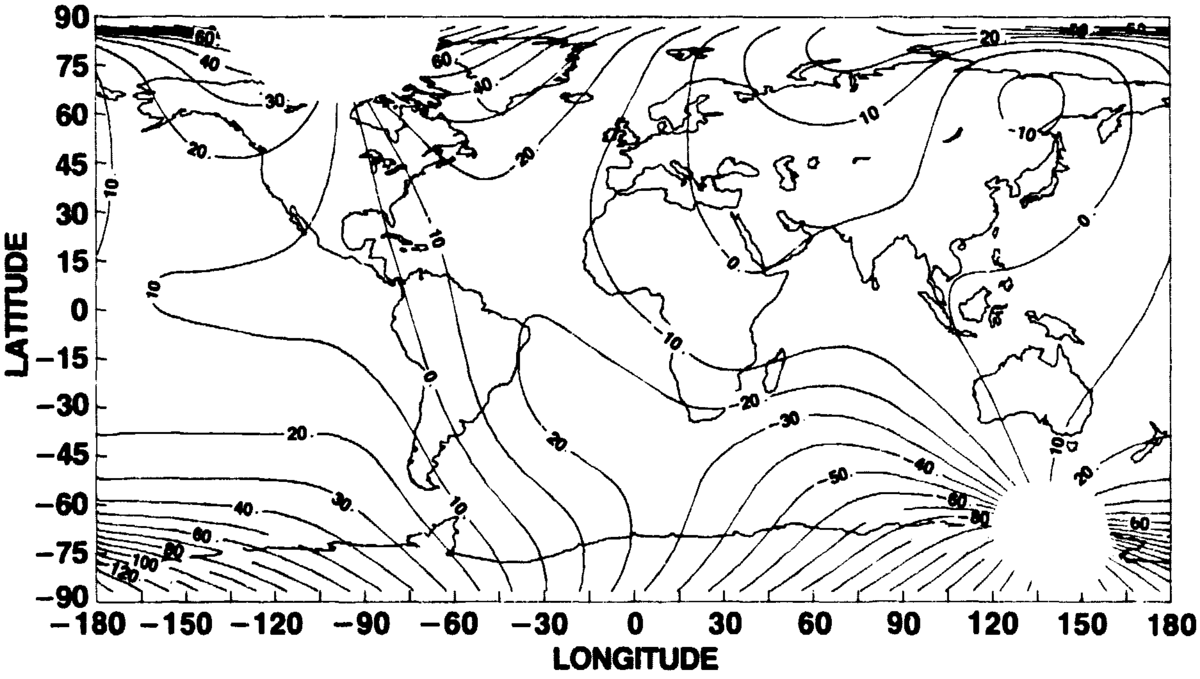


A) FIELD MAGNITUDE, B, GAUSS.



B) DECLINATION, D, DEGREES.

Figure 2. Geomagnetic field magnitude (a) and declination (b) at 400 km altitude, as computed from the MGST(3/80) model.

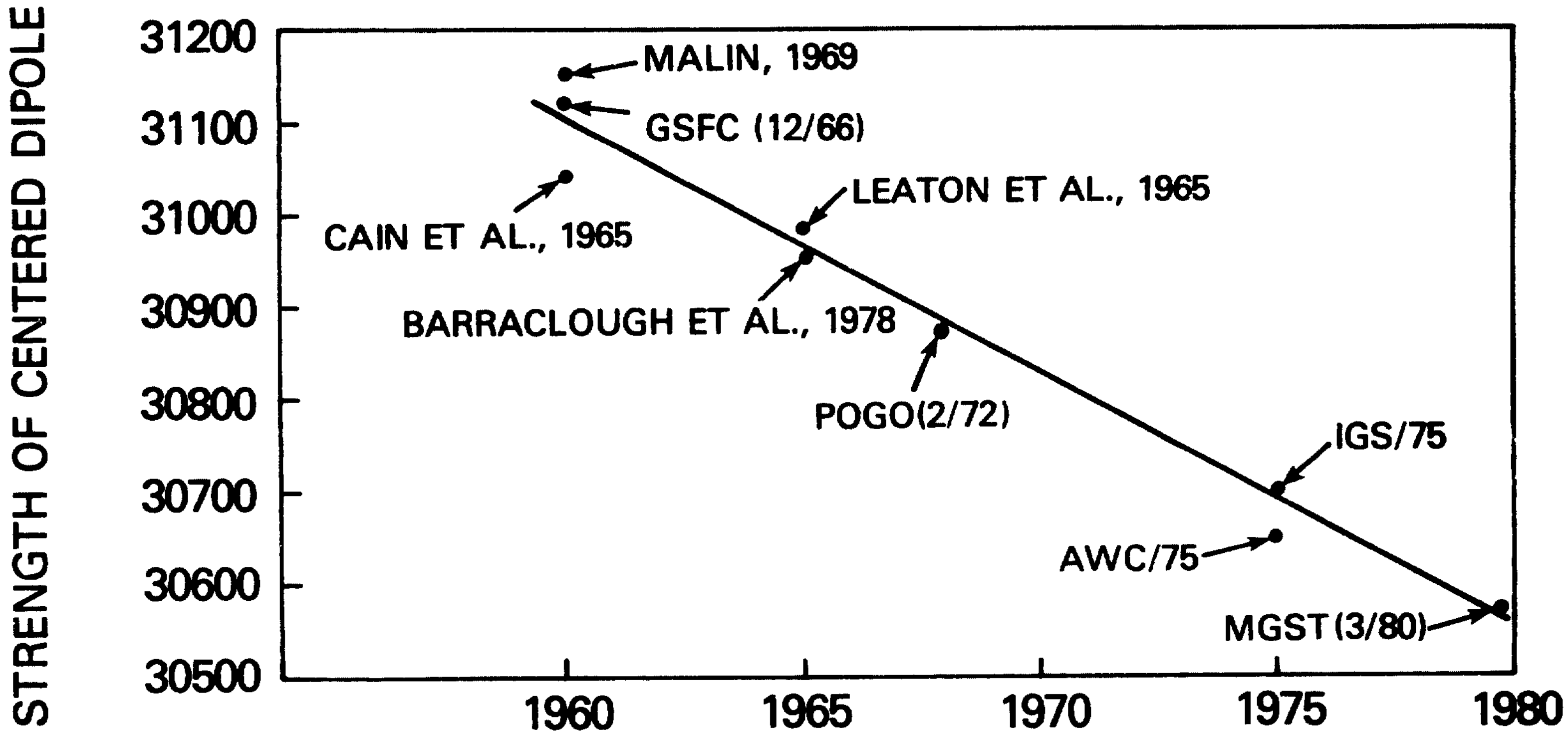


Figure 3. Strength of the Centered Dipole since 1960. Slope of the line is -27 nT/year.

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16. Abstract

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