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THE GEOMAGNETIC SURVEY BY THE POLAR ORBITING GEOPHYSICAL OBSERVATORIES OGO-2 AND OGO-4 1965-1967

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DECEMBER 1968

GSFC

GODDARD SPACE FLIGHT CENTER
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Introduction

The only complete pole-to-pole survey of the geomagnetic field to date has been that performed by the polar Orbiting Geophysical Observatories OGO's 2, 4, and 6 (Heppner, 1963; Ludwig, 1963)*. Some of the characteristics of the orbits are as follows:

Official Designations		Launch Date	Inclination	Perigee (km)	Apogee (km)
OGO-2	1965 81A	Oct. 14, 1965	87.3°	410	1510
OGO-4	1967 73A	July 28, 1967	86°	410	910
OGO-6	1969 51A	June 5, 1969	82°	400	1100

The magnetic survey instruments used on these spacecraft were optically pumped, self-oscillating rubidium vapor magnetometers measuring the absolute scalar field (Farthing and Folz, 1967). The sampling interval was 0.5 seconds for OGO's 2 and 4, and 0.288 seconds for OGO-6. OGO-2 acquired data from launch until October 2, 1967 whenever the orbit was in full sunlight; OGO-4 operated almost continuously from launch until January 19, 1969; OGO-6 operation is planned for a year from launch.

Since all of the data from these experiments have not been reduced, this report is limited to a summary of data from OGO-2 and 4 from October 14, 1965 until the end of 1967.

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* Also unofficially referred to as "POGO"

<u>Accuracy of Observations</u>

The accuracy of the instrument is better than 2γ (Farthing and Folz, 1967) as determined by direct comparison with proton magnetometers. The digitization "noise" resulting from measuring the frequency [frequency(cps) = (4.66737)field(γ)] over a finite interval is $\pm 0.4\gamma$ for OGO-2 and 4, and $\pm 0.6\gamma$ for OGO-6. Extraneous magnetic fields from the rest of the spacecraft were tested prior to launch and found to be below 1γ at the rubidium vapor sensor which is mounted on the end of a six-meter long boom.

A recent article by Allen (1968) indicated that single cell rubidium magnetometers such as those used in the automatic surface observatories (Alldredge and Saldukas, 1966) could be in error as much as 7γ. No such drift error is possible with the units used on POGO since they are of the dual cell type and automatically cancel such first order errors (B. G. Ledley, private communication). There is a pair of such dual cell instruments on each spacecraft and the output frequency is a phase-locked sum of the signal from each. When the spacecraft happens to be in a spinning mode the magnetic field vector alternately rotates through zones of insensitivity for each of the two instruments; at these times the output signal results from only one of the dual cell units. Under these conditions it is thus possible to observe a small oscillation in the output data of about 2.5γ peak-to-peak amplitude. It is likely that the absolute error is less than this amount.

A source of error frequently comparable to that of the instrument is the absolute time assigned to any given observation. Since the field changes up to 40γ/sec due to the movement of the spacecraft, an error of 25 msec could be equivalent to a measurement error of one gamma. The timing accuracy is estimated to be generally better than 30 msec with rare excursions to 60 msec. It is thus likely that this source of error is also of the order of 1γ.

However, the instrumental and timing accuracies are overshadowed by the errors added due to uncertainties in the orbital position at the time of measurement. The effective accuracy of the observations can be no greater than the difference in field between that at the assumed and true position of the spacecraft at the time of measurement. Computations with geomagnetic field models show that an altitude error of as little as 40 meters can give an effective error of 1γ, whereas the horizontal uncertainty can be over 200 meters for the same effect. The evaluation of absolute orbital errors is difficult since the quantity of tracking data for a spacecraft operating as low as POGO is barely sufficient to define an accurate orbit. We have attempted an estimate of errors by having two independent determinations of the orbit on the assumption that the computed difference in field gives an indication of the errors. The details of one of the orbital determinations and our accuracy evaluation are obtainable from the National Space Science Data Center (Greenbelt, Maryland) as part of the reference material available to users of the POGO data. This evaluation was done on a daily basis and shows that for OGO-2 the difference is 5γ or less on about half the days, and 10γ or less on 90% of the days. The other 10% show differences up to 20γ except for a few cases where one of the orbits used in the comparison obviously has large errors.

The corresponding positional differences range up to a few hundred meters vertically and one or two kilometers horizontally. The OGO-4 and 6 orbits have not been evaluated but since the tracking data are of the same type, one might assume that the errors would be no larger than for OGO-2.

Data Extent

The quantity of data acquired by the POGO magnetometer far exceeds the total for all other magnetic survey sources. Data acquisition for only about a two-week interval gives virtually complete global coverage. Figure 1 is a plot of the positions of the OGO-2 observations acquired during the first ten days from launch [one point is plotted every 37 seconds ($\sim$ 250 km)]. Since the POGO satellites were long-lived, it was not necessary to follow the early recommendations (Vestine, 1961) to design the orbit so that the profiles from each day would evenly fill the spatial gaps in longitude. The tracks are thus essentially random except that the location of receiving stations available for reading out the recorded data have made the longitudes near 130°E and W slightly less well covered than others.

The intervals of time over which data were acquired prior to December 15, 1967 is given by Figure 2. The solid horizontal lines for each month and day indicate continuous data acquisition with time gaps no greater than five minutes. The only contribution by OGO-2 after May 1967 was during the interval September 19 to October 2, 1967 when operation was very intermittent. When remaining OGO-4 data are reduced, they will cover almost all of the dates from launch (July 28, 1967) until January 19, 1969 plus a few segments from July 17 through August 6, 1969. The OGO-6 data commence at launch (June 5, 1969) and are expected to continue for a year.

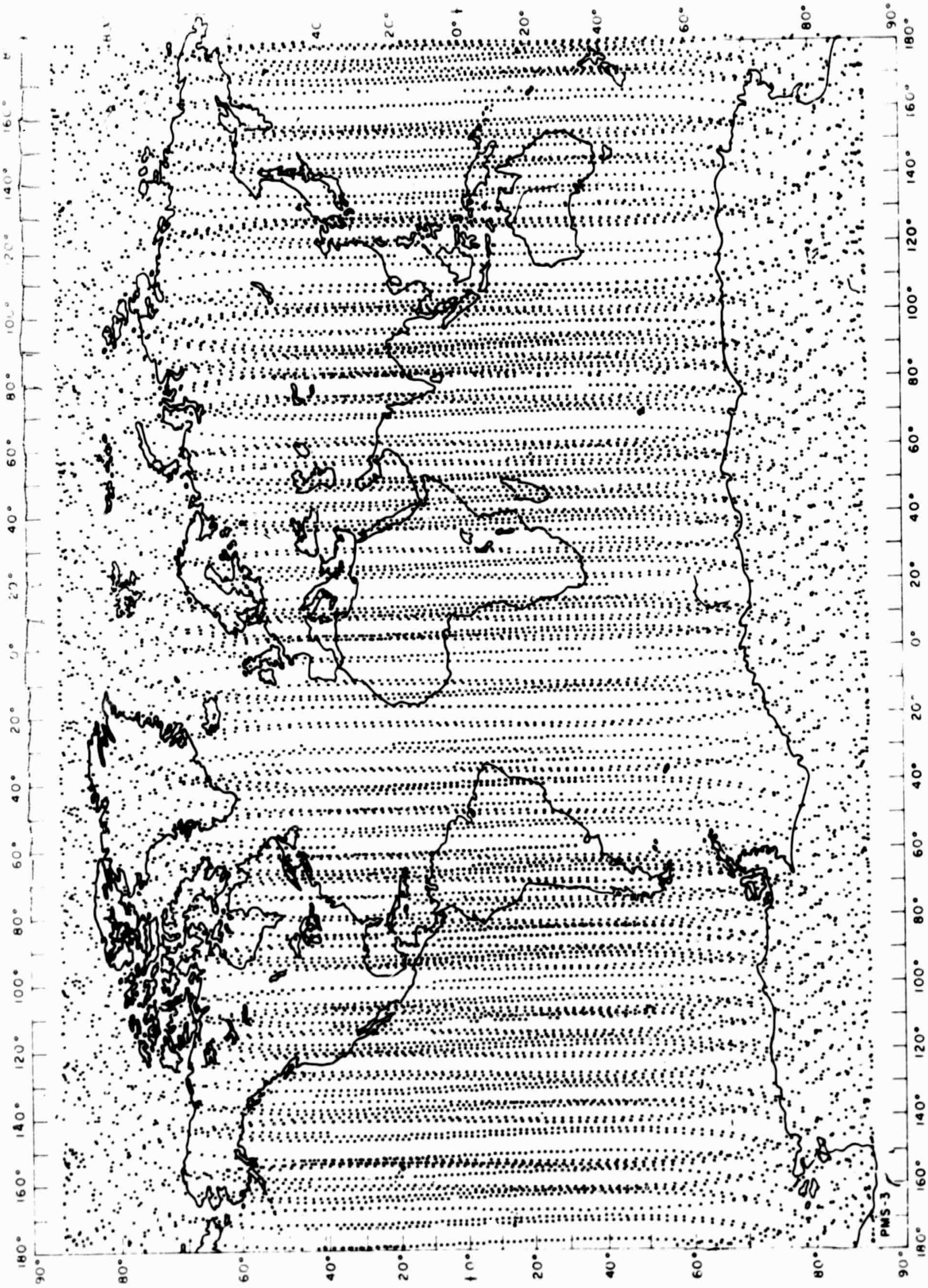


FIGURE 1

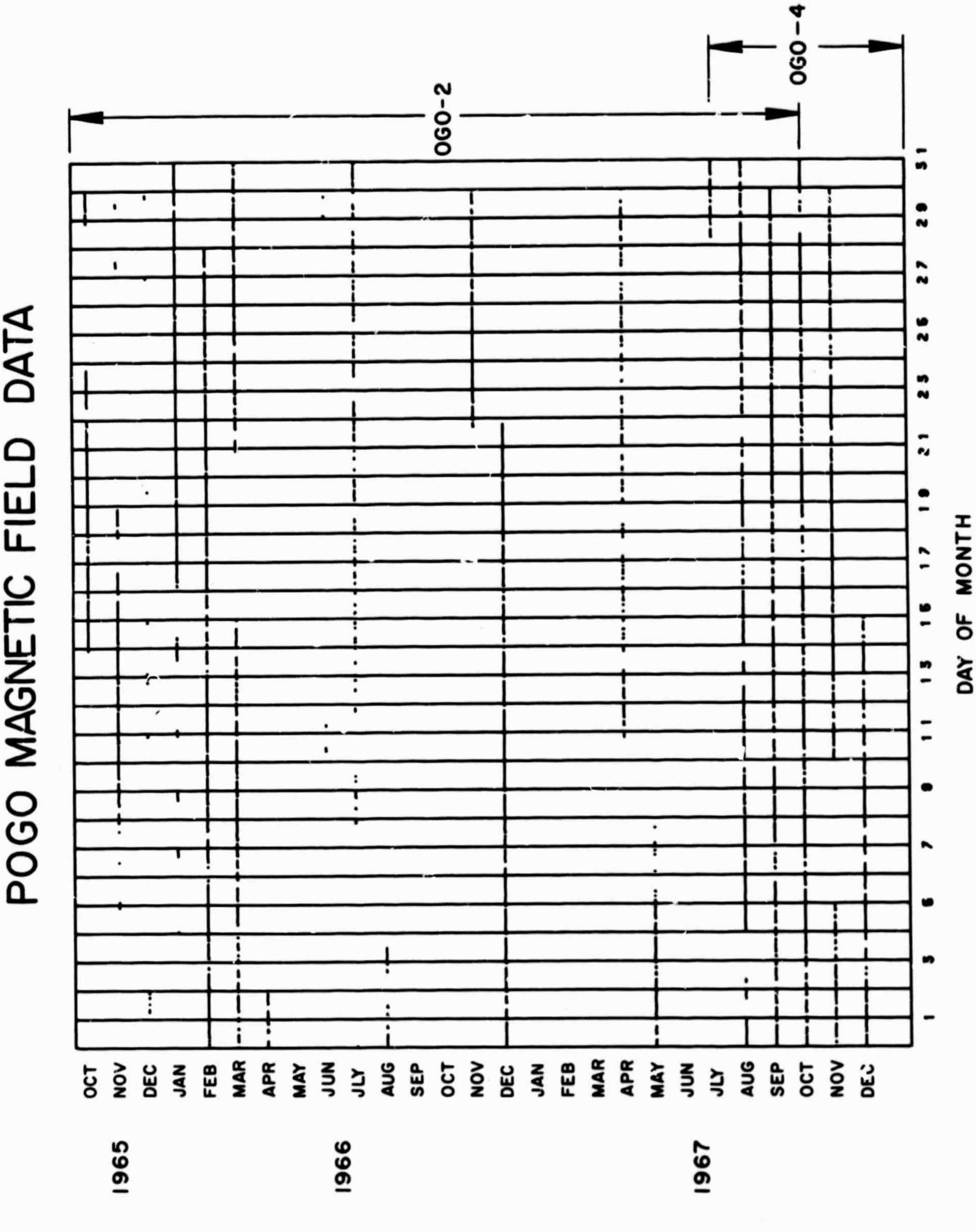
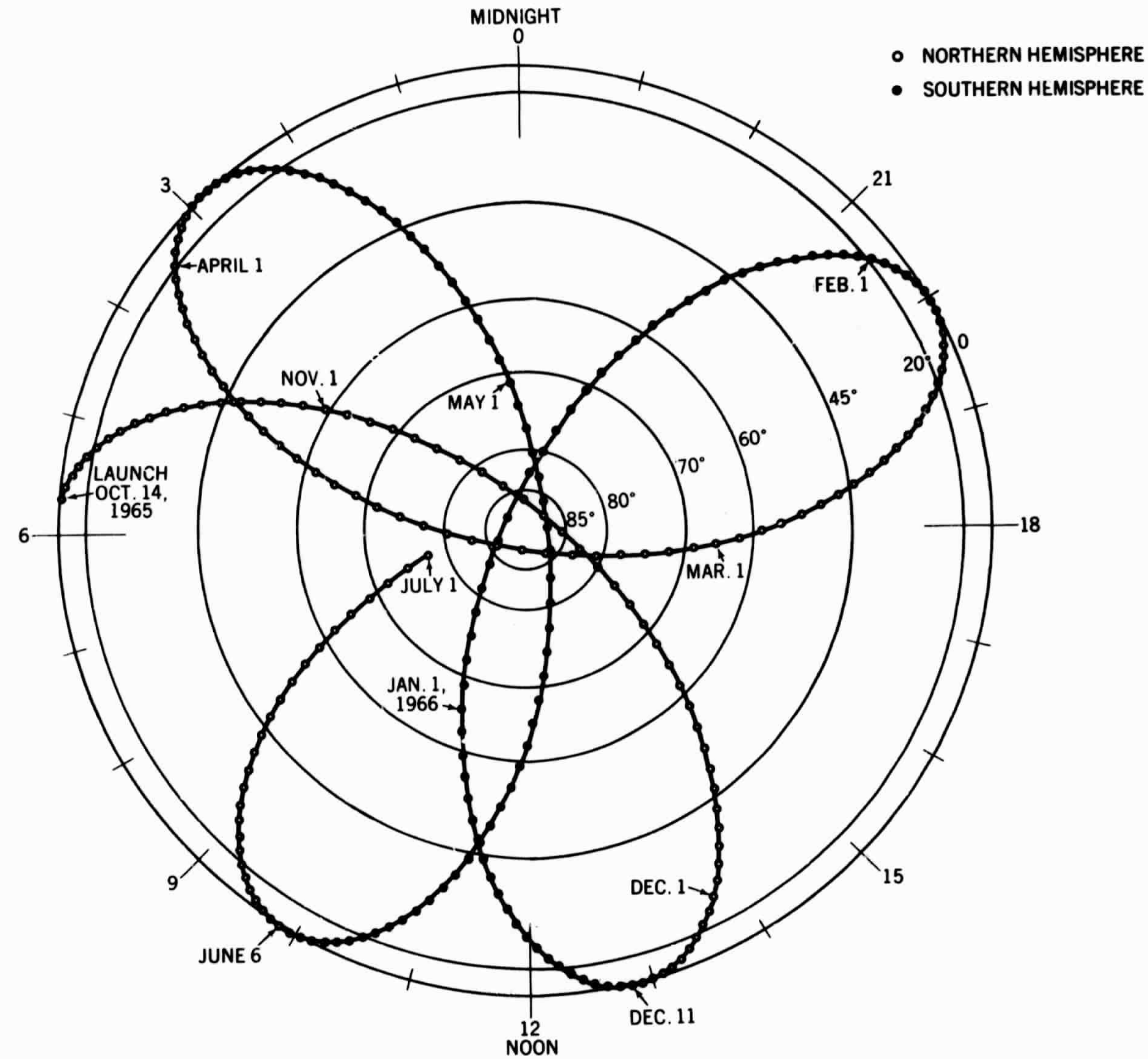

POGO MAGNETIC FIELD DATA
OGO-2
OGO-4
1965
1966
1967
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JLY
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JLY
AUG
SEP
OCT
NOV
DEC
DAY OF MONTH

FIGURE 2

The total data (about 12,200,000 observations) for OGO-2 is equivalent to approximately 2,000 hours or 50 million track kilometers. If one considers that the earth can be adequately covered in say 100 orbits, OGO-2 has performed over 10 complete surveys, whereas OGO-4 and 6 will each have performed more than double that number.

Having such a large base of data makes it feasible to go beyond the original concept of the World Magnetic Survey which was to obtain the main field to an accuracy only of the order of 100γ (Vestine, 1960, 1961). It becomes possible to look more carefully into the effect of external sources and time variations and may lead to a reference field whose accuracy is of the order of a few gammas. Also, it may be possible to follow the secular changes more accurately and with a finer time definition than ever before. It is thus useful to look into factors concerning data acquisition which may systematically bias the results at the 10γ level.

The most significant factor which is new and special to spacecraft surveys is that the plane of a satellite orbit moves very slowly in inertial space. Since the earth's rotation brings each longitude under the orbit plane, the data are globally well distributed. However, all observations at one latitude have nearly the same local time for several weeks. This movement is illustrated by Figure 3 (Langel, 1967). This diagram shows a plot (for the first few months from launch) of the locus of perigee for OGO-2 as seen from above the north pole. The concentric circles are parallels of geographic latitude; the azimuth scale is hours of local time. The OGO-2 orbit at any epoch would project onto this



PERIGEE MOTION OF POGO -1 ORBIT
OCT. 14, 1965 - JULY 1, 1966

FIGURE 3

diagram as a thin ellipse passing through the point given for perigee and the parallel of latitude equal to its inclination (87.3°). Thus, for the first ten days from launch, each observation equatorward of 60° latitude occurred between 4 and 6 o'clock (a.m. and p.m.) local time. Further, all of the morning data were at a low altitude while the evening data were taken near apogee. Since both quiet-day and disturbance time variations of the field have diurnal components, any analysis of the data neglecting such effects could contain systematic biases.

Of course, as the orbital plane rotates, data will normally be acquired at all local times. However, due to spacecraft malfunctions OGO-2 was only able to acquire data when the orbital path was almost fully sunlit. Thus, as seen in Table 1, less than 1% of the total OGO-2 data were obtained within two hours of noon and midnight, whereas the distribution for OGO-4 is much more uniform.

As shown in Table 2 the total quantity of OGO-4 data is more than double that from OGO-2. Also, since the OGO-4 apogee is lower, the quantity below 600 km altitude is more than three times that for OGO-2.

However, the interval during which OGO-2 was in operation was generally magnetically quieter than for OGO-4 as expected from the phase of the sunspot cycle. The percentage distribution of the data obtained below 600 km during intervals with a given magnetic Kp index is as follows:

Kp	OGO-2	OGO-4
0	22%	9%
1	30%	24%
2	21%	27%
3-5	26%	39%
6-8	1%	1%

TABLE 1

Percent Distribution of OGO-2 and OGO-4 Data In Local Time
(Data Excluded Poleward of 80°)

Local Time Ranges (Hours)

	22–2	2–6	6–10	10–14	14–18	18–22
OGO-2	.7	34	14	1	20	31
OGO-4	12	20	11	19	19	18

TABLE 2

Distribution of OGO-2 and OGO-4 Data By Altitude
(one observation tabulated each 70 sec)

	OGO-2	OGO-4*
Below 600 km	30,000	91,500
600 - 1000 km	30,000	104,700
1000 - 1500 km	62,300	0
TOTAL	122,300	196,200

* OGO-4 reduced data September 28, 1967 - May 28, 1968. Data were also acquired through January 19, 1969 but are not yet available.

Thus about half of the OGO-2 and a third of the OGO-4 data should be free of systematic variations due to magnetic disturbance. Of course, even on magnetically very quiet days one needs to make allowance for the few tens of gammas change in the level of the field due to external effects (Sugiura, 1964; Sugiura et al., 1969).

Data Analysis

In using only total field data for magnetic mapping or modeling, one is faced with the question of whether a true vector field can be obtained from only scalar measurements. Although the theoretical basis is yet lacking, we have numerically demonstrated that this can be done with "perfect" data. That is, we have computed total field values on a 10° grid at one altitude from a finite set of spherical harmonic coefficients (g_n^m, h_n^m). Then, using the linearized least squares technique as given by Cain et al.(1967) the original coefficients were retrieved to an accuracy comparable to the computer word length round-off error (10^{-7}): using as initial conditions a g_1° -30,000γ, with all other terms = 0.

In our original work with the OGO-2 data (Cain, Langel, and Hendricks, 1966) we found that it was possible to fit a three-day span of magnetically quiet data 143 internal spherical harmonic coefficients (maximum degree and order of 11) with a root-mean-square residual of 4γ. However, satisfactorily reducing a longer span of data required allowing the coefficients to change with time to account for secular variation. Also, even by careful selection of the quietest intervals, the data still contain time variations from external magnetospheric sources, and from ionospheric and induced currents internal to the shell of measurements.

An example of the results of fitting a longer span of data is contained in the POGO(3/68) set of coefficients submitted March 15, 1968 as a candidate for the International Geomagnetic Reference Field (IGRF)(Cain and Cain, 1968). This fit was made to a set of OGO-2 and 4 data selected from the magnetically quiet days given in Table 3. The OGO-2 data were sampled at 60-second intervals on these dates whereas for OGO-4 the interval was 30 seconds. Maps showing the distribution of data for each year (1965, 1966, and 1967) are given in Figure 4. These 22,252 observations were fit with the 99 coefficients given in Table 4 to a root-mean-square residual of 11γ. As shown in Table 5, the distribution of residuals from the fit is very symmetric.

Previous to the POGO(3/68) model the best estimate of the current geomagnetic field was given by the GSFC(12/66) set of coefficients (Cain et al., 1967a). This prior analysis used a sample of OGO-2 data taken from the interval October 29-November 15, 1965 plus the comprehensive selection of World Magnetic Survey data 1900-1963. However, as seen in Table 6 the POGO(3/68) model gives better fit to the whole set of POGO data than the GSFC(12/66) model. An inspection of plots of $\Delta F = F_{measured} - F_{calculated}$ for August 1, 1967* using these two models shows that the peak values using GSFC(12/66) range from +90 to -130γ; those using POGO(3/68) all lie within the band $\pm 50\gamma$.

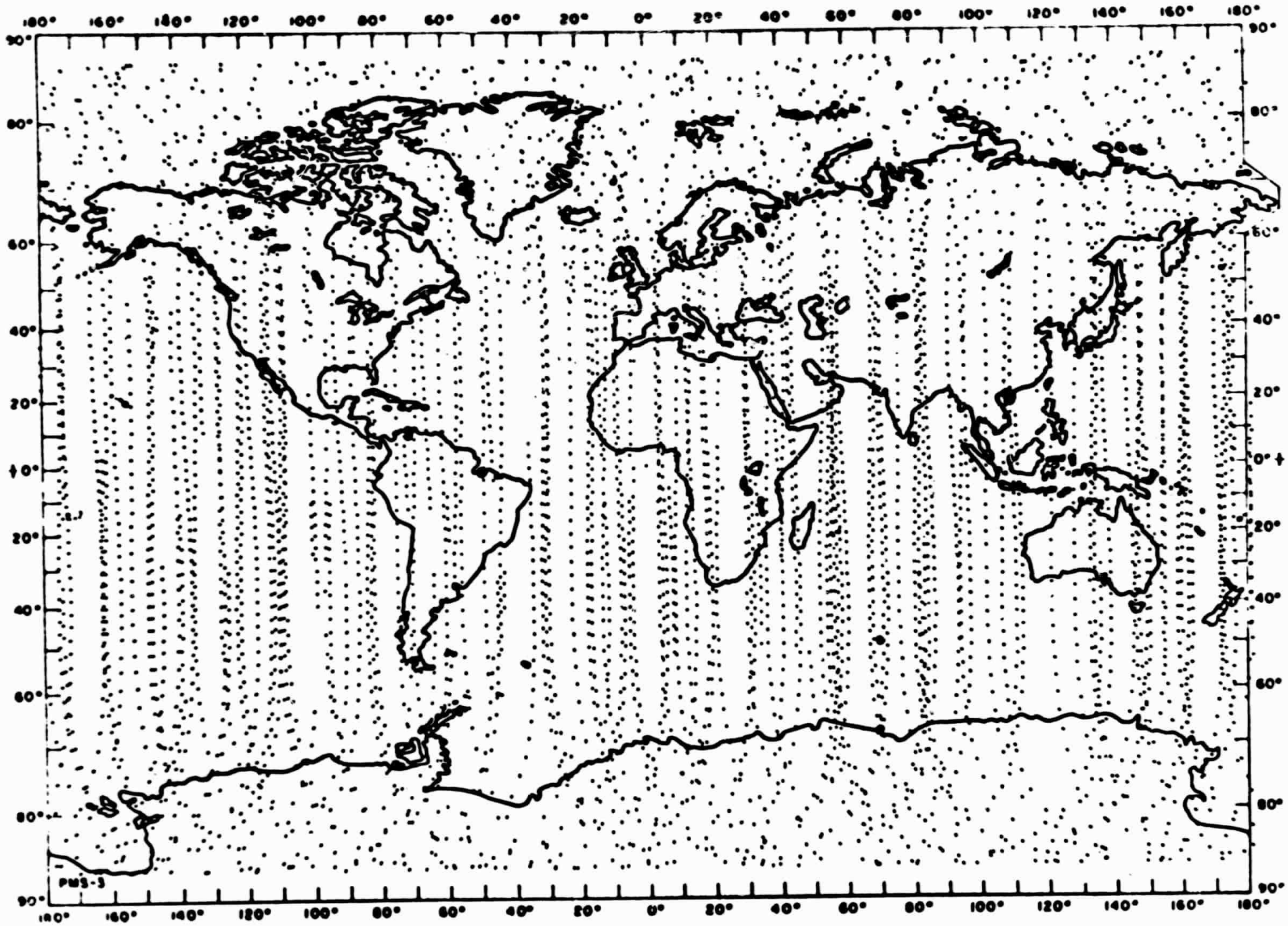
* This day was one of the selected five quietest days for August.

Table 3

Data Selection For POGO(3/68) Coefficients

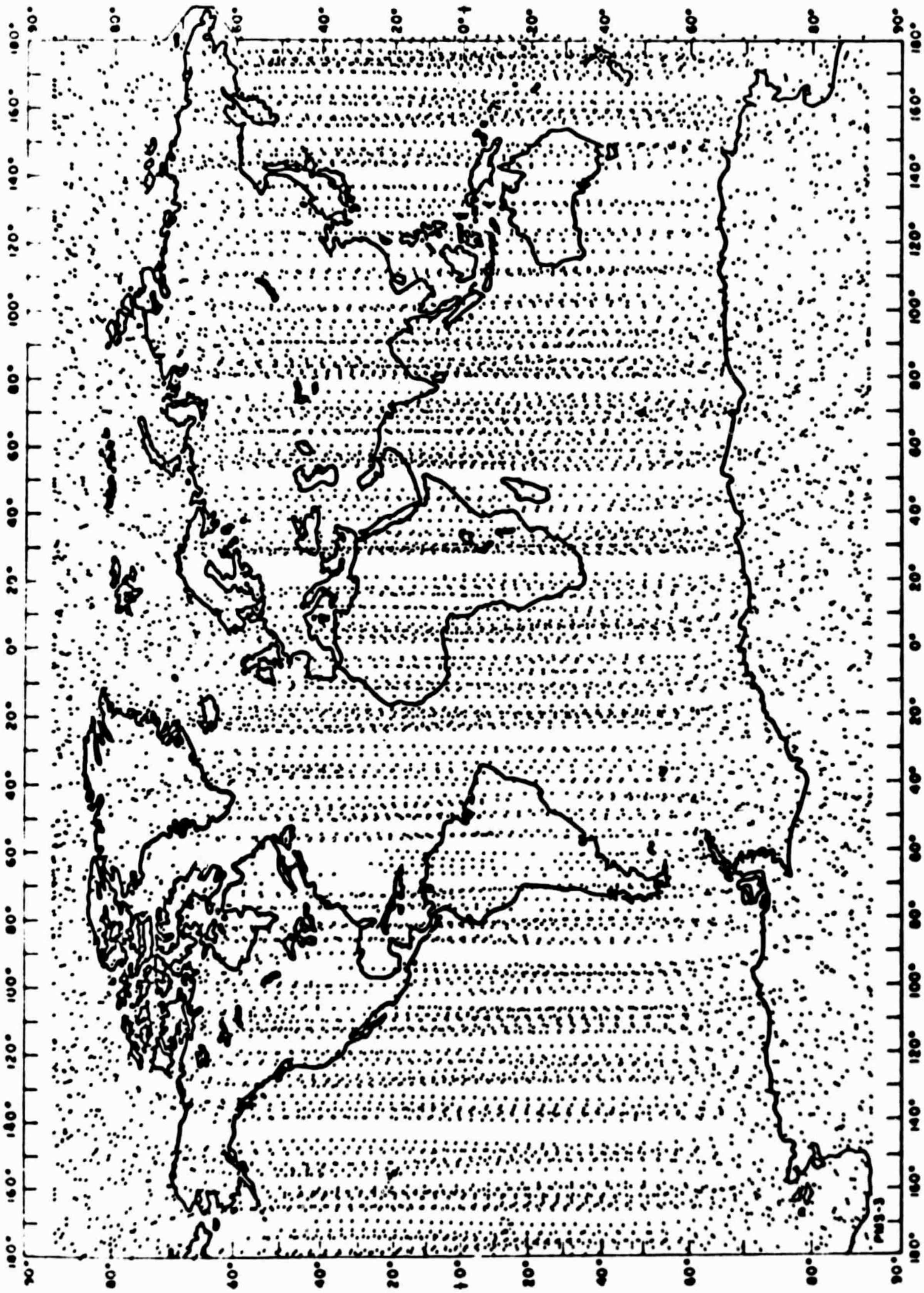
Satellite	Year	Date	Observations
OGO-2	1965	Oct 12	1209
		Oct 16	693
		Nov 10	904
		Nov 12	964
		Nov 14	1162
		Nov 16	827
		Dec 14	93
		Dec 15	79
		Dec 17	61
	1966	Jan 12	18
		Jan 14	312
		Jan 17	760
		Feb 1	752
		Feb 9	769
		Feb 14	521
		Feb 28	607
		Mar 2	145
		Mar 7	696
		Jun 11	27
		Jul 18	182
		Jul 25	261
		Jul 31	391
		Aug 1	394
		Aug 2	74
OGO-2	1966	Nov 22	241
		Nov 23	908
		Nov 25	819
		Nov 26	432
		Dec 9	927
		Dec 11	140
		Dec 12	998
OGO-4	1967	Jul 31	2318
		Aug 1	2598
		Aug 2	403

Note that OGO-2 data were sampled at 60 sec intervals ($\sim$ 400 Km) and OGO-4 at 30 sec intervals. Most data were taken when orbit planes were near twilight meridians.

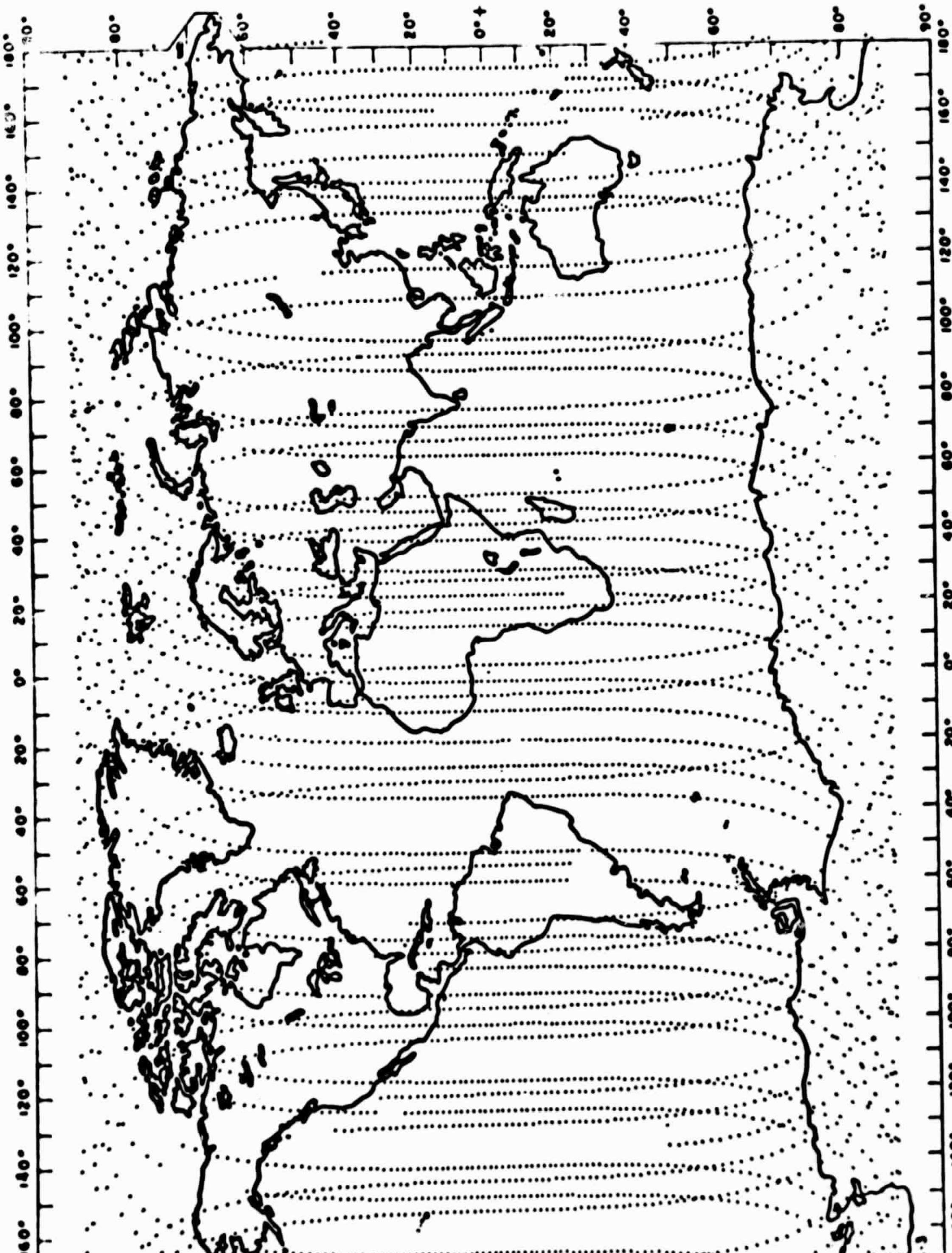


a) OGO-2 (1965)

FIGURE 4: <u>Positions of POGO Data Entering POGO(3/68) Model</u>.



b) OGO-2 (1966)



c) OGO-4 (1967)

TABLE 4

POGO(3/68) EPOCH 1965.0

DATA RANGE 1965.8 - 1967.6

n	m	g_n^m	h_n^m	$\dot{g}_n^m$	$\dot{h}_n^m$
1	0	-30338.5		26.23	
1	1	-2111.6	5769.7	4.68	-6.08
2	0	-1661.3		-23.26	
2	1	2999.1	-2011.4	2.27	-8.98
2	2	1595.4	123.1	11.79	-8.81
3	0	1301.5		-8.19	
3	1	-2042.7	-405.5	-9.26	10.71
3	2	1298.9	238.9	-0.80	2.63
3	3	856.1	-160.0	-10.99	0.77
4	0	955.1		-0.30	
4	1	802.9	152.3	-1.47	4.27
4	2	477.7	-275.3	-5.97	-0.85
4	3	-381.5	14.9	-6.30	2.88
4	4	254.5	-229.9	-3.35	-14.22
5	0	-222.4		3.80	
5	1	360.6	19.2	-0.54	-0.97
5	2	246.7	126.6	1.18	1.08
5	3	-32.9	-126.1	1.81	-4.47
5	4	-167.5	-98.0	-3.54	0.71
5	5	-53.9	75.8	1.16	-5.28
6	0	45.7		-0.35	
6	1	61.8	-10.8	0.94	-0.96
6	2	10.6	106.4	2.09	-0.51
6	3	-232.7	68.1	5.65	0.54
6	4	2.5	-44.5	0.61	1.98
6	5	-11.5	2.7	2.09	0.83
6	6	-143.6	-24.8	-3.92	0.12
7	0	71.6		-0.94	
7	1	-53.2	-63.0	0.04	-0.53
7	2	3.5	-26.7	0.08	0.83
7	3	14.3	-8.5	-0.78	0.46
7	4	-22.4	7.3	2.51	1.19
7	5	-5.5	23.7	0.44	1.18
7	6	11.5	-18.8	0.19	-0.56
7	7	-9.7	-18.9	1.37	1.92
8	0	9.8		0.44	
8	1	2.8	9.8	0.38	0.36
8	2	-4.4	-13.4	0.49	-0.22
8	3	-9.6	7.6	-1.53	-0.54
8	4	-4.7	-12.6	-0.62	-1.58
8	5	14.1	-1.3	-0.71	0.04
8	6	4.7	26.2	1.53	0.09
8	7	15.2	-10.0	0.37	-0.12
8	8	9.1	-10.5	-2.55	1.06
9	0	9.6		0.46	
9	1	7.4	-20.6	0.20	-0.82
9	2	1.8	17.0	-0.50	-0.95
9	3	-13.3	6.0	0.95	0.22
9	4	10.0	-2.1	-1.50	-0.27
9	5	2.0	-4.1	-0.51	-0.74
9	6	2.2	6.2	-0.98	0.80
9	7	5.7	11.3	-1.03	-0.71
9	8	2.7	-1.9	0.48	0.61
9	9	-1.5	-0.7	-1.54	2.09

TABLE 5

Distribution of Residuals of Data from POGO(3/68) Model

ΔF = F(measured) - F(computed)

ΔF Interval (γ)	0	-10	-20	-30	-40	-50	-60	-70
Data	7303	2477	725	173	46	14	3	

ΔF Interval (γ)	0	10	20	30	40	50	60	100
Data	8360	2376	521	166	69	11	8	

TABLE 6

RMS Deviations Between Evenly Selected POGO Data and Models

	Data		Residuals(γ)	
Spacecraft	Interval	No.	GSFC(12/66)	POGO(3/68)
OGO-2	1965.8 - 1966.0	2150	17	12
OGO-2	1966.0 - 1966.9	8573	29	18
OGO-4	1967.6 - 1967.7	2784	44	20

After having derived the POGO(3/68) fit for submission as an IGRF candidate, we also derived a more updated model. This was done with an improved set of 32,649 POGO observations. The resulting 143 internal spherical harmonic coefficients, labelled POGO(10/68) are listed here in Table 7. The improvements in the data set over that used for the earlier model include:

a) the use of data that are more completely processed (having fewer erroneous values);

b) extending the data selection for OGO-4 from launch through December, 1967;

c) selecting data from Kp = 0 or 0+ intervals (deleting those intervals following a disturbance which have high residual Dst) in place of whole selected quiet days; and,

d) utilizing more accurate orbital positions for the OGO-2 data.

The geographical distributions of data are very similar to those shown in Figure 4 except that the OGO-4 data coverage (August-December, 1967) is much more dense. Since the data were somewhat improved and the number of coefficients increased to 143, the residual of fit was reduced to 7γ with a percentage distribution as seen in Table 8.

TABLE 8

<u>Distribution of Residuals of POGO Data</u>
<u>(1965.8 - 1967.9 From POGO(10/68) Model</u>

$\lvert\Delta F\rvert\gamma$	0		10		20		30		40		70		100
%		85		13		2		.4		.2		.04	

TABLE 7

POGO(10/68) EPOCH 1960.0
DATA RANGE 1965.8 - 1967.9

n	m	g_n^m	h_n^m	$\dot{g}_n^m$	$\dot{h}_n^m$
1	0	-30465.0		25.42	
1	1	-2163.3	5791.0	9.88	-4.66
2	0	-1541.4		-23.90	
2	1	2976.3	-1977.2	3.50	-7.07
2	2	1607.5	156.6	-2.14	-10.70
3	0	1325.8		-5.59	
3	1	-1983.7	-445.3	-11.52	8.48
3	2	1316.9	233.4	-4.41	0.68
3	3	842.0	-94.9	2.87	-14.89
4	0	959.1		-0.62	
4	1	819.6	135.4	-2.51	3.45
4	2	486.4	-266.7	-1.22	-0.39
4	3	-372.4	20.7	-2.96	-0.87
4	4	256.2	-241.5	0.86	-6.52
5	0	-234.3		2.72	
5	1	357.7	16.9	0.48	0.05
5	2	233.9	113.3	3.17	3.00
5	3	-21.0	-128.7	-2.46	0.32
5	4	-147.1	-115.1	-0.89	3.11
5	5	-45.2	130.3	-3.15	-6.35
6	0	49.1		-0.61	
6	1	54.5	-9.6	1.06	-0.26
6	2	4.8	106.4	0.62	-0.48
6	3	-249.1	56.8	3.96	2.58
6	4	1.7	-27.2	-0.94	-0.80
6	5	-3.7	-14.9	1.49	0.50
6	6	-91.6	-4.3	-1.67	0.82
7	0	75.9		-0.89	
7	1	-52.4	-57.9	-0.21	-0.87
7	2	8.0	-25.0	-1.08	-0.46
7	3	10.0	-0.8	0.70	-1.02
7	4	-36.7	6.3	1.07	0.25
7	5	-8.3	9.5	0.9[illegible]	1.88
7	6	6.6	-11.7	1.01	-2.43
7	7	-22.7	-37.6	5.23	2.32
8	0	7.4		0.61	
8	1	6.0	10.1	-0.12	-0.15
8	2	-8.1	-13.0	0.87	-0.10
8	3	-9.2	11.5	-0.33	-1.22
8	4	-0.8	-16.4	-0.14	-0.26
8	5	9.1	5.5	-0.85	0.15
8	6	-11.4	22.3	0.99	-0.37
8	7	7.9	-4.9	0.81	0.29
8	8	35.1	-26.2	-4.98	0.91
9	0	11.0		-0.24	
9	1	6.6	-20.4	0.30	-0.38
9	2	1.8	14.4	0.04	0.16
9	3	-12.5	0.6	0.04	0.67
9	4	15.8	-1.5	-0.40	-0.14
9	5	1.7	1.4	-0.28	-0.83
9	6	2.6	3.4	-0.57	1.30
9	7	8.7	14.8	-1.32	-0.33
9	8	5.1	2.4	-0.14	-0.38
9	9	-2.4	-0.9	0.50	0.99
10	0	-2.6		-0.01	
10	1	-2.0	1.1	-0.09	0.21
10	2	1.0	0.9	0.12	0.05
10	3	-5.5	-0.3	0.19	0.54
10	4	-0.7	7.5	-0.20	-0.26
10	5	7.5	-2.3	-0.02	-0.30
10	6	7.8	1.4	-0.43	-0.03
10	7	1.7	-0.5	-0.33	-0.39
10	8	-5.3	4.3	1.03	-0.02
10	9	1.3	8.0	0.22	-1.04
10	10	-2.7	-13.7	0.46	0.79
11	0	2.3		0.03	
11	1	-1.8	-0.8	0.11	0.35
11	2	-2.1	4.4	0.05	-0.26
11	3	5.5	-0.1	-0.30	-0.17
11	4	-1.5	-3.9	0.01	0.17
11	5	2.4	-0.6	-0.34	0.18
11	6	-3.5	1.8	0.48	-0.50
11	7	-1.3	-3.2	0.52	0.23
11	8	2.5	0.8	-0.19	-0.34
11	9	-1.2	-5.9	-0.03	0.37
11	10	12.7	-1.7	-1.65	0.22
11	11	5.0	10.5	-0.40	-1.55

We have compared the fields computed from the POGO and GSFC(12/66) models to see how well they extrapolate into the future and to see if surface components can be derived in practice from only total field measurements. The difference between GSFC(12/66) and POGO(3/68) at the surface and at 1000 km altitude is given in Table 9. The root-mean-square (rms) is obtained by differencing values computed on a grid 10° in latitude and longitude but weighting according to the area of the grid block. The maximum value is thus the largest absolute difference found on this grid. Since the two models contained overlapping data in 1965, the differences for that epoch are likely symptomatic of their inherent errors. The growth by a factor of three of the differences by 1970 is indicative of the discrepancies in their secular change coefficients. Indeed, the satellite derived models reflect an annual decrease of the main dipole ($\dot{H}_0$) of 27γ whereas GSFC(12/66) predicts only 15γ/yr. Although it is not clear whether this increase in rate of dipole collapse is a true feature of the internal field or only a short-term effect possibly due to external causes (see, e.g., Chapman and Bartels, p. 134) such results as given by Table 6 show that the change is necessary to fit the recent data. It is not now possible to judge which of these two models more accurately describes the surface component field at recent epochs, since the latest component survey data is epoch 1963 and the coverage is far from global.

TABLE 9

Absolute Maximum and Root-Mean-Square Differences
In Field Computed From POGO(3/68) and GSFC(12/66) Models

Epoch	|Maximum|						rms					
	X^{γ}	Y^{γ}	Z^{γ}	D°	I°	F^{γ}	X^{γ}	Y^{γ}	Z^{γ}	D°	I°	F^{γ}
	1000 km Altitude											
1965	100	200	250	1.4	.7	50	28	45	60	.2	.2	16
1970	230	290	460	13.5	1.5	160	73	94	143	.5	.7	67
	Surface											
1965	320	570	710	2.3	1.3	200	80	120	160	.3	.3	50
1970	530	770	1180	6.6	2.6	470	170	210	310	.6	.6	140

As might be expected for fits performed with a nearly common data base, the two POGO models give more similar results. As seen in the top line of Table 10, at an altitude of 1000 km and epoch 1966, the total field difference is only 17γ maximum and 5γ rms. This small difference is expected because of the common data volume. However, one can also see on this line that the differences in field components are considerably higher than these figures which probably indicates that some of the previously mentioned systematic biases are affecting the results.

When the two POGO models are extrapolated to the earth's surface (lower half of Table 10) the differences between the components increase by a factor of three whereas those for the total field show a ratio of six. Extrapolating into the future at this level gives quite large differences by 1972.

TABLE 10

Maximum and Root-Mean-Square Differences In Field Computed From POGO(3/68) and POGO(10/68)

Epoch	|Maximum|						rms					
	X^γ	Y^γ	Z^γ	D°	I°	F^γ	X^γ	Y^γ	Z^γ	D°	I°	F^γ
	1000 km Altitude											
1966	90	180	260	1.7	.7	17	20	40	50	.2	.2	5
1968	110	210	320	2.6	.9	23	30	60	70	.2	.2	7
1970	170	370	490	3.0	1.1	43	50	80	100	.3	.3	13
1972	250	520	700	4.0	1.6	70	70	100	140	.4	.4	19
	Surface											
1966	290	610	780	1.5	1.4	100	70	120	150	.3	.3	30
1968	340	700	890	1.7	1.7	90	90	140	190	.3	.4	30
1970	470	930	1250	2.1	1.9	120	120	190	250	.4	.4	40
1972	690	1320	1810	3.3	2.6	150	160	240	320	.5	.6	60

Conclusions

The global survey of the magnetic field by the POGO spacecraft which began near the close of the IQSY is expected to continue into 1970. Inasmuch as there are no other comprehensive data, it is likely that the models resulting from fits to these data give the best available estimate of the field for the current epoch and for short extrapolations into the future. However, a truly accurate definition of the vector field and its secular change must yet include sorting out possible systematic biases in the data.

Comparing the POGO survey measurements with previously derived extrapolations based on earlier data makes it clear that to adequately follow the secular change irregularities, the satellite surveys need to be repeated at frequent intervals. These results indicate that a hiatus in measurements of more than a year could lead to errors at the earth's surface exceeding 1000γ.

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REFERENCES

Alldredge, L. R., and I. Saldukas, The automatic standard magnetic observatory, ESSA Tech. Bulletin No. 31 (Boulder, Colorado), June, 1966.

Allen, J. H., Long-term stability of self-oscillating rubidium magnetometers, J. Geomagnet. Geoelec., Kyoto, 20, 197-204, 1968.

Cain, Joseph C., Shirley J. Hendricks, Robert A. Langel, and William V. Hudson, A proposed model for the International Geomagnetic Reference Field-1965, J. Geomagnet. Geoelec., Kyoto, 19, 335-355, 1967a.

Cain, J. C., R. A. Langel, and S. J. Hendricks, First magnetic field results from the OGO-2 satellite, Space Res. 7, 1466-1476, North-Holland, Amsterdam, 1966.

Cain, Joseph C., and Shirley J. Cain, Derivation of the International Geomagnetic Reference Field [IGRF(10/68)], GSFC Report X-612-68-501, 1968.

Chapman, S., and J. Bartels, Geomagnetism, Oxford University Press, London, 1940.

Farthing, W. H., and W. C. Folz, Rubidium vapor magnetometer for near earth orbiting spacecraft, Rev. Sci. Instr. 38, No. 8, 1023-1030, August 1967.

Heppner, James P., The world magnetic survey, Sp. Sci. Rev. 2, 315-354, 1963.

Langel, Robert A., A representation of the perigee motion of a satellite as a function of local time, GSFC Report X-612-67-34, February, 1967.

Ludwig, G. H., The Orbiting Geophysical Observatories, Sp. Sci. Rev. 2, 175, 1963.

Sugiura, Masahisa, Hourly values of equatorial Dst for the IGY, Annals of the International Geophysical Year, 35, Part I, 9-45, 1964.

Sugiura, M., T. L. Skillman, B. G. Ledley, and J. P. Heppner, Magnetic field observations in high beta regions of the magnetosphere, GSFC Report X-612-69-359, August 1969.

Vestine, E. H., The survey of the geomagnetic field in space, Trans. Am. Geophys. Union, 41, 4-21, 1960.

Vestine, E. H., Instruction manual on World Magnetic Survey, IUGG Monograph 11a, August 1961.