R-21-009-004

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
SILVER SPRING, MARYLAND

THE SCALAR MAGNETIC INTENSITY AT 1100 KILOMETERS IN MIDDLE AND LOW LATITUDES*

A. J. Zmuda, W. E. Radford, F. T. Heuring, and P. Verzariu

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) $3.00

Microfiche (MF) .65

ff 653 July 65

The Applied Physics Laboratory
The Johns Hopkins University
Silver Spring, Maryland

September 1967

N68-11591
(ACCESSION NUMBER) (THRU)
28 (PAGES)
1 (CODE)
CR-90522 (NASA CR OR TMX OR AD NUMBER)
13 (CATEGORY)
[redacted]
FF No. 602(A)

*This work was supported by the Naval Ordnance Systems Command, Department of the Navy, under Contract NOw-62-0604-c, by the National Aeronautics and Space Administration, and by the Air Force Cambridge Research Laboratories.

ABSTRACT

With a Varian Rb-85 magnetometer, satellite 1964 83C measured the scalar magnetic intensity in middle and low latitudes at about 1100 km altitude. The differences between observed and computed values show quasi-sinusoidal spatial variations indicative of errors in the harmonic coefficients with $n \approx 3$, $m \approx 4$, and $m \approx 6$. The isodynamic lines in the South Atlantic anomaly form closed loops around a center at 20° S and 45° W. In the recovery phase of the storm of 1312 UT April 17, 1965, a decrease in intensity occurs which is comparable to the decrease at the earth's surface.

INTRODUCTION

Satellite observations of the geomagnetic intensity are of interest in a number of geophysical problems which include field mapping [Cain et al, 1962; Heppner et al, 1963; Cahill and Amazeen, 1963; Ness et al, 1964; Hagg, 1964; Ness, 1965; Dolginov et al, 1966; Muzzio et al, 1966; Konovalova and Nalivaiko, 1967; Cain et al, 1967; Heppner et al, 1967]; evaluation of analytic descriptions [Heuring, 1964, 1965; Cain et al, 1965; Fougere, 1965; Cain, 1966; Cain et al, 1967]; the world magnetic survey [Vestine, 1960; Heppner, 1963];

It is the purpose here to discuss magnetic results obtained with the Navy satellite 1964 83C launched on December 13, 1964, into an orbit with inclination 89.992°; period 106.2 minutes; perigee, 1040 km; apogee, 1089 km. The satellite contains a telescope-photometer sensitive to far ultraviolet radiation [Smith, 1966] and a Varian Rubidium-85 vapor magnetometer.

Some Satellite Characteristics

The Varian Associates Rb-85 vapor magnetometer consists of an electronics module placed inside the satellite body and a sensing head and lamp oscillator mounted near the far end of an extendable boom. Zero crossings of the magnetometer output are counted for 0.0819265 second during each 0.65536 second, periods when the satellite traverses essentially latitudinal arcs of respective lengths 0.6 and 4.8 km. The magnetometer frequency f in Hz relates to magnetic intensity F in oersted by $F = f/(4.667393 \times 10^5) - 1.34 \times 10^{-15} f^2$ [R. L. Driscoll, communicated to L. R. Alldredge and I. Saldukas, 1963].

The satellite contains a permanent Alnico V magnet with moment $M_m = 1.475 \times 10^5$ gauss cm^3 and a calibration magnet M_c with a reversible moment of magnitude 6.85×10^3 gauss cm^3. The complete calibration circuit consists of a voltage source, a capacitor, reversing and charging switches, and coil around a core of $3\frac{1}{2}$ percent chrome steel. Upon command the capacitor charges to a present level, then discharges through the coil to magnetize the steel core, with the direction of the moment altered in successive commands but either parallel or anti-parallel to that of the main magnet.

The satellite is magnetically stabilized; that is, geomagnetic torques align the magnetic axis of the satellite along the local field direction. The optical axis of the magnetometer sense head makes an angle of 45° with the satellite magnetic axis, so that data are potentially receivable (1) at the maximum signal-to noise ratio and (2) throughout the orbit with only one magnetometer. The head attaches near the end of a gas-actuated, telescoping boom manufactured by the Raymond Engineering Laboratories of Middletown, Connecticut, and used as an antenna on Project Mercury capsules. In its non-telescoped configuration the boom forms an aluminum tube 60.96 cm long and 5.08 cm outside diameter and contains 12 tubular sections with tapered forward and flared back ends that wedge together when fully extended to form a boom of length 4.88×10^{2} cm (16 feet). In the launch configuration a lock of biphenyl holds the sense head rigidly to the boom housing. With the satellite in orbit, the biphenyl sublimes and a spring pushes the lead boom-segment (to which the sense head is connected) out of the boom housing, an action subsequently confirmed by telemetry from the orbiting satellite.

In a view from the satellite body towards the far end of the fully extended boom and along the boom axis, the center of the calibration magnet lies 11.43 cm to the right, 19.0 cm downward and 5.75×10^{2} cm away from the magnetometer. The corresponding distances from the center of the main magnet are 15.1 cm to the left, 11.6 cm downward, and 5.79×10^{2} cm away. In orbit the boom leads the satellite body and points, for example, downward over the north magnetic pole.

Radford (1967) gives an additional discussion of satellite characteristics. We are indebted to F. F. Mobley of APL/JHU for the design and implementation of the calibration system and of the means to contain and then extend the boom (some aspects of which are also discussed in the succeeding section).

Field of Satellite Magnets

Two provisions were made for an in-flight determination of the field at the magnetometer due to the satellite magnets. This contribution depends on the length to which the boom extends and must be subtracted from the observations to yield the geomagnetic intensities.

As earlier noted, the boom is launched in its collapsed configuration. After achievement of orbit, sublimation of the biphenyl lock, and the movement of the first boom section out of the housing, a squib fires upon ground-station command and ignites a JETEX cartridge to power the extension of the remainder of the boom. If each boom section had wedged completely into the adjacent section, then for full-boom extension, the electrical resistance of the boom would have dropped to that of a short circuited condition. We received no telemetry signal that this form of contact actually occurred. Thus, the ultimate boom extension was determinable solely by means of the in-flight values from the calibration magnet, with a moment known from preflight tests.

The observed intensity consists of the contribution from the satellite magnets and that from the (much larger) geomagnetic field. Considering the scalar intensity Rb-vapor magnetometer, the satellite components of importance are those either parallel or anti-parallel to the local geomagnetic field direction. For these components and large magnet-to-magnetometer separations, which include those of present concern, the relationship $F_c/F_m = M_c/M_M$ holds independent of this distance, where F_c and F_m are the component values from the calibration and main magnets of respective moments M_c and M_m: an advantage suggested to us by Dr. George Weiffenbach of APL/JHU. (The experimental arrangement closely approximates the limiting case of two coincident magnets.)

Thus with M_c/M_m known beforehand, an in-flight determination of F_c leads to F_m without an independent measure of boom extension beyond determining from the value of F_c that the magnet-to-magnetometer distances are sufficiently large. The quantity $F_m \pm F_c$ represents the bias field from the satellite; F_m always adds to the geomagnetic field but F_c may add (+) or subtract (-), depending on the (reversible) orientation of M_c.

Figure I shows examples of the extremes in the quality of the raw data obtained in the 29 in-flight calibrations. Upon command from the ground station at APL/JHU the direction of the moment M_c reverses at which time transients often appear and persist for a period of about two seconds. However, the values for the epoch preceding the moment-reversal and for that following the transient have a nearly constant slope of about 11 zero crossings per counting interval per unit change in the sequence number (or 14.4γ per second of satellite transit). The constancy lightens considerably the still difficult in-flight calibrations and stems from the constancy of the spatial gradient of the field encountered as the satellite traverses the area near the command ground station. The data for each of these two epochs are extrapolated to the time of moment reversal where the difference between the two sets equals 2 F_c.

In this manner the in-flight value of 2 F_c at the magnetometer position was determined to be 13.6 ± 1.2 crossings per counting interval, or 17.8 ± 1.6 γ; the related value for F_m becomes 192 ± 17 γ. We conclude that for perfect magnet stabilization the total bias field at the magnetometer is 201 ± 18 γ when F_m and F_c add and 183 ± 18 γ when F_m and F_c oppose, (the uncertainty being a relatively small part of the geomagnetic intensity, which ranged from about 15,000 to 31,000 γ). From the known relationship between M_c and F_c, the value of 17.8 γ for 2 F_c shows that the separation along the boom axis between the center of the calibration magnet and the magnetometer is 5.39×10^2 cm or 36 cm less than that expected for full-boom extension in which case 2 F_c would equal 14.4 γ (and F_m,154 γ). Detailed examination of the data passes gives no indication that the boom is not rigid in this state; for example, there is no field modulation even suggestive of a movement of the magnetometer towards and away from the satellite body.

The satellite contains a Schonstedt fluxgate magnetometer (one of three) which shows that the satellite magnetic axis oscillates about the local field direction in an angular range lying mainly between 0° and 20° and averaging about 10°. This deviation makes the instantaneous satellite bias field ($F_m \pm F_c$) cos θ where the angular factor has values varying from 1 for perfect magnetic alignment to 0.94 for a misalignment of 20°.

Results

The satellite telemetered a total of 350,000 useable data points to a network of sixteen stations from those in the following groups: TRANET, Atlantic and Pacific Missile Range and NASA STADAN. Power and voltage limitations confined the data periods inside the intervals December 13 to 31, 1964, and April 10 to June 26, 1965, and relatedly to the local time epochs 0300-0800 and 1500-2000. Observations exist for four storms, a mixture of smaller disturbances, and undisturbed conditions; but we here treat morning non-stormtime measurements as a group and the data for the storm of April 17. In a companion paper Heuring et al [1967] consider these non-stormtime data in relation to harmonic coefficients being proposed for an International Geomagnetic Reference Field. In addition studies are in progress on the other storms as well as on temporal variations at satellite altitude and their connection to surface intensities.

The data refer to middle and low latitudes as a design shortcoming precluded meaningful observations for higher latitudes. In the two days allotted for preflight testing of the magnetic elements as part of the entire satellite, the unit operated in a test field of 18,000 γ. It turned out in flight that intensities $> 31{,}000\gamma$ were unmeasurable. In the regions where these values would normally occur, the magnetometer-counter output corresponded to field values considerably less and was marked by large fluctuations-- oscillations of 500 to 1000 γ amplitude about a mean of 10,000 to 15,000 γ were not uncommon.

We could not conclusively determine the reason for this high-field limit but note our best estimate, obtained with the aid of some spare components. With increasing field values the magnetometer frequency increases but the signal magnitude decreases while the threshold of detectability in the counting circuits rises. These characteristics combined could have producedthe property that intensities > 31, 000 γ would appear as fluctuating field values of considerably lower magnitude. We emphasize that these data are readily recognized as highly anomalous and eliminated from further analysis; Radford [1967] gives some examples.

For a fixed latitude the observations lie within the geocentric radial range 7405 and 7465 km (see Fig. 2) and within a set of narrow longitudinal bands. The data distribution permits an easy computation of spatial gradients and a reduction to a single geocentric distance which equals 7450 km for the lines of constant magnetic intensity shown in Figure 3. With the earth's surface as a spheroid of semi-major axis 6378.4 km and flattening 1/297, the geocentric distance of 7450 km corresponds to a height above the surface in the range, for example, from 1072 km at 0° latitude to 1077 km at 30°. In the area called the South Atlantic (or Brazilian, or South American) magnetic anomaly, many of the lines form either closed loops or segments of what would probably become a closed loop, with the center (a field minimum) of the entire system at about 20° S and 45° W, slightly different from the center at 350 and 450 km ($\approx$ 23° S and $\approx$ 47° W) determined by Konovalova and Nalivaiko [1967] with Cosmos 26 and 49 data. We agree with Konovalova and Nalivaiko that a single minimum exists in the anomaly, in opposition to the double minimum at 1000 km reported in a preliminary study by Muzzio et al [1966] using a combination of electron gyrofrequency resonances and magnetic data.

With intensities and spatial gradients from 1964 83C field values were computed for some locations where observations exist from Satellite 1965 81A [J. C. Cain, personal communication]. These calculations required extrapolations on interpolations for radial distances separated by 2 to 66 km and longitudes by 0° to 5°. Table I shows the good agreement between the two groups: the differences lie between 1 and 86 γ and average 35 γ.

Comparison with Computed Intensities

It is well known that the geomagnetic field of internal origin has a potential V given for points above the surface by a series of spherical harmonic.

$$V = a \sum_{n=1}^{n=\infty} \sum_{m=0}^{m=n} \left[\frac{a}{r}\right]^{n+1} P_n^m (\cos\theta) \left[g_n^m \cos m\lambda + h_n^m \sin m\lambda\right]$$

where a is a mean radius; r, the geocentric distance; θ, the colatitude; λ, the east longitude; P_n^m, a semi-normalized associated Legendre function introduced by Schmidt and of degree n and order m; g_n^m and h_n^m, harmonic coefficients. The field components are given by $X = (1/r)\partial V/\partial\theta$,

$Y = -(1/r \sin\theta)\, \partial V/\partial\lambda$, and $Z = \partial V/\partial r$; the scalar magnetic intensity F equals $[X^2 + Y^2 + Z^2)^{\frac{1}{2}}$.

Since each harmonic set invariably has some error, it is always desirable to test an analytic description with a new set of observations and we here consider the data from satellite 1964 83C in relation to the GSFC 4/64 coefficients of J. C. Cain, D. C. Jensen, W. E. Daniels and S. Hendricks [J. C. Cain, personal communication] updated to 1965.0, a series of 63 coefficients for the main field and 35 for the secular variation. Values of the scalar magnetic intensity computed with these harmonics, hereafter called the theoretical field F_T, are compared with our satellite geomagnetic observations, say F_G, and discussed in terms of the difference or residual $\Delta = F_G - F_T$.

We find no radial dependence for the residual, so that the Δ's represent changes with latitude and/or longitude at essentially any fixed height in the geocentric span 7505-7465 km. Figure 4 shows the resultant curves drawn through Δ values for integral latitudes spaced one degree apart; the longitudes for the end points are listed and for intermediate points could be linearly interpolated. This variation of the residual is primarily a latitudinal effect and often has a quasi-sinusoidal form of 60° angular periodicity, which considering the structure of the P_n^m's indicates that the harmonic coefficients $n \approx 3$ need correcting. The longitudinal variation also often has a quasi-sinusoidal form which for latitudes $\leq -20^\circ$ has a periodicity of about 60° and for latitudes $\geq -10^\circ$, one of about 90° (see Fig. 5). This form indicates errors in the coefficients with $m \approx 6$ (for the 60° variation) and with $m \approx 4$ (for the 90° variation), considering the associated trigonometric functions. For the total region, the residuals lie mainly between +100 γ and -100 γ and have an rms of 88 γ.

Attempts to correct harmonic coefficients are deferred until we complete determining residuals for the other analytic descriptions being considered to form part of a recommendation on a temporary International Geomagnetic Reference Field by the IAGA working group on the Analysis of the Geomagnetic Field. It is worth emphasizing, however, that the present results show a spatial structure in the residuals which indicates the need for modication of certain harmonic coefficients in the existing set, residuals not likely to be reduced by the addition of terms and coefficients beyond those already present. This aspect is important since a prime question on an IGRF relates to the number of harmonic terms it should contain. Additional evaluation of harmonic sets is contained in the paper by Heuring et al [1967], from which we note that the present theoretical field would rank right after the best of the six others considered by Heuring et al (88 γ to 67 γ in the rms difference), with the difference likely to be narrowed by applying the characteristics found here.

Storm of 1312 UT April 17

Figures 6a and 6b each show residuals at integer latitudes for a set of two data passes that traverse similar regions of space. In accord with an earlier discussion the residuals have a latitudinal variation indicative of errors in a few harmonic coefficients. Note however that each stormtime (recovery-phase) group of Δ-values lies considerably below its non-stormtime counterpart. This lowering re-results from a decrease in the total geomagnetic intensity (F_G) due primarily to the superposition of an oppositely-directed horizontal storm-field on the main geomagnetic field, considering the changes detectable with a scalar magnetometer and the direction of the main field in the equatorial region.

The stormtime decrease reaches 46 γ for the pass of 1644 UT April 19 and 60 γ for that of 2351 UT April 19 where there also are temporal variations near the dipole equator and where each of these passes is considered with respect to its non-stormtime complement. These diminutions compare favorably with those of (surface) Dst (H) for corresponding times - 47 and 56 γ respectively (see Fig. 7) and the similarity shows that the storm ring current lies considerably above the satellite position, which at the equator has a value of McIlwain's shell parameter L = 1.17. Thus our data are in accord with but also add a little to one of Cahill's [1966] findings for this storm: that the ring current during the recovery phase has its maximum on the McIlwain shell parameter L = 3.5 with reduced effects down to at least L = 2.

In relation to the data in Figure 6a we examined the magnetograms for Huancayo, Peru, at the dipole equator and at 285° E. For the period between the satellite equatorial passages, the Huancayo decrease in the horizontal component equalled 45 γ, practically that (42 γ) in F at the equator at the satellite altitude. Thus, in this case, at 1944 local time, the evening ionosphere below the satellite has essentially no effect on the disturbance field in the recovery phase of the storm.

Table I. Intensities from Two Satellites

Position			Intensity, γ		Intensity difference γ
S. Lat. °	E. Long. °	Geocentric distance km	1965-81A	1964-83C	
17	319.1	7444.5	16063	16062	1
11	319.1	7385.9	16774	16757	17
16	35.2	7435.5	21023	20993	30
17	264.2	7456.2	18894	18855	39
11	140.1	7378.5	28134	28048	86

Figure Captions

1. Examples of data obtained during in-flight calibrations of the satellite magnetic field at the magnetometer position.
2. Some values of the observed geomagnetic intensity.
3. Isodynamic lines at a geocentric distance of 7450 km with the intensity values in units of 1000 gammas, and the locations of the ground stations.
4. The latitudinal variation of the field residuals.
5. The longitudinal variation of the field residuals.
6. The field residuals for stormtime and non-stormtime passes. The longitude and altitude of each end point are also noted.
7. Dst (H) values for the storm of 1312 UT April 17, 1965, and the times of some low-latitude passes of satellite 1964 83C

REFERENCES

Alldredge, L. R. and I. Saldukas, An automatic standard magnetic observatory, publication of U. S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., August 1963.

Cahill, L. J., and P. J. Amazeen, The boundary of the geomagnetic field, J. Geophys. Res. 68, 1835-1844, 1963.

Cahill, L. J., Inflation of the inner magnetosphere during a magnetic storm, J. Geophys. Res. 71, 4505-4519, 1966.

Cain, J. C., I. R. Shapiro, J. D. Stolarik, and J. P. Heppner, Vanguard 3 magnetic field observations, J. Geophys. Res. 67, 5055-5069, 1962.

Cain, J. C., W. E. Daniels, S. J. Hendricks, An evaluation of the main geomagnetic field, 1940-1962, J. Geophys. Res. 70, 3647-3674, 1965.

Cain, J. C., Models of the earth's magnetic field, "Radiation trapped in the earth's magnetic field" ed. by B. M. McCormac, D. Reidel Publishing Company, Dordrecht-Holland, 7-25, 1966.

Cain, J. C., R. A. Langel, and S. J. Hendricks, First magnetic field results from the OGO-2 satellite, Space Res. 7, 1466-1476, 1967.

Dolginov, Sh. ,   Y. G. Yeroshenko, and L. N. Zhuzgov, Investigation of the earth's magnetosphere in the region of the radiation belts ($3 - 6\ R_E$) in February-March 1964, Space Res. 6, 790-809, 1966

Fougere, P. F., Spherical harmonic analysis 2. A new model derived from magnetic observatory data for epoch 1960.0, J. Geophys. Res. 70, 2171-2179, 1965.

Hagg, E. L., in I. G. Bulletin No. 79, January 1964, prepared by F. T. Davies, Trans. Am. Geophys. Union, 45(1), 221-227, 1964.

Heppner, J. P., N. F. Ness, C. S. Scearce, and T. L. Skillman, Explorer 10 magnetic field measurements, J. Geophys. Res., 68, 1-46, 1963.

Heppner, J. P., The world magnetic survey, Space Sci. Rev. 11, 315-354, 1963.

Heppner, J. P., M. Sugiura, T. L. Skillman, B. G. Ledley, and M. Campbell, OGO-A magnetic field observations, Goddard Preprint X-612-67-150, submitted to J. Geophys. Res. 1967.

Heuring, F. T., the analytic description of the geomagnetic field at satellite altitudes, J. Geophys. Res. 69, 4959-4968, 1964.

Heuring, F. T., Comparison of some recently defined geomagnetic field models to the Vanguard 3(1959 η) data, J. Geophys. Res. 70, 4968-4971, 1965.

Heuring, F. T., A. J. Zmuda, W. E. Radford and P. Verzariu, an evaluation of geomagnetic harmonic descriptions for 1100 km altitude, submitted to J. Geophys Res., September 1967.

Konovalova, L. V. and V. I. Nalivaiko, Magnetic chart of the Brazilian Anomaly, Geomagnetism and Aeronomy, 7, 394-395, 1967.

Muzzio, J. L. R., P. R. Mardo, F. De Mendonca, Measurements of the earth's total magnetic field at heights of 1000 km in the Brazilian anomaly, Space Res. 6, 217-221, 1966.

Ness, N. F., C. S. Scearce, and J. B. Seek, Initial results of the IMP I magnetic field experiment, J. Geophys. Res. 69, 3531-3569, 1964.

Ness, N. F., Earth's magnetic field: a new look, Science 151, 1041-1052, 1965.

Radford, W. E., the 5E-5 Rubidium-85 vapor magnetometer, TG-890, the Johns Hopkins University, Applied Physics Laboratory, February 1967.

Smith, A. M. Stellar photometry from a satellite vehicle, The Astrophysical Journal, 1 (1), 158-171, 1967.

Vestine, E. H., The survey of the geomagnetic field in space, Trans. Am. Geophys. Union, 41, 4-20, 1960.

ACKNOWLEDGMENT

We gratefully acknowledge the contribution of members of the Space Development Department of APL/JHU, particularly Dr. C. O. Bostrom, project scientist; J. Dassoulas, project engineer; S. J. Kowal, payload engineer, Dr. G. C. Weiffenbach, F. Mobley, R. E. Cashion, S. Favin, E. Fyler. We also gratefully acknowledge the use of the Magnetic Test Facility of the Naval Ordnance Laboratory, White Oak, Maryland.

This work was supported by the Naval Ordnance Systems Command, Department of the Navy under Contract NOw-62-0604-c, by the National Aeronautics and Space Administration, and by the Air Force Cambridge Research Laboratories.

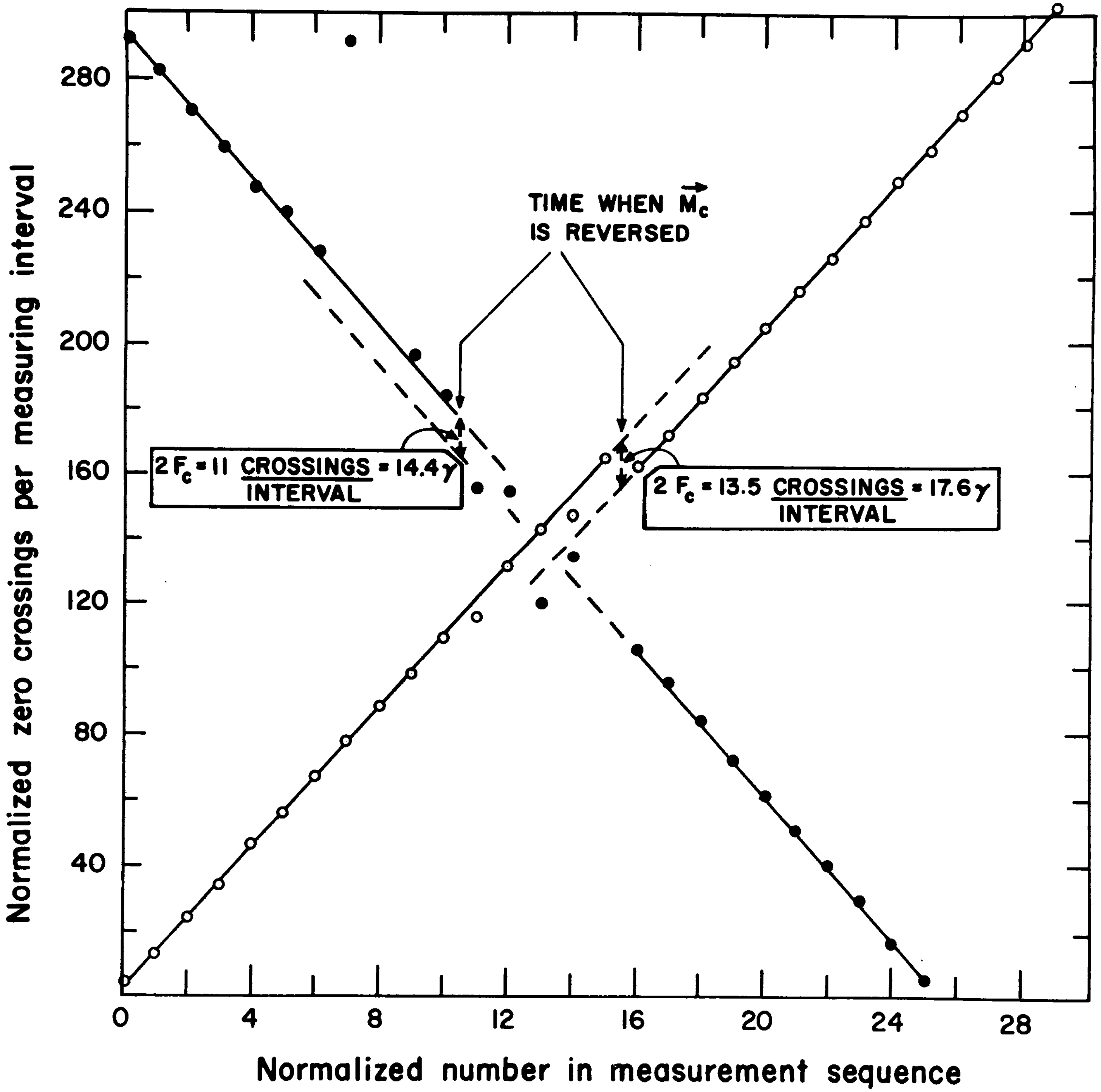

TIME WHEN $\vec{M_c}$ IS REVERSED
$2 F_c = 11 \frac{\text{CROSSINGS}}{\text{INTERVAL}} = 14.4\gamma$
$2 F_c = 13.5 \frac{\text{CROSSINGS}}{\text{INTERVAL}} = 17.6\gamma$
Normalized zero crossings per measuring interval
40
80
120
160
200
240
280
0
4
8
12
16
20
24
28
Normalized number in measurement sequence

Fig 1

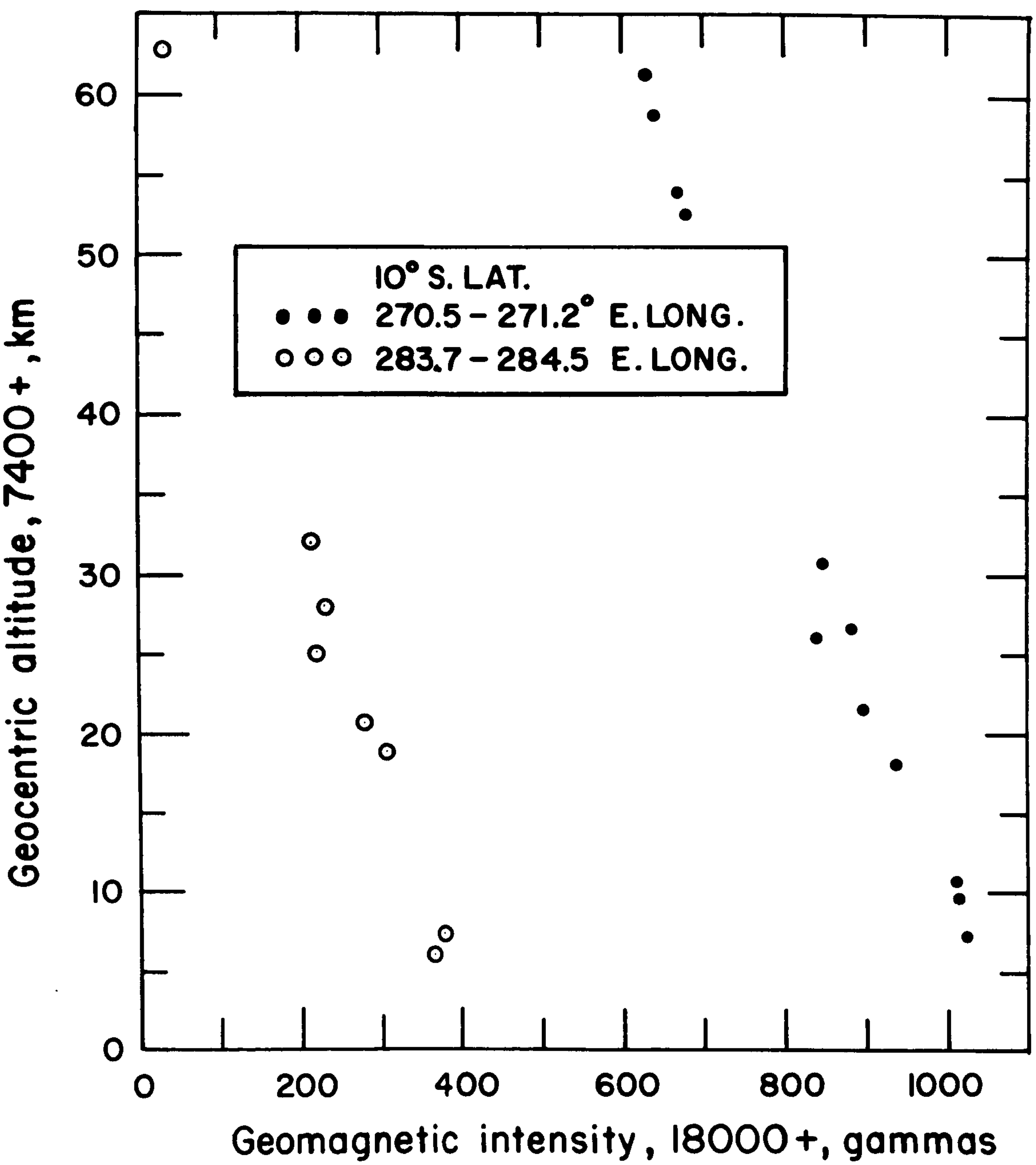
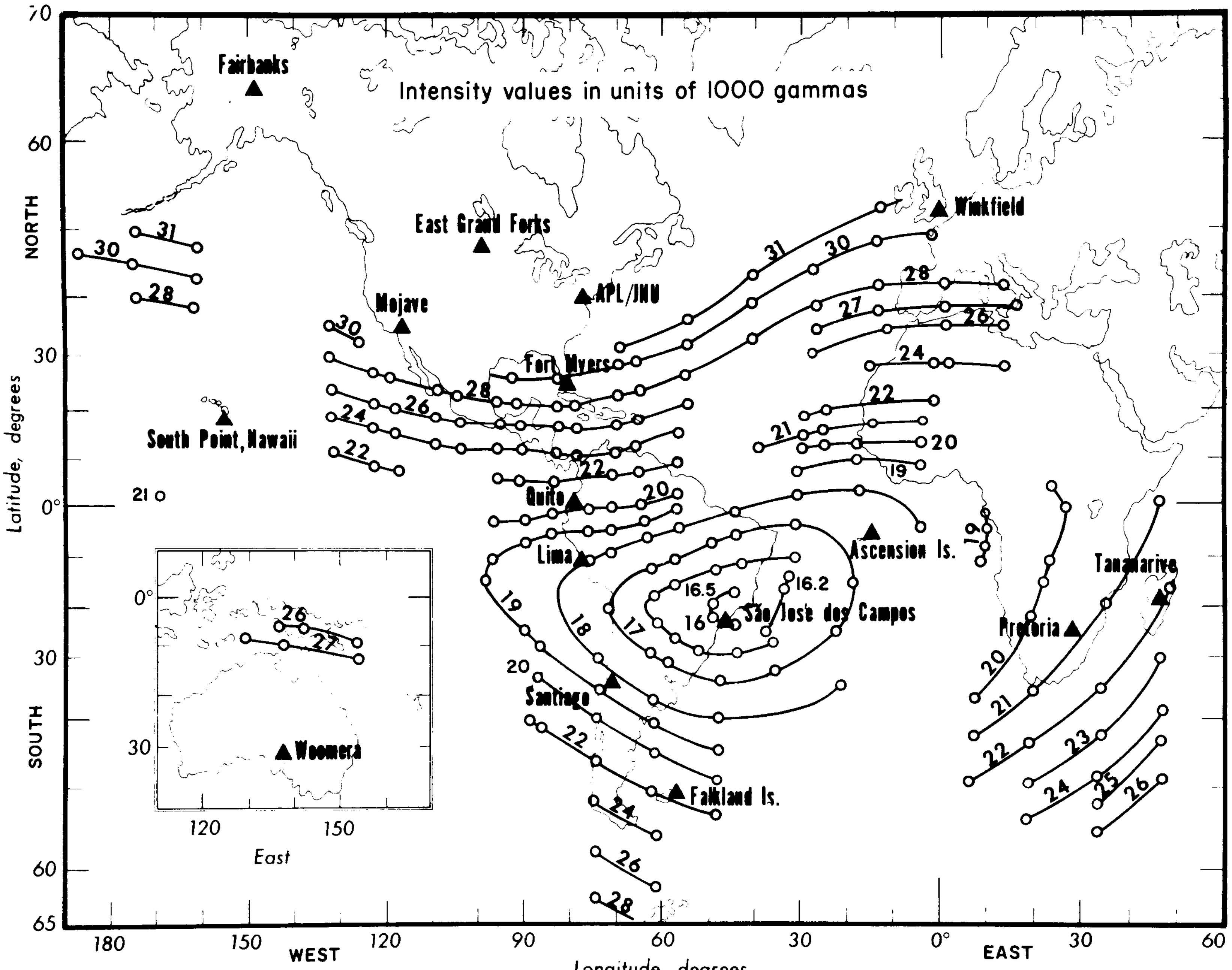
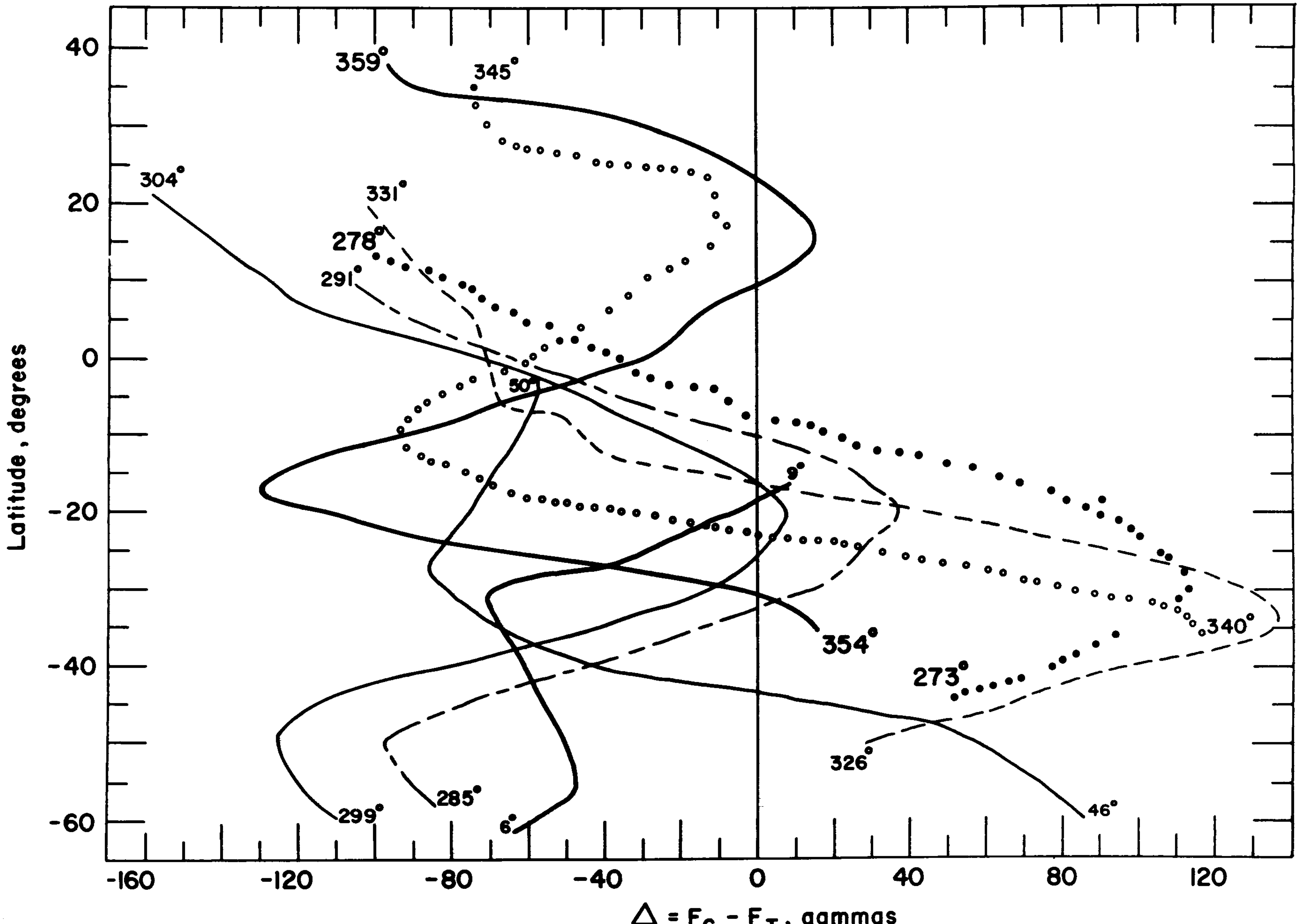

10° S. LAT.
270.5 - 271.2° E. LONG.
283.7 - 284.5 E. LONG.
Geocentric altitude, 7400+, km
Geomagnetic intensity, 18000+, gammas
0
10
20
30
40
50
60
0
200
400
600
800
1000

Fig 2



Intensity values in units of 1000 gammas
Fairbanks
East Grand Forks
Mojave
APL/JHU
Fort Myers
Winkfield
South Point, Hawaii
Quito
Lima
Santiago
Falkland Is.
São José dos Campos
Ascension Is.
Pretoria
Tananarive
Woomera
East
Latitude, degrees
NORTH
SOUTH
Longitude, degrees
WEST
EAST

Fig 3



40
20
0
-20
-40
-60
Latitude , degrees
-160
-120
-80
-40
0
40
80
120
$\Delta = F_G - F_T$, gammas
359°
345°
304°
331°
278°
291°
50°
9°
354°
340°
273°
326°
46°
299°
285°
6°

Fig 4

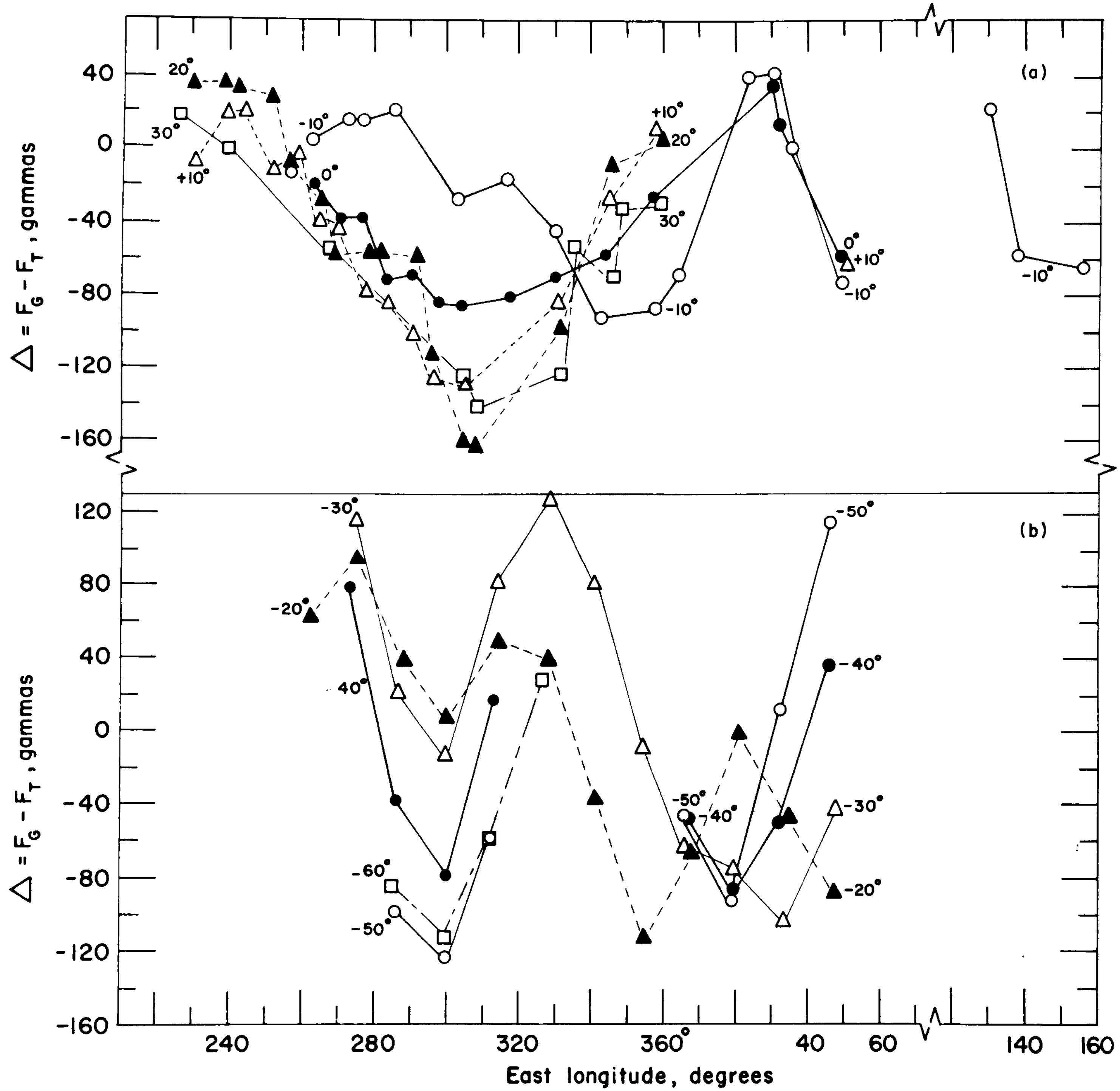
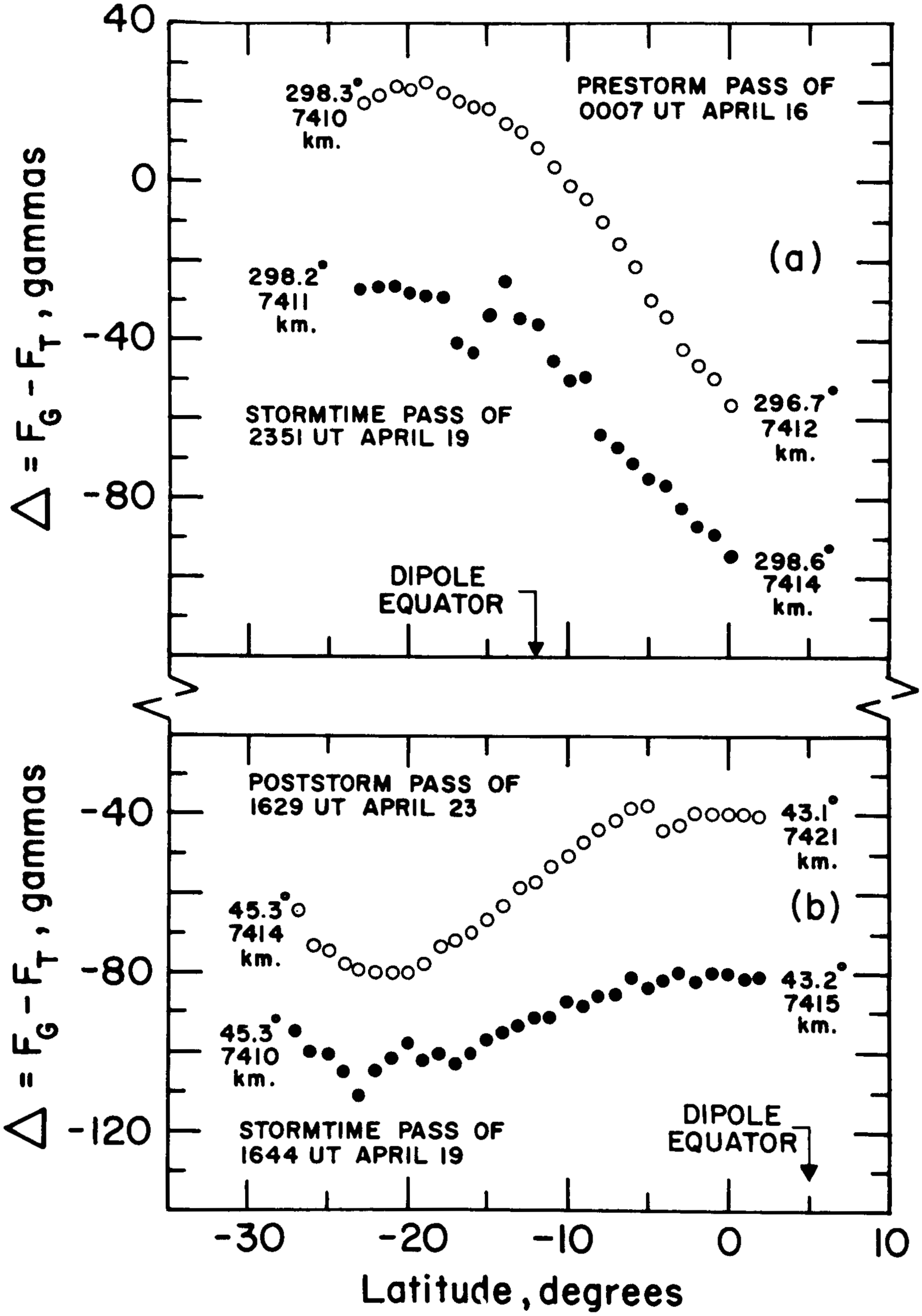
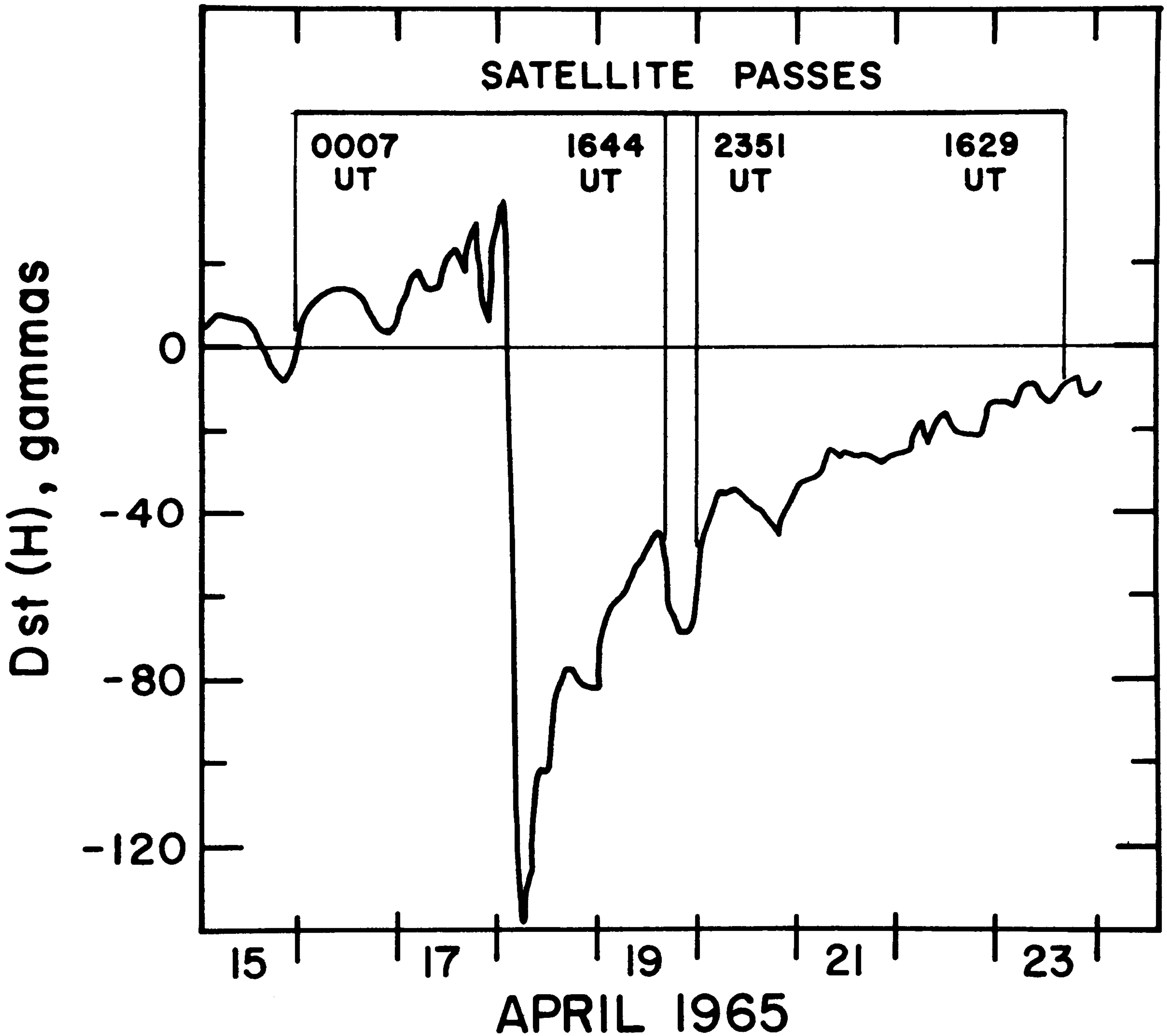

(a)
(b)
$\Delta = F_G - F_T$, gammas
East longitude, degrees
40
0
-40
-80
-120
-160
120
80
240
280
320
360°
40
60
140
160
20°
30°
+10°
-10°
0°
-50°
-40°
-30°
-20°
-60°
40°

Fig 5



PRESTORM PASS OF
0007 UT APRIL 16
298.3°
7410
km.
298.2°
7411
km.
(a)
STORMTIME PASS OF
2351 UT APRIL 19
296.7°
7412
km.
298.6°
7414
km.
DIPOLE
EQUATOR
POSTSTORM PASS OF
1629 UT APRIL 23
43.1°
7421
km.
45.3°
7414
km.
(b)
43.2°
7415
km.
45.3°
7410
km.
STORMTIME PASS OF
1644 UT APRIL 19
DIPOLE
EQUATOR
40
0
-40
-80
-120
$\Delta = F_G - F_T$, gammas
-30
-20
-10
0
10
Latitude, degrees

Fig 6



SATELLITE PASSES
0007 UT
1644 UT
2351 UT
1629 UT
Dst (H), gammas
0
-40
-80
-120
15
17
19
21
23
APRIL 1965

Fig 7