Technical Note 1

MIDDLE-LATITUDE CHANGES IN TOPSIDE ELECTRON DENSITY THROUGH A MAGNETIC STORM

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Prepared for:

NASA-AMES RESEARCH CENTER
MOUNTAIN VIEW, CALIFORNIA

CONTRACT NAS 2-2112

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ABSTRACT

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Contours of electron density, as measured by the Alouette satellite, are drawn for the middle latitudes for three days in June 1963 during which a magnetic storm occurred. The changes in the patterns at local noon are discussed in terms of a two-dimensional curve fit of a separable function of height and latitude for 25° to 45°N.

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I INTRODUCTION

Several papers have discussed the characteristics of the data received from the Alouette satellite.[1,2*] Contours of electron density or of plasma frequency are an accepted method of displaying the data from a section of an orbit.[3,4] The purpose of this technical note is to discuss the change in such contour lines through the middle latitudes. This area lies between the auroral or polar zone[3] and the equatorial anomaly.[4,5,6] The data used are those received at Stanford University on 24, 27, and 28 June 1963. Although all the data received are displayed in the figures, the mathematical analysis is limited to the region from 25° to 45°N.

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*References are given at the end of this report.

II DESCRIPTION OF THE DATA

The three orbits analyzed are 3664, 3705, and 3718. The pertinent geographic and temporal data are given in Table I. For the purposes of this study, the differences in longitude and in time of day are ignored.

Table I

TIME AND SPACE COVERED BY THE DATA

Date 1963	Orbit No.	Time Span (GMT)	Geographic Latitude	Geographic Longitude	K_p Index
24 June	3664	1809:28-1816:27	22.16-45.45	108.28-112.53	13^-
27 June	3705	1809:51-1823:17	21.31-65.43	115.73-136.59	24^-
28 June	3718	1704:36-1714:35	23.02-56.21	100.81-108.98	21^o

The ionograms were loaned by Stanford University. Virtual heights versus frequency were scaled, and the true depth below the satellite was computed from these by a polynomial technique.[7] Throughout the paper, depth below the satellite is used as a variable.

Figure 1 shows the pattern of electron density for 24 June 1963. The data were plotted with frame number as abscissa and, as a result, are not quite linear in latitude. In the region studied, the change in latitude is almost equivalent to the change in dip angle, so no magnetic coordinates were used. The solid contour lines connect points of equal electron density (electrons/cc $\times 10^{-5}$). These contour lines are interpolations on the data and represent no statistical smoothing. The broken lines are discussed in Sec. III. For this day, the contour lines are essentially horizontal. This implies that lines of constant density are perpendicular to the lines of constant magnetic intensity. While 24 June was not a magnetically "quiet" day, the K_p index was low enough that the day is representative of "quiet summer days" in the report of Dayharsh and Farley.[8]

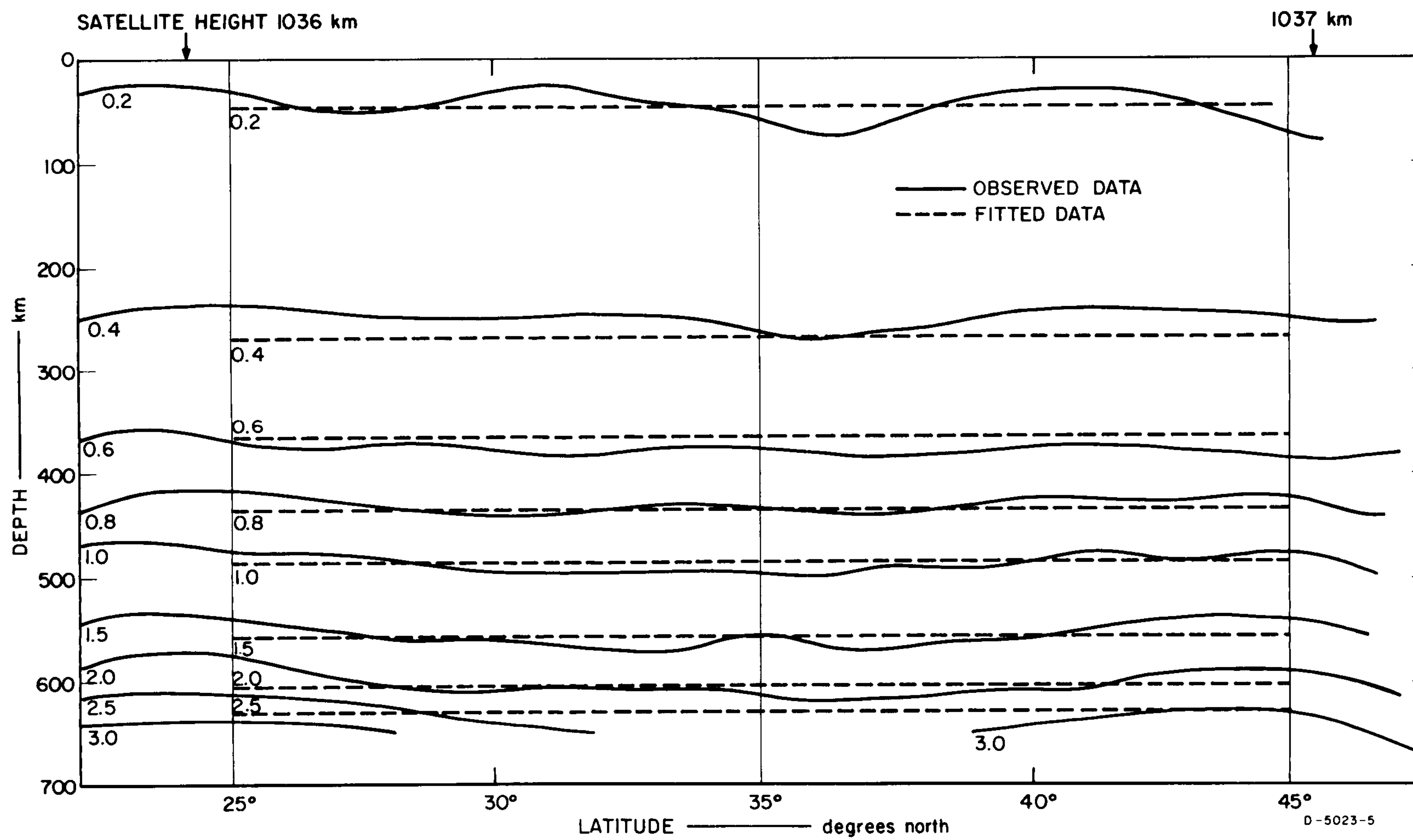

FIG. 1 CONTOURS OF ELECTRON DENSITY FOR 24 JUNE 1963

Figure 2 shows a similar plot of the data for 27 June 1963. The contour lines are now sharply descending through the middle latitudes, relatively constant at very low values from 45° to 55°N, and slope upward north of 55°N. This gradient south of 45° is primarily caused by the lessening of the density at the northern latitudes, but there is also some increase at the southern latitudes. This day was the peak of the magnetic storm, and the change in the contour lines is such that they are now parallel to the lines of constant magnetic intensity.[8]

The data for 28 June 1963 are shown in Fig. 3. The state of magnetic disturbance has lessened and so has the pitch of the contour lines. The pattern is a weakened repetition of that of the day before.

In order to facilitate direct comparison of the data for the three days, the change in the profiles from 25° to 45°N is shown in Fig. 4. The wider the area, the greater is the change. For each day, the southern limit coincides with the right edge of the shaded area. Because of the mild oscillations of the contour lines on 24 June, the profiles at the edges of the area of interest do not necessarily represent the maximum distance between soundings. For 27 and 28 June however, the area is very close to the maximum. In order to obtain numerical values for comparison of all the soundings of one day with all the soundings of another, it is necessary to make some least-square fit of the data. The two variables under consideration are depth and latitude.

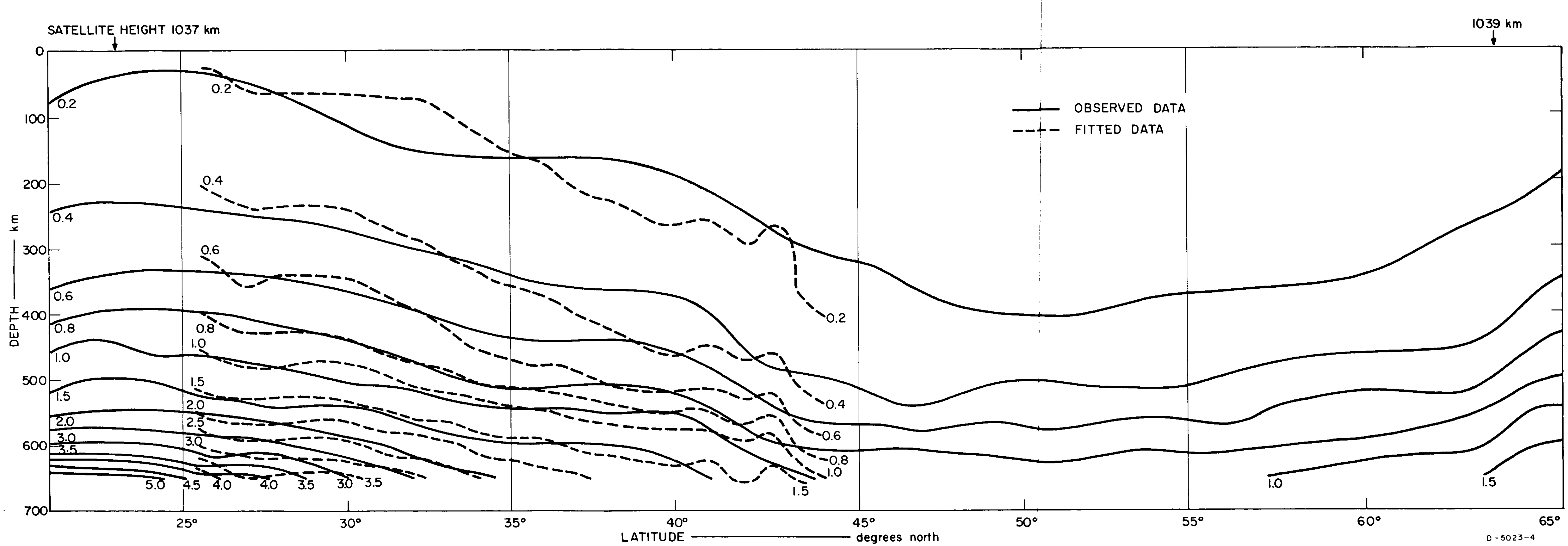

FIG. 2 CONTOURS OF ELECTRON DENSITY FOR 27 JUNE 1963

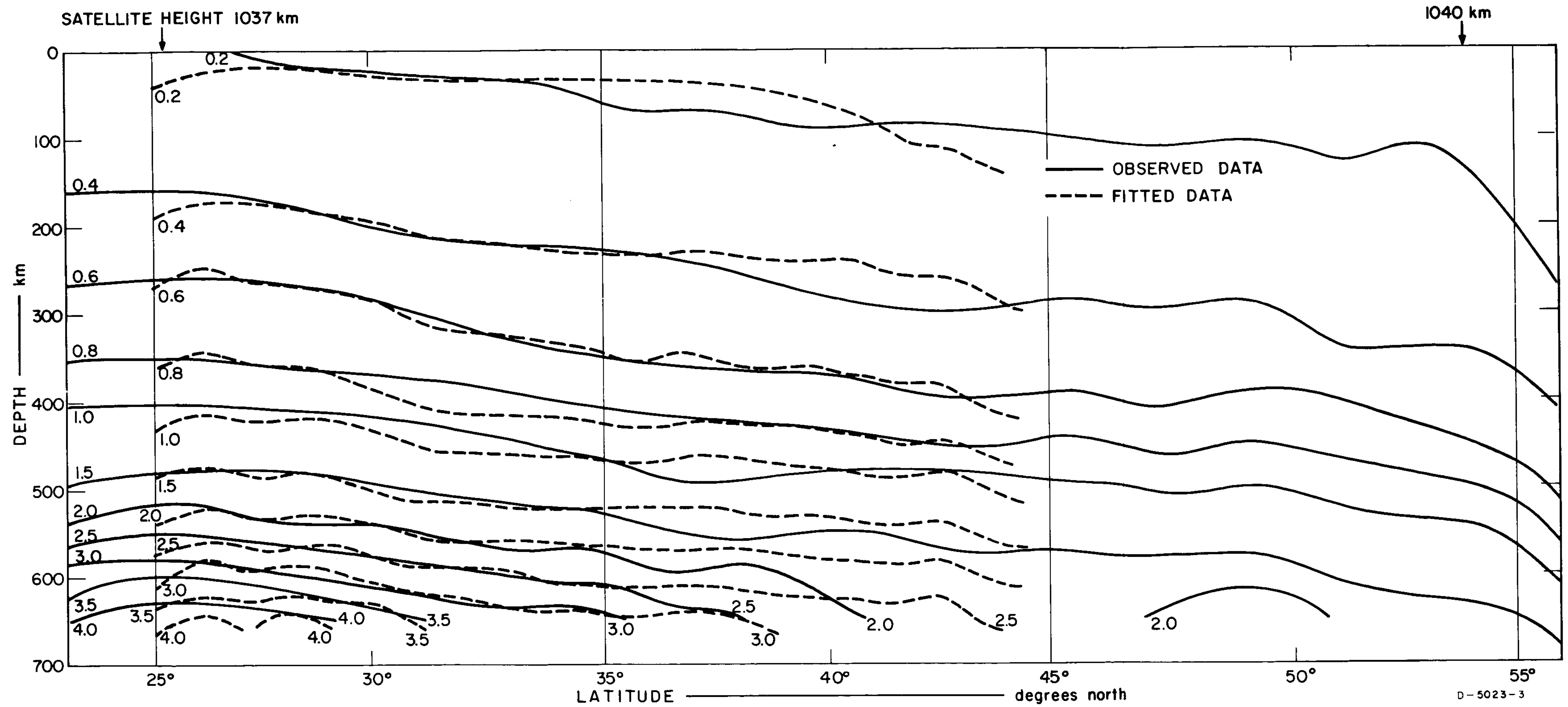

FIG. 3 CONTOURS OF ELECTRON DENSITY FOR 28 JUNE 1963

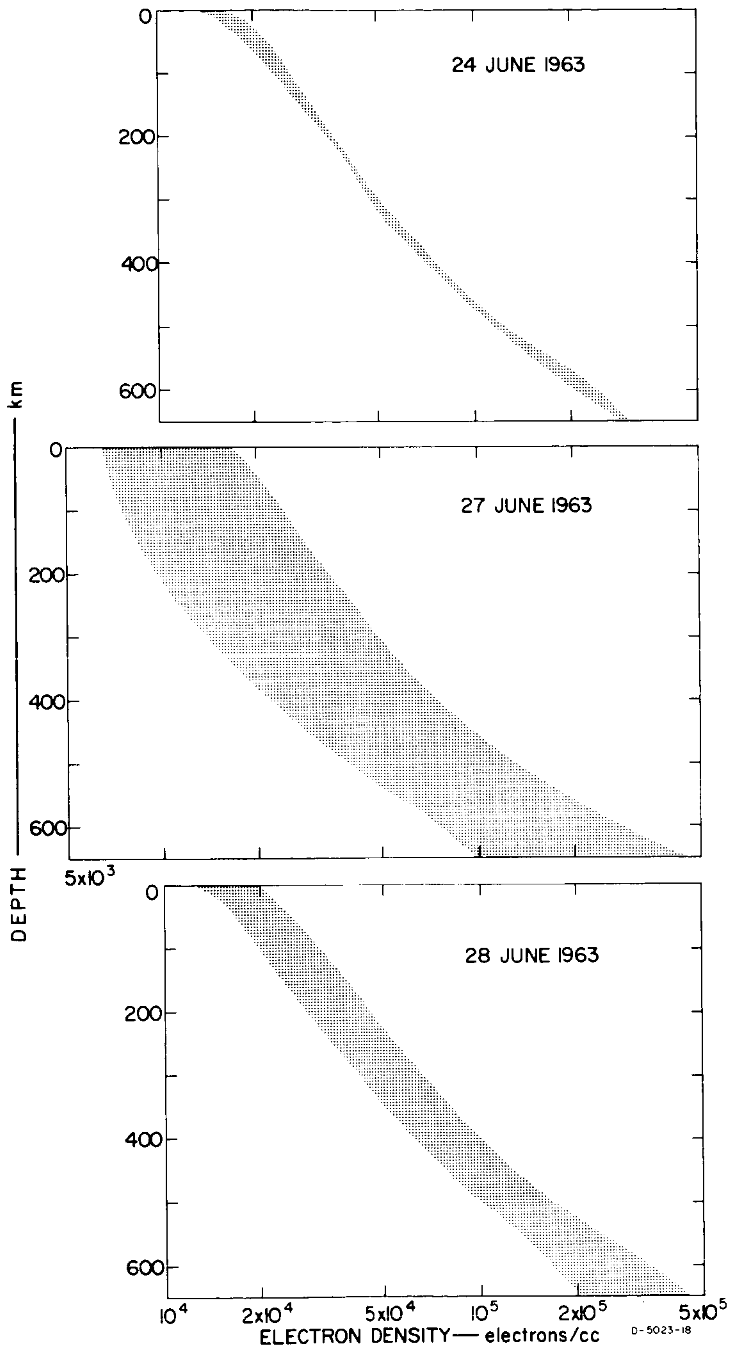

FIG. 4 CHANGE IN ELECTRON DENSITY PROFILES BETWEEN 25° AND 45°N FOR 24, 27, AND 28 JUNE 1963

III DATA ANALYSIS

The simplifying assumption was made that the electron density could be described as a separable function of depth and latitude,

$$N = N_1 (z) N_2 (L) \quad .$$

The form for $N_1 (z)$ chosen was a seventh-order polynomial,

$$N_1 (z) = \sum_{i=0}^{7} c_i z^i \quad .$$

For each of the three days, the data were fit to this function by least squares. This meant disregarding the latitude values and considering, for the moment, that each electron density value was a function only of depth. The polynomial thus derived is the best single representation of the area as a whole, for the single variable. The coefficients of the polynomials are given in Table II and the plots of the polynomials in Fig. 5. The effect of the storm on 27 June was to decrease the electron density, particularly at depths of 0 to 500 km.[9] On the next day, as the storm lessened, the electron density increased until it surpassed the pre-storm values, particularly at depths of 500 to 600 km. This is similar to Muldrew's results,[10] except that he did not have available the pre-storm quiet day to show the initial drop. There is no marked difference in the slope of the lines, implying no major change in H from day to day. The changes appear as translations on semi-log paper.

It is interesting to compare these lines with the data in Fig. 4. For 24 June, the line closely follows but does not lie wholly in the shaded area. For 27 and 28 June, the curve lies entirely within the shaded area and is roughly parallel to the edges. For 27 June, however, the values do not lie in the middle of the area, but are more like the data at the southern (right) edge. This implies that the gradient from south to north is not uniform.

Table II

COEFFICIENTS OF POLYNOMIALS OF DEPTH

Coefficients	24 June	27 June	28 June
c_0	0.16125	0.11802	0.14245
$10^2 c_1$	- 0.04736	- 0.095103	0.36460
$10^4 c_2$	0.45432	0.53809	- 0.62286
$10^6 c_3$	- 0.47793	- 0.58121	0.47791
$10^8 c_4$	0.22472	0.29242	- 0.15684
$10^{10} c_5$	- 0.052502	- 0.074133	0.022839
$10^{12} c_6$	0.0060148	0.0091778	- 0.0011031
$10^{14} c_7$	- 0.00026658	- 0.00043619	- 0.000012407

The ratio of the measured electron density to the polynomial evaluated at the appropriate depth is the variation still to be fitted as a function of latitude. There are as many values of this ratio at each latitude as there were readings of the sounding at that latitude. No ratio was negative, and all values were between 0 and 2. The ratio was averaged for each latitude, yielding the values to be fit for the latitude effect, called α_j. They are given in Table III. Further, the mean deviation of α_j from unity is the mean percentage deviation of the input values from the polynomial alone. The average percentage deviation was used instead of the standard error, in an attempt to give each point equal weight. Otherwise a 5-percent error at 100- and at 500-km depth for 24 June would have resulted in a twenty-fold contribution from the greater depth. As might be expected, 24 June with the nearly horizontal contour lines was the best fit, with 3.6 average percentage deviation. The sharp gradient of contour lines for 27 June increased the deviation of 27.0 percent. For 28 June the average percentage deviation dropped to 16.3, still noticeably slanted, but less than that for the previous day.

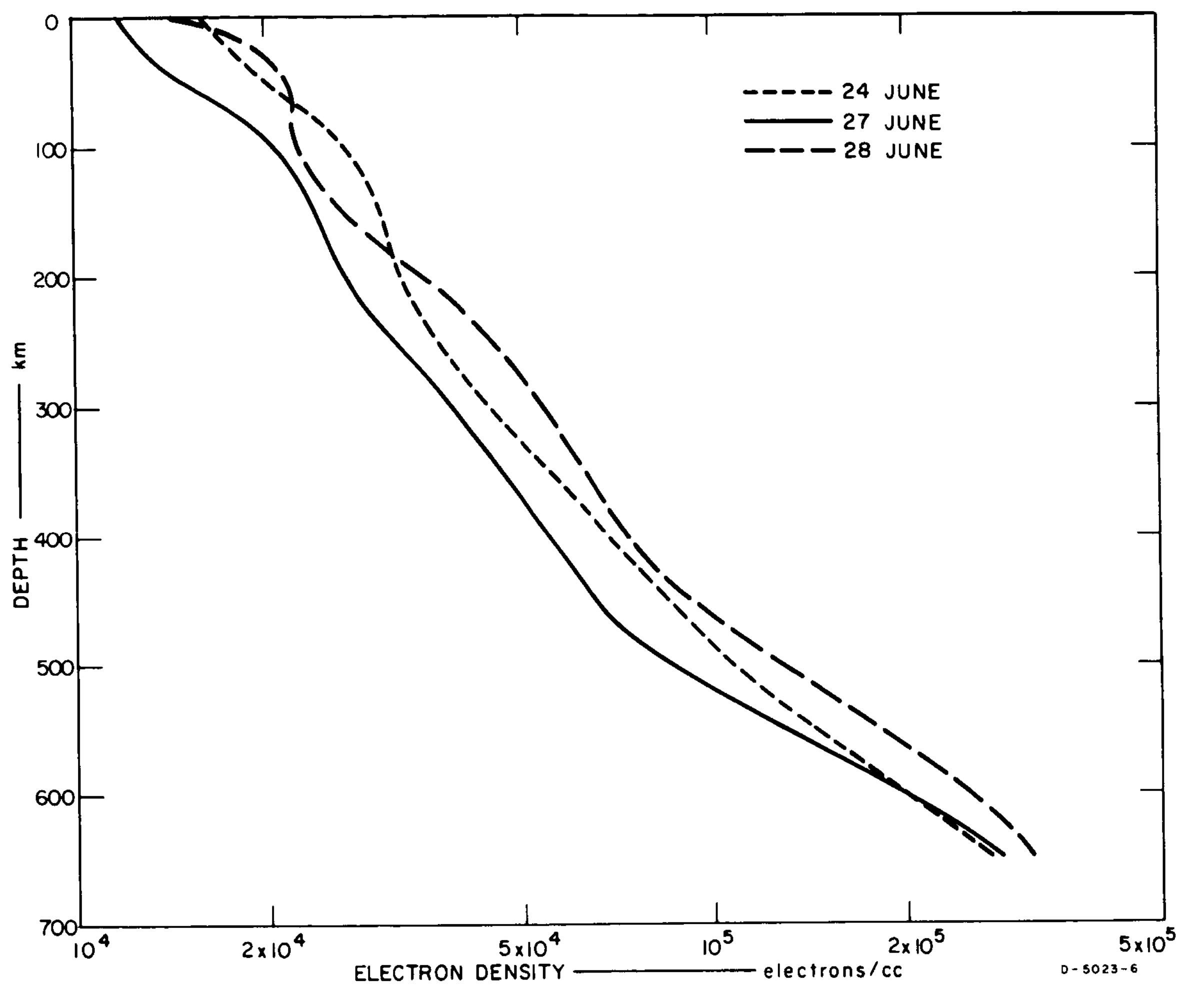

FIG. 5 POLYNOMIALS OF LEAST-SQUARE FIT FOR ELECTRON DENSITY BETWEEN 25° AND 45°N

Table III

INPUT VALUES FOR FOURIER SERIES

Latitude Coefficients	24 June	27 June	28 June
α_0	1.138*	1.432	1.378
α_1	1.088	1.437	1.346
α_2	1.038	1.429	1.308*
α_3	1.016*	1.280	1.269
α_4	0.994	1.243	1.231*
α_5	1.026	1.164	1.193
α_6	1.013	1.028	1.146
α_7	1.001	1.008	1.117*
α_8	0.994	0.919	1.087
α_9	0.995	0.920	0.996
α_{10}	0.946	0.825	0.986
α_{11}	0.922	0.779	0.914
α_{12}	0.948	0.811	0.927
α_{13}	0.928	0.784	0.906
α_{14}	0.979	0.753	0.854
α_{15}	1.049	0.743	0.838
α_{16}	0.990	0.686	0.877
α_{17}	1.043	0.520	0.850
α_{18}	0.967	0.466	0.757
α_{19}	1.079	0.414	0.778
α_{20}	1.007	0.362*	0.806

*Interpolated.

The same effect can be seen in the individual values of the α_j. The first set are all near one. The higher values and tighter gradient of the electron density near the southern edge on the succeeding days are reflected in the larger values of the α_j. The assumption was made that the latitude function could be represented as a Fourier series. In order to have integral values of the variable, the sounding number rather than the true latitude was used. The soundings are approximately one degree of latitude apart. The second function is then written

$$N_2\ (x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left(a_n \sin \frac{2\pi nx}{L} + b_n \cos \frac{2\pi nx}{L} \right) .$$

The Fourier series was evaluated for the first ten harmonics and all values were included in the series. The coefficients are given in Table IV. The values for 24 June are generally smaller than for the stormy days.

Also, since the most noticeable single feature on both 27 and 28 June is the downward slope of contour lines from south to north, the coefficients of the cosine terms are larger than those of the sine terms, with the first harmonic the most important. In order to obtain a measure of the fit of the entire function to the data, the α_j were divided by the Fourier output, and the average deviation from unity was computed. This is not exactly the mean percentage deviation, because the average at each latitude was used, but it gives a measure of the improvement due to the Fourier series. The values were 5.5, 12.2, and 6.3 percent, respectively, for the three days. For 24 June, the value before the series was lower. The greatest improvement was for 27 June, when the pattern was strongest. The evaluation of the two-dimensional fit is superposed on the data in Figs. 1, 2, and 3. In Fig. 1, the horizontal lines of the simple polynomial fit are used, since it is the closer approximation.

To recapitulate, the original data were fit to a least squares seventh-order polynomial of depth, without regard to latitude. Then the residues, defined as the ratio of the original value to the polynomial

Table IV

FOURIER COEFFICIENTS

Coefficients	24 June	27 June	28 June
a_0	2.009	1.811	2.047
a_1	0.049	0.040	0.044
a_2	0.002	- 0.029	- 0.003
a_3	0.013	- 0.002	0.003
a_4	0.014	0.003	- 0.002
a_5	0.004	0.004	0.013
a_6	- 0.004	- 0.012	0.009
a_7	0.006	- 0.011	- 0.002
a_8	0.001	- 0.001	0.004
a_9	- 0.007	0.005	- 0.004
a_{10}	- 0.008	0.000	0.002
b_1	0.068	0.378	0.153
b_2	0.053	0.135	0.090
b_3	0.008	0.085	0.051
b_4	0.015	0.083	0.035
b_5	0.012	0.063	0.029
b_6	0.014	0.064	0.033
b_7	0.007	0.047	0.031
b_8	0.014	0.050	0.024
b_9	0.008	0.034	0.021
b_{10}	0.004	0.034	0.018

at that height, were averaged at each latitude and fit to a Fourier series. This produced a separable function of depth and latitude which had a mean percentage deviation of about 10.

IV CONCLUSIONS

An inspection of the plot of the data shows as the most noticeable feature of the magnetic storm the change in orientation of the lines of constant electron density. The use of the two-dimensional curve-fit permits a quantifying of this effect and displays the difference in the average profile as well. The decrease in density at the start of the storm and overshooting increase can be seen only through mathematical analysis. The use of an equation permits ready comparison between orbits, and the reasonably good fit of the curve to the data implies a great reduction in the number of numbers needed to represent the state of the atmosphere in this region.

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