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SOLAR AND MAGNETIC DECLINATION CONTROL ON THE ELECTROJET AND DISTRIBUTED CURRENTS IN THE IONOSPHERE OVER JICAMARCA**

AUTORES/AUTHORSHIP

P. Muralikrishna
M.A. Abdu

*Revised work in September, 1987.

RESUMO - NOTAS / ABSTRACT - NOTES

Daytime variation in the average east-west drift velocity of electrons in the height range of 95-110km over Jicamarca (0.9°N, dip latitude), Peru, estimated from VHF radar measurements, is compared with variation in the horizontal component of the geomagnetic field at the closeby Huancayo station (0.6°N, dip latitude). On magnetically quiet days, the ratio of ΔH to the electron drift velocity shows a local time variation asymmetric with respect to local noon, though one would expect a symmetric cos χ (where χ is the solar zenith angle) type of variation for the same, if indeed ΔH arises solely from the electrojet region in which the electron drift velocities are measured. The observed asymmetry indicates significant contribution of distributed currents from height regions above the electrojet in the integrated current represented by ΔH. Further the observed seasonal variation in the degree of the asymmetry seems to point out the importance of magnetic and solar declination angles in controlling the relative contributions of the distributed (and electrojet) currents to the magnitude of the observed ΔH values.

** This work was presented in XIX General Assembly of IUGG, Vancouver-Canada, August 9-22, 1987, with following title "ON THE EFFECT OF GEOMAGNETIC DECLINATION ON THE DISTRIBUTED CURRENTS IN THE EQUATORIAL IONOSPHERE OVER JICAMARCA"

OBSERVAÇÕES / REMARKS

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SOLAR AND MAGNETIC DECLINATION CONTROL ON THE ELECTROJET AND DISTRIBUTED CURRENTS IN THE IONOSPHERE OVER JICAMARCA

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ABSTRACT. Daytime variation in the average east-west drift velocity of electrons in the height range of 95-110km over Jicamarca (0.9°N, dip latitude), is compared with variation in the horizontal component of the geomagnetic field at the closeby Huancayo station (0.6°N, dip latitude). On magnetically quiet days, the ratio of ΔH to the electron drift velocity shows a local time variation asymmetric with respect to local noon, though one would expect a symmetric cos χ (where χ is the solar zenith angle) type of variation for the same, if indeed ΔH arises solely from the electrojet region in which the electron drift velocities are measured. The observed asymmetry indicates significant contribution of distributed currents from height regions above the electrojet in the integrated current represented by ΔH. Further the observed seasonal variation in the degree of the asymmetry seems to point out the importance of magnetic and solar declination angles in controlling the relative contributions of the distributed (and electrojet) currents to the magnitude of the observed ΔH values.

Introduction

Ground level magnetic field variations are known to be caused by overhead current system flowing in ionospheric and magnetospheric regions as well as by the currents induced by them on the ground. Since induced currents are proportional to the external currents the magnitude of observed magnetic field variations at a given station can be considered to be proportional to the integrated currents flowing overhead of that station. The world wide E region current system and the dynamo electric field responsible for the same have been extensively studied in the past (see, Matsushita and Mozer, 1973). In a narrow latitudinal belt along the magnetic equator the daytime magnetic field variations are primarily caused by overhead electrojet current system. Specifically, at a station located directly under the electrojet, like Huancayo (0.6° dip latitude), the variations in the horizontal component H, on a magnetically quiet day, are produced mainly by the electrojet currents, the contribution from other sources being negligible especially near midday when the current is at its peak. The diurnal range, ΔH, in the horizontal component (H) over Huancayo is therefore a good indicator of the strength of the overhead current whose height structure is the subject of primary concern in this work.

From theoretical considerations on the electrical conductivity parameter the vertical height range in which the midday electrojet currents flow was found to be within 90 and 130 km (Baker and Martyn, 1953). Also, the conductivity and hence the current density above about 110 km was found to be significantly less than at heights below 110 km. From Jicamarca incoherent scatter radar measurements Balsley et al. [1976] showed that in the region 115-200 km the horizontal component of the electric field arises from the combined effects of (1) the coupling of off-equatorial E region fields along magnetic field lines and (2) in situ electrostatic fields. It is important to know the influences of these electric fields on the current distribution in the equatorial ionosphere above the electrojet region. Experimental determination of the height profiles of the current distribution by rocket borne magnetometers offers rather low accuracy.

In the present work we have carried out an analysis using the data on average horizontal ionization drift velocities in the 95-110 km range measured by the Jicamarca (0.9°N dip latitude) radar and the diurnal range of the horizontal magnetic field variation over Huancayo (close to Jicamarca), with the objective to identify integrated effects due to possible presence of distributed currents above the electrojet region. The results of the analysis suggest presence of such currents with significant strength above the electrojet region especially during the forenoon hours of winter and equinoctial months. Further, the seasonal behaviour of this current component seems to be influenced by the magnetic declination angle.

Currents Above the Electrojet Region

On a magnetically quiet day the variations, in the horizontal component of the geomagnetic field, ΔH, at Huancayo can be written as the sum of two terms, one representing the contribution by the electrojet current flowing in the height region of 95-110 km, which we shall denote by ΔH_E, and another by currents flowing above this height range, which we shall denote by ΔH_R so that $\Delta H = \Delta H_E + \Delta H_R$. Let E_{y_1} be the primary (driving) east-west electric field responsible for the electrojet current, and E_{y_2} the off-equatorial east-west field mapped on to the heights > 110 km above the electrojet region. We shall also refer as region 1 and 2 those in which currents are driven primarily by E_{y1}, and E_{y2} respectively. ΔH can now be written as:

$$\Delta H = C_1 n_1 E_{y1} + C_2 n_2 E_{y2} \tag{1}$$

where C_1 and C_2 are constants depending upon an effective, or height averaged Pederson and Hall mobilities for the two height regions, respectively, and n_1 and n_2 are the corresponding mean electron densities. If we consider further that n_1 and n_2 are related by a fraction f, the equation (1) can be rewritten as:

$$\Delta H = C_1 n_1 E_{y1} \left(1 + C_3 \frac{E_{y2}}{E_{y1}} \right) \tag{2}$$

Here C_3 is a new constant that includes f, C_1 and C_2. If V_E is the average east-west drift velocity of ionization irregularities, measured by the radar, in the height region of 95-110 km, the electron east-west drift velocity V_d in this region is given by:

$$V_d = V_E \ (1 + \psi) \tag{3}$$

where $\psi = \nu_e \nu_i / (\Omega_e \Omega_i)$; $\nu_{e,i}$ and $\Omega_{e,i}$ being the electron and ion collision frequencies, and gyrofrequencies respectively. This relation is based on the linear theories for the generation of type II irregularities [Rogister and D'Angelo, 1970, Sudan et al., 1973]. V_d is in fact produced by the vertical polarization electric field in the electrojet region whose primary driving force is E_{y1} and hence is proportional to it (see for example Fejer and Kelly, 1980), namely, $V_d \ \alpha \ E_{y1}$. Therefore equation (2) can be rewritten as:

$$\Delta H = K_1 n_1 V_E \left(1 + C \frac{E_{y2}}{E_{y1}} \right) \tag{4}$$

Here the constant K_1 represents the combined effects of C_1, ψ, and the magnetic field intensity B. It should be noted that ΔH, n_1, V_E, E_{y1} and E_{y2} are all functions of time. In the electrojet region and above we shall assume that the average electron density follows a cos χ variation, χ being the solar zenith angle. Thus equation (4) can be written as:

$$\left(\frac{\Delta H}{V_E} \right)_{\chi} = K_1 n_{1,o} \cos \chi \left(1 + C \ \frac{E_{y2}}{E_{y1}} \right) \tag{5}$$

For midday conditions we are justified in assuming that $C_3(E_{y2}/E_{y1})$ is very small. Therefore, normalizing the measured $\Delta H/V_E$ values at all local times to its midday value

$$\left(\frac{\Delta H}{V_E}\right)_{n,\chi} = \cos\chi\ [1 + R(\chi)] \qquad (6)$$

where $R = C_3 E_{y2}/E_{y1}$.

From (6) we can get

$$R(\chi) = \frac{(\Delta H/V_E)_{n,\chi} - \cos\chi}{\cos\chi} \qquad (7)$$

where $(\Delta H/V_E)_{n,\chi}$ represents the normalized values. It should be noted that R is in fact a measure of the currents above the electrojet region, and depends upon the ratio of the east-west electric field outside the electrojet to that inside, multiplied by the ratio of the mobility terms, namely C_2/C_1.

Results

The horizontal east-west drift velocity of ionization irregularities representing average values for the height region of 95-110 km measured by the radar over Jicamarca, as well as the ground level geomagnetic H component variation at Huancayo, as presented by Balsley and Woodman [1971] were used for the present studies. All the days on which both the drift velocity and H variation data were smooth and existed for over six to seven hours on a day (0700 to 1700h) were chosen covering the period of July 1967 to March 1970. The data were then grouped into three seasons. ΔH values were determined choosing an appropriate nighttime base level for H variations. The daytime variation of the normalized value of $\Delta H/V_E$ averaged for the three seasons are shown in Figures (1) to (3), and the average of the three curves representative of the annual average daytime variation is shown in Figure (4). Also shown in these figures are the cos χ and the values of $R(\chi)$ calculated using Equation (7). The parameter R given in percentage unit can, in fact, be considered as the integrated currents above the electrojet region expressed in percentage of electrojet currents. The uncertainity in the value of R close to the reversal of currents in the electrojet region in the early morning and late evening hours is rather large, and values above 60 to 80 percent should not be given undue significance.

An examination of the variations in $\Delta H/V_E$ clearly shows presence of a forenoon - afternoon asymmetry, in general, in all the figures. Specifically, the departure from the cos χ pattern is quite pronounced during the forenoon hours, specially, of the winter and equinoctial months. As can be seen from the equation (6), in the absence of R, $\Delta H/V_E$ should follow a cos χ pattern of variation. The value of R practically remains close to zero during the summer months, except for a short duration (about an hour) in the morning. The annual average also shows large values of R in the forenoon hours, indicating that the values of R remain large on most of the days of the year except during the summer months. It may be noted also that the value of R is small or close to zero near the midday in all the seasons, thus substantiating the assumption used in obtaining Equation (6). Further, there is a consistent trend for change of the sign of R near the noon so that it has predominantly negative values in the afternoon hours of the winter and equinoctial months.

Discussion

The large electrical conductivity parallel to the magnetic field lines causes the electrical coupling of the E and F regions [Martyn, 1947; Farley, 1959, 1960], and the off-equatorial E-region dynamo electric fields are accurately mapped into the upper E region and the F-region over the equator, namely, region 2, even for scale sizes down to a few kilometers. In addition to this one may expect the development of in-situ dynamo fields generated by the thermospheric winds, though, winds are known to be inefficient in the generation of dynamo electric fields in the equatorial ionosphere. Thus the currents at these heights over the equator are mainly dependent on the generation of electric fields in the nonequatorial E-region, as also on the local electrical conductivity. A horizontal projection of the magnetic meridian over Jicamarca is shown in Figure (5) and the geometry of several field lines in this magnetic meridional plane, estimated from the dipole approximation, is shown in Figure (6). Latitudes and longitudes of the E-regions (at ~ 103 km) towards north and south of Jicamarca, connected by geomagnetic field lines through different F-region altitudes (200-800 km) over Jicamarca, as estimated from Figures (5) and (6) are given in Table 1.

The differences in longitude between Jicamarca (12°S, 76.8°W) and those of the conjugate E-regions for different F-region altitudes (dependent on the finite magnetic declination angle) over Jicamarca, as well as the varying solar declination (dependent on the season) seem to be responsible for the present observations of relatively larger currents above the electrojet region over Jicamarca, in the forenoon hours during winter (May, June, July) and equinoctial (Feb., Mar., Apr., Aug., Sep., Oct.) months. The solar declination angle of the sun as seen from Jicamarca varies between 23.5°N and 35°N during winter months. During equinoctial and summer months, the solar declination angle varies in the ranges (0.5°N-23.5°N) and (0.5°N - 11°S) respectively. Accordingly the sunrise times at E-regions over Jicamarca and over conjugate latitudes also vary from season to season. The development of electric fields in the nonequatorial conjugate E-region, by dynamo action, should closely follow the sunrise at these latitudes depending also upon the magnetic declination angles at the locations under consideration. However, what really matters is not the absolute times of sunrise, but the differences in the sunrise time (ΔT) in the E-region over Jicamarca, with respect to those over the conjugate points from where the electric fields are mapped onto higher altitudes over Jicamarca, which is a function of the magnetic declination angle as well. These differences are shown in Table (2), as function of altitudes, from 200 to 800 km, over Jicamarca, and for the three seasons. ΔT is taken to be positive when the sunrise in the E-region over Jicamarca occurs later. The solar declination ranges as observed from Jicamarca are also given in Table (2).

The ratio R of the integrated currents above the electrojet region to the electrojet currents, over Jicamarca, can be easily seen to be:

1) inversely proportional to the strength of the electrojet currents;

2) directly proportional to positive values of ΔT.

It can be seen that positive values of ΔT for a given latitude, indicate that the electric fields developed at these latitudes are already transported to higher regions over Jicamarca, giving rise to E_{y2} fields before the electrojet currents develop over Jicamarca. Negative values of ΔT would indicate that E_{y2} fields are not developed even when the electrojet currents are developed. On the other hand the solar declination angle will act in such a way that the larger is its value the lower will be the strength of the electrojet currents, and hence larger the value of R.

Winter months

During winter months as can be seen from Table (2), ΔT varies from +37 minutes to -59 minutes for the northen most and southern most conjugate E-region, respectively, for different solar declination angles and heights (considered here upto 800 km) over Jicamarca. If we consider lower height limits for the F-region currents the ΔT variations will also be correspondingly less. At all conjugate latitudes towards south of Jicamarca, ΔT has negative values, and hence does not contribute for F-region (or region 2) currents, and hence for the enhancement in R. However, the dynamo electric fields at conjugate latitudes towards north of Jicamarca develop 7 to 37 minutes earlier than the development of electrojet currents over Jicamarca and therefore the conditions for the development of distributed currents above the electrojet region, earlier than the electrojet currents, are favourable in the morning hours.

In addition to this, the solar declination angle as measured at Jicamarca varies from 23.5°N to 36°N during the winter months. This large solar declination angle results in a decrease in the electrojet current strength in winter months when compared with equinoctial and summer months. This in turn contributes for an increase in R. The fact that the average electrojet currents are less in the winter months compared with equinoctial and summer months is indicated by the average peak (midday) value of 93 gamma for ΔH at Huancayo in winter months, compared with 127 gamma in equinoctial months and 135 gamma in summer months, estimated for the days selected for the present studies. Thus, increased values of ΔT as well as solar declination angles, seem to be responsible for the forenoon enhancement in R.

Equinoctial months

During equinoctial months ΔT at conjugate latitudes towards north of Jicamarca varies from -2 to 21 minutes, while at conjugate latitudes towards south it remains negative for almost all cases. Though this is less than its value in winter, its effect seems to be still pronounced. The solar declination angle during the equinoctial months varies between 23.5°N and

0.5^oN (with respect to Jicamarca) and hence contributes for an increase in R, as in winter months.

Summer months

ΔT during the summer months ranges between -1 and 19 minutes at conjugate latitudes towards south of Jicamarca. Though it seems to be sufficiently large for causing an increase in R during the forenoon hours, the low solar declination angle, which varies between 0.5^oN and 11^oS, seems to almost nullify the positive effect due to ΔT, by increasing the electrojet currents over Jicamarca. The average peak value of ΔH at Huancayo during summer months is about 135 gamma, compared with its winter and equinox values of 93 gamma and 127 gamma, respectively.

One should also note here that during summer months the conjugate latitudes with positive ΔT values are towards south of Jicamarca, unlike in the cases of winter and equinoctial months, while Jicamarca itself is in the northern magnetic hemisphere with a dip latitude of 0.9^oN. This may be another factor responsible for low R values observed in summer months.

Prakash and Muralikrishna [1981], from a comparative study of the horizontal drift velocity of electrons in the E-region, and the vertical drift velocity in the F-region over Jicamarca, showed that the horizontal electric field in the F-region, most of the time, is stronger than the E-region field; and the ratio of the two has a forenoon afternoon asymmetry (see figures 2 and 3 in Prakash and Muralikrishna, 1981). The F-region field is stronger than the E-region field during the forenoon hours, and this effect is most pronounced during the winter months. The striking similarity of this with the present results, strongly supports the present finding about the solar and geomagnetic declination control of the distributed currents above the electrojet region.

An important question relevant at this juncture is whether it is possible to attribute the observed daily and seasonal variation in the distributed currents above the electrojet region to thermospheric winds. The answer is no. The hypothesis that the distributed currents above the electrojet region are driven by electric fields generated in-situ by the dynamo action of thermospheric winds, in the first place, cannot explain the observed forenoon afternoon asymmetry, as well as the positive correlation between the intensity of the distributed currents and the difference in sunrise times. For example during the winter and equinoctial months, the electrical conductivity in the non-equatorial E-region at the feet of the flux tubes is sufficiently high (sunrise occurs earlier here) to short any polarization field generated in-situ by the thermospheric winds above the electrojet region. This will result in reduced intensity of the distributed currents in the winter and equinoctial months. On the otherhand during summer months, the difference in the sunrise times is minimum, and one would not expect the rapid shorting of the electric fields generated by the thermospheric winds, and hence would expect stronger distributed currents above the electrojet region. This hypothesis, thus leads to an anticorrelation between the intensity of distributed currents and the difference in sunrise times, which is, in fact, contrary to what is really observed. However the effect of thermospheric winds on the distributed currents cannot be completely ruled out.

Conclusions

The development of electric fields associated with dynamo action at nonequatorial latitudes and their mapping into the altitude region above the electrojet considerably influences the development of the distributed currents. Depending on the difference in sunrise times at these nonequatorial conjugate latitudes, and in the electrojet region that are functions of the solar and magnetic declination angles these currents show a seasonal variation.

i) During winter months when the sun is in the northern hemisphere, the distributed currents over the electrojet region are relatively strong due to the large difference in the sunrise times at conjugate latitudes and in the electrojet region over Jicamarca.

ii) The distributed currents above the electrojet region are still considerable during equinoctial months, though less than during winter months. This can be attributed to the solar declination angle that varies between 23.5°N and 0.5°N during the equinoctial months.

iii) During summer months, the distributed currents above the electrojet region are the weakest due, possibly to two reasons. While the difference in the sunrise times tends to increase the distributed currents, the low solar declination angle tends to nullify this effect by increasing the electrojet currents over Jicamarca.

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FIGURES CAPTIONS

Fig. 1. Average daytime variation of $\Delta H/V_E$ (normalized) and R during winter months.

Fig. 2. Average daytime variations of $\Delta H/V_E$ (normalized) and R during equinoctial months.

Fig. 3. Average daytime variations of $\Delta H/V_E$ (normalized) and R during summer months.

Fig. 4. Average daytime variations of $\Delta H/V_E$ (normalized) and R estimated for the period July 1967 to March 1970.

Fig. 5. Geometry of a geomagnetic field line passing through Jicamarca, Perú.

Fig. 6. Geometry of geomagnetic field lines estimated from dipole approximation, showing the geographic latitudes of conjugate points.

TABLE 1

E-REGION LATITUDES AND LONGITUDES CONJUGATE TO F-REGION ALTITUDES OF 200-800 KM OVER JICAMARCA

Altitude above Jicamarca (km)	Lat. and Long. of Conjugate E-region points			
	Towards North		Towards South	
	Lat.	Long.	Lat.	Long.
200	6°S	76.3°W	20°S	78.4°W
300	3°S	76.0°W	23°S	79.1°W
400	1°S	75.9°W	25°S	79.6°W
500	1°S	75.8°W	27°S	80.3°W
800	5.5°S	75.2°W	31.5°S	82.1°W

TABLE 2

DIFFERENCE BETWEEN THE SUNRISE TIMES IN THE E-REGION OVER JICAMARCA AND IN THE E-REGION CONJUGATE TO VARIOUS F-REGION ALTITUDES OVER JICAMARCA

Height above Jicamarca km	Range of ΔT for conjugate E- region latitudes (in min.)					
	Winter $\delta \rightarrow 23.5^oN - 35^oN$		Equinox $\delta \rightarrow 23.5^oN - 0.5^oN$		Summer $\delta \rightarrow 0.5^oN - 11^oN$	
	Towards North	Towards South	Towards North	Towards South	Towards North	Towards South
200	7 to 13	-13 to -21	7 to -2	-13 to 1	-2 to -9	1 to 9
300	11 to 19	-18 to -29	11 to -5	-18 to 1	-5 to -13	2 to 13
400	13 to 23	-22 to -35	13 to -5	-22 to 1	-5 to -15	2 to 15
500	16 to 28	-27 to -42	16 to -6	-27 to 1	-6 to -18	1 to 16
800	21 to 37	-39 to -59	21 to -7	-39 to -1	-7 to -23	-1 to 19

(13)

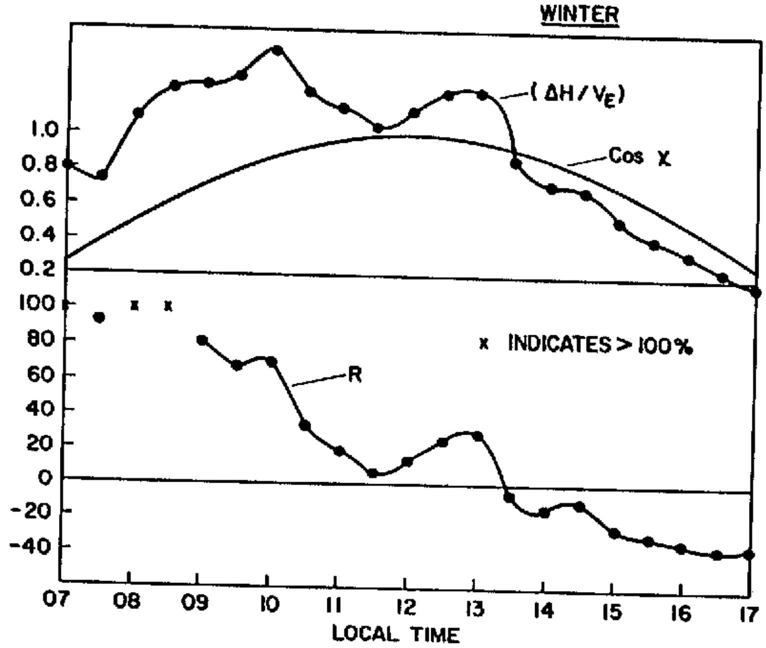
WINTER
(ΔH/V_E)
Cos χ
1.0
0.8
0.6
0.4
0.2
100
80
60
40
20
0
-20
-40
x INDICATES > 100%
R
07
08
09
10
11
12
13
14
15
16
17
LOCAL TIME

Fig. 1

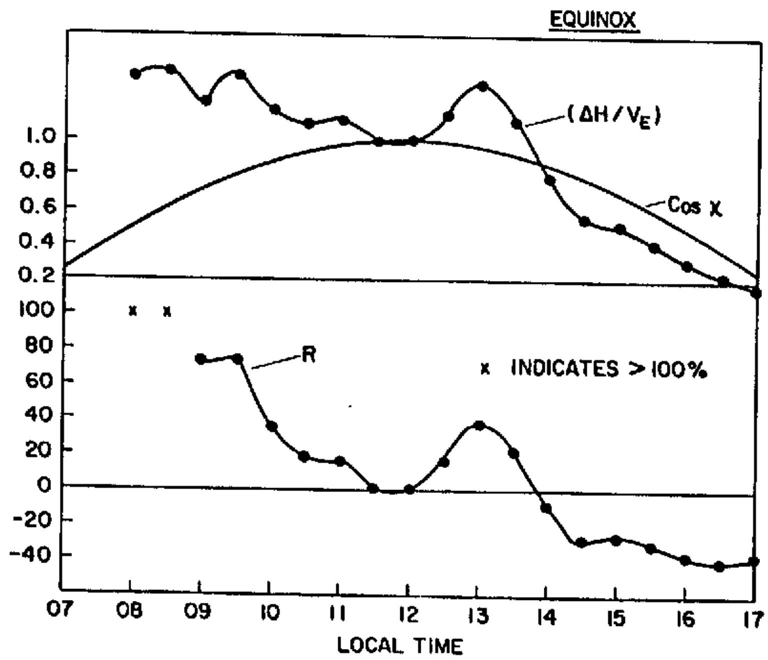
EQUINOX
(ΔH/V_E)
Cos χ
1.0
0.8
0.6
0.4
0.2
100
80
60
40
20
0
-20
-40
R
x INDICATES > 100%
07
08
09
10
11
12
13
14
15
16
17
LOCAL TIME

Fig. 2

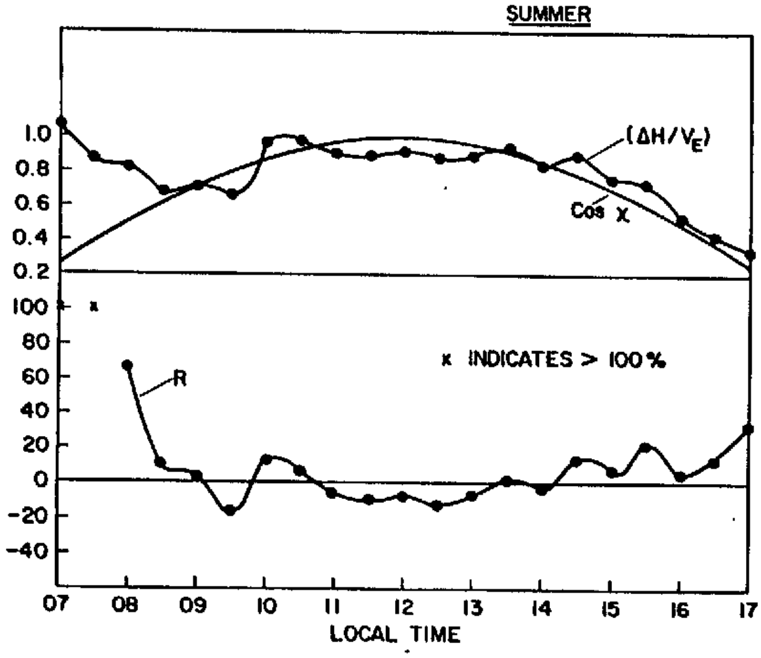
SUMMER
(ΔH/V_E)
Cos χ
1.0
0.8
0.6
0.4
0.2
100
80
60
40
20
0
-20
-40
R
x INDICATES > 100%
07
08
09
10
11
12
13
14
15
16
17
LOCAL TIME

Fig. 3

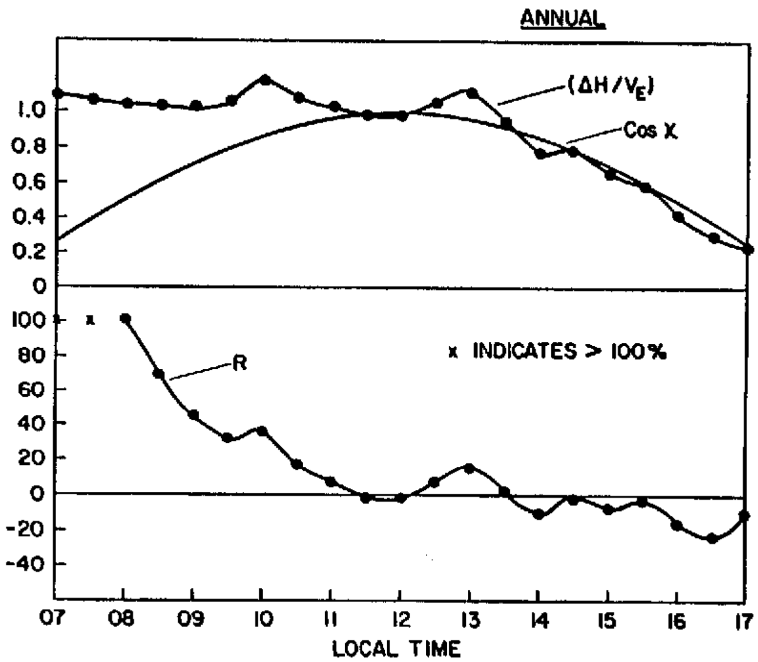
ANNUAL
(ΔH/V_E)
Cos χ
1.0
0.8
0.6
0.4
0.2
0
100
80
60
40
20
0
-20
-40
R
x INDICATES > 100%
07
08
09
10
11
12
13
14
15
16
17
LOCAL TIME

Fig. 4

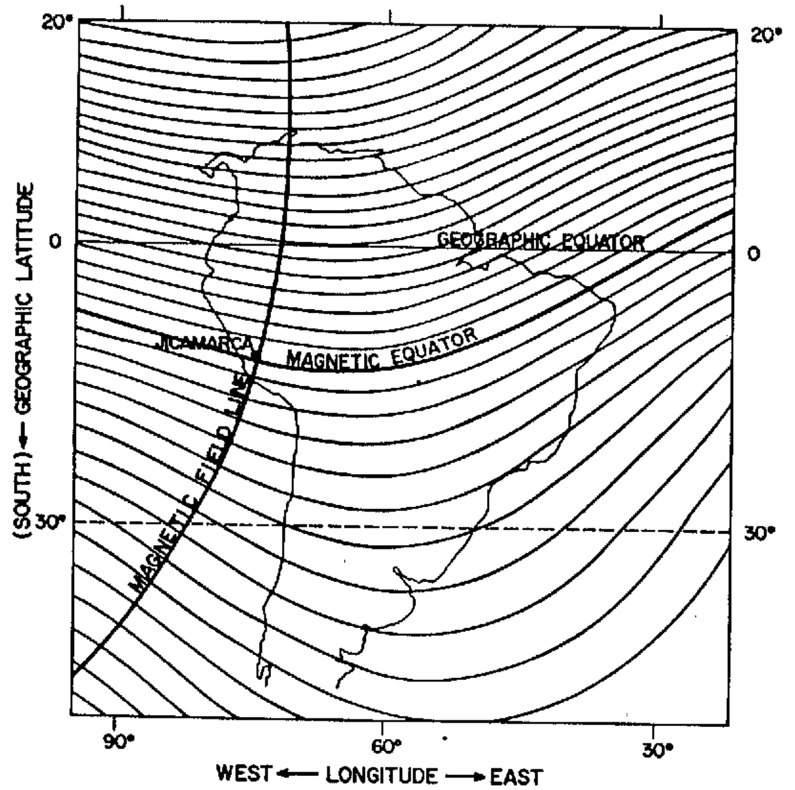
20°
20°
0
0
30°
30°
(SOUTH) ← GEOGRAPHIC LATITUDE
GEOGRAPHIC EQUATOR
JICAMARCA
MAGNETIC EQUATOR
MAGNETIC FIELD LINE
90°
60°
30°
WEST ← LONGITUDE → EAST

Fig. 5

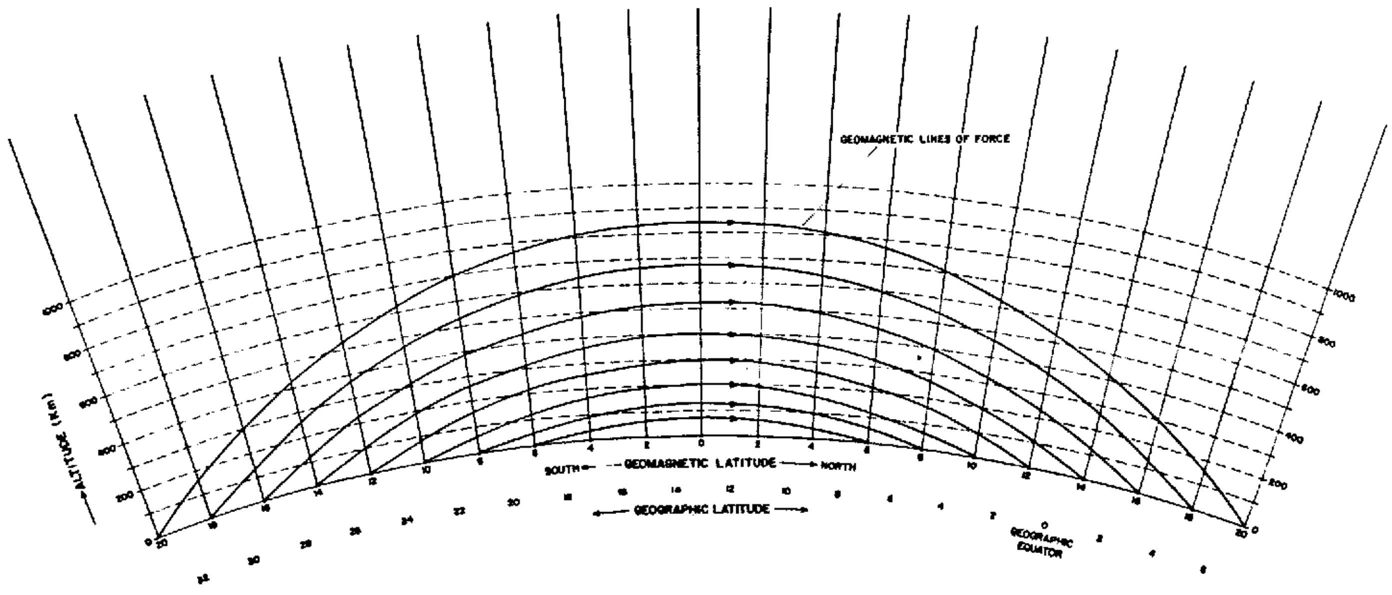
GEOMAGNETIC LINES OF FORCE
ALTITUDE (Km)
SOUTH ← GEOMAGNETIC LATITUDE → NORTH
← GEOGRAPHIC LATITUDE →
GEOGRAPHIC EQUATOR

Fig. 6