EQUATORIAL GEOMAGNETIC FIELD IN INDIAN
&
AFRICAN SECTORS

Project work submitted in the

partial fulfillment of the requirements

For the award of

Master of Science in PHYSICS

of Manonmaniam Sundaranar University

by

L.SURESH.

DEPARTMENT OF PHYSICS
POPE'S COLLEGE
SAWYERPURAM.

2000-2001.

EQUATORIAL GEOMAGNETIC FIELD IN INDIAN & AFRICAN SECTORS

Submitted
by

L.SURESH

To the Pope's College for the Degree of M.Sc in PHYSICS

under the guidence of

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Certificate

TO WHOMSOEVER IT MAY CONCERN

Certified that this the bonafide record of the project work done by L.SURESH during the year August 2000-March 2001, in fulfillment of the award of the Master's degree in Physics from Pope's college.

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CERTIFICATE

This is certify that the project work entitled is EQUATORIAL GEO-MAGNETIC FIELD IN INDIAN & AFRICAN SECTORS in record of bonafide work done by L.Suresh. Results of this project work have not been submitted to any other university for Insitute for the award of any degree.

Project Guide

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Bonafide Certificate

certificate that this is the bonafide record of the project work done by

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During the year 2001

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HELD AT

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Dedicated to my Mother

Acknowledgement

"My heart first thanks to the creator,our almighty God"

I am profoundly thanks to our H.O.D of Physics Mr. S.Sankararaman M.Sc.,M.Phil., to give the chance to do the project work in the Equatorial Geophysical Research Lab,Tirunelveli.

I wish to record my deep gratitude to Dr.S.Gurubaran,Head,Equatorial Geophysical Laboratory,Tirunelveli for his esteemed guidance to this subject and how to study the subject research idea's and to give the clearance of Why,What" questions.

My sincer thanks to Mr.T.K.Ramkumar,Research fellow in EGRL, and India's best research student.I am thank to god, to give the chance to meet him.I am the blind of this subject and he givethe picture of my mind.He is esteemed guidence,suggestions and supervision which enabled me to complete the work succesfully.

I am specialy thank to Mr.Sridharan another research fellow, help rendered to me throughoot my project work.

Special thanks to librarian EGRL,Tirunelveli for supplying meterials and all facilities.I thank one and all of EGRL,Tirunelveli for the help i received.

I Very thankfull to EGRL Technical Staff members. They give the Ideas and advices to my future Studies and my Project Studies

My gratitude in due to my mother without whose blessing I could have not reached this stage.I express my deep regard and love for my family members for thank encouragement inspiration given to me.

I am thankful to securities of EGRL,to maintain the friendship to me. Also thankful to directly or indirectly extended their help to me in completing this work.

Finally, I thanksfull to Pearl Computers and Graphics Authoor Timely helped to completed my project work successfully.

L.SURESH

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Chapter 1

Geomagnetic Field

Geomagnetic Field

Introduction

The magnetic field measured at any point on the Earth's surface contains contributions from the interior of the Earth, and from space around the Earth. Thus

$$B_T = B_i + B_e$$

$$B_T = (B_o + B_r + B_c) + B_e$$

Where B_T is the total field measured at the surface of the Earth;

B_O is the main dipole field originating within the Earth;

B_r is the residual field, i.e., the non-dipole part of the main field;

B_c is the crustal field, i.e, anomalies due to the magnetic nature of local rocks; and

B_e is the external field orginating in outer space.

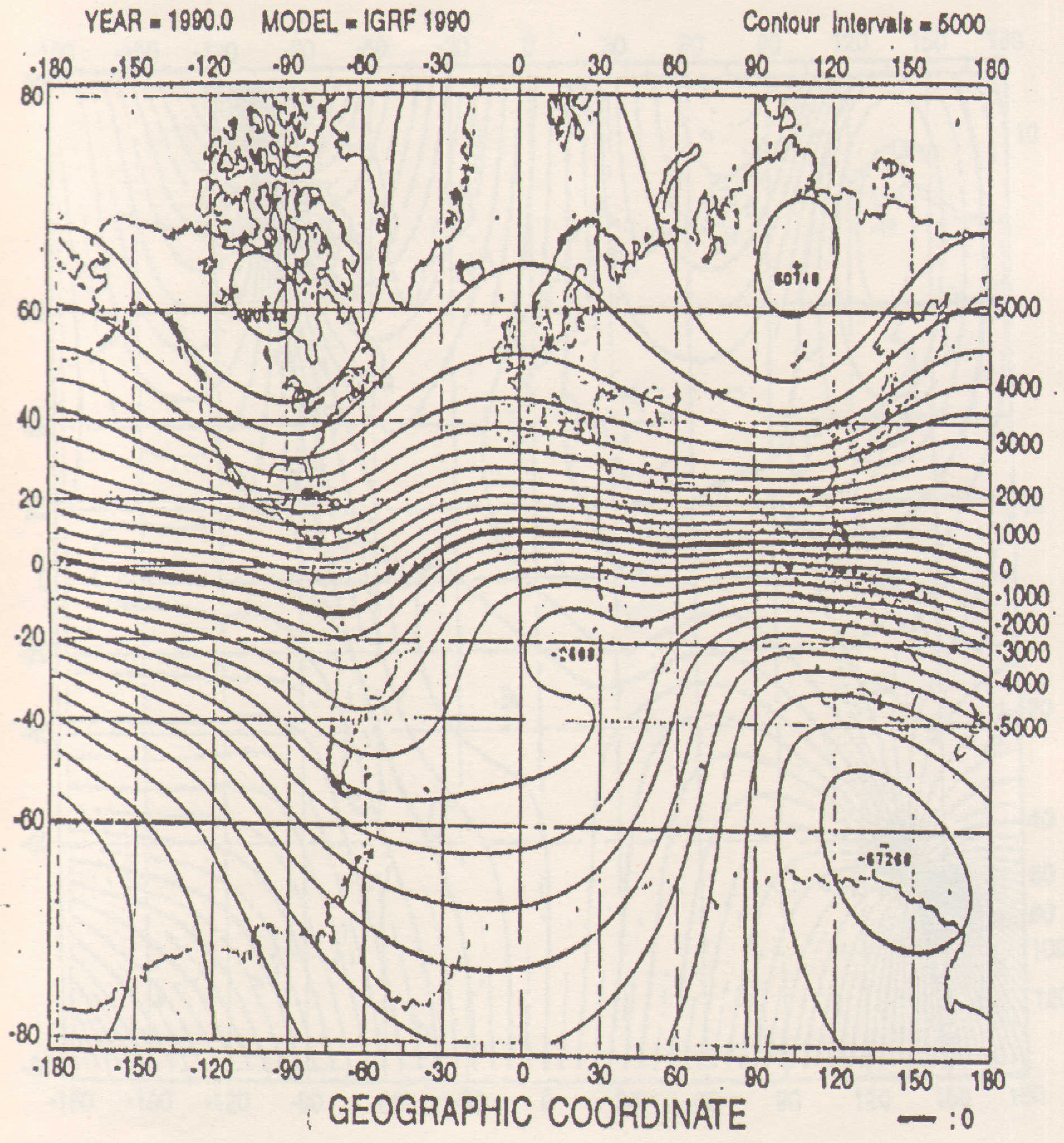
B_i is the internal field orginating with in the Earth

The main field of internal origin accounts for almost 99 per cent of the measured field. It is believed to orginate mainly in the Earth's molten outer core, and to some extent in the Earth's Crust which contains ferromagnetic rocks. The mantle is believed to be a non - contributor, because its temperature is thought to exceed the Curie temperature, which would destroy any ferromagnetism.

Generation of the Main Field

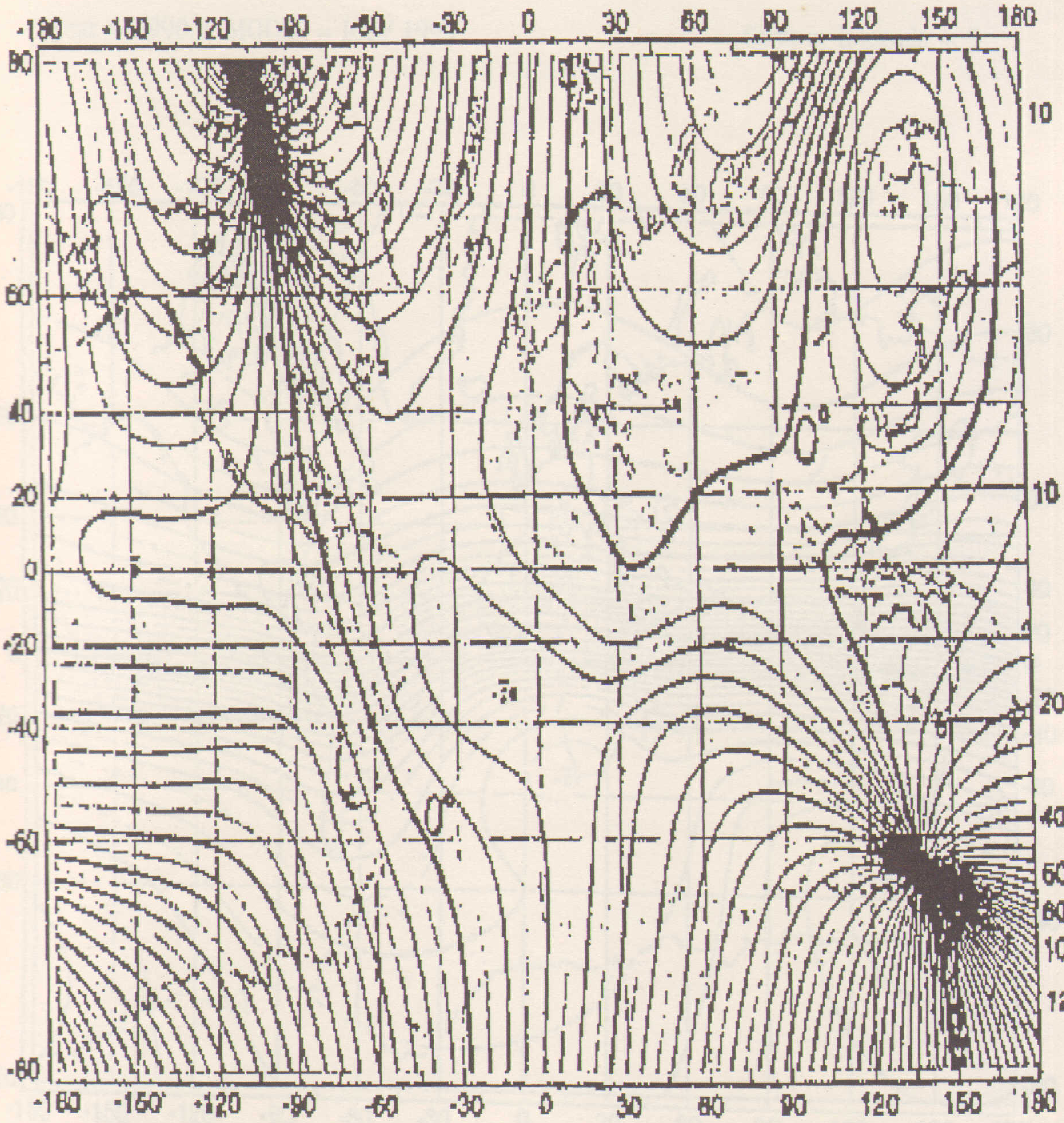
It believed that the main field is generated in the Earth's molten outer core through hydro-dynamic p cesses which create eddy - like cells in the conducting fluid. This seems to be the case with other planets of the solar system also, Estimates of the rotation rates of different planets, and of the possible sizes

VERTICAL COMPONENT :Z (nT)



DECLARATION (degrees)

Year = 19990.0 MODEl = 1GFR 1990 Contour Intervals = 5



GEOGRAPHIC COORDINATE

INCLINATION (degree)

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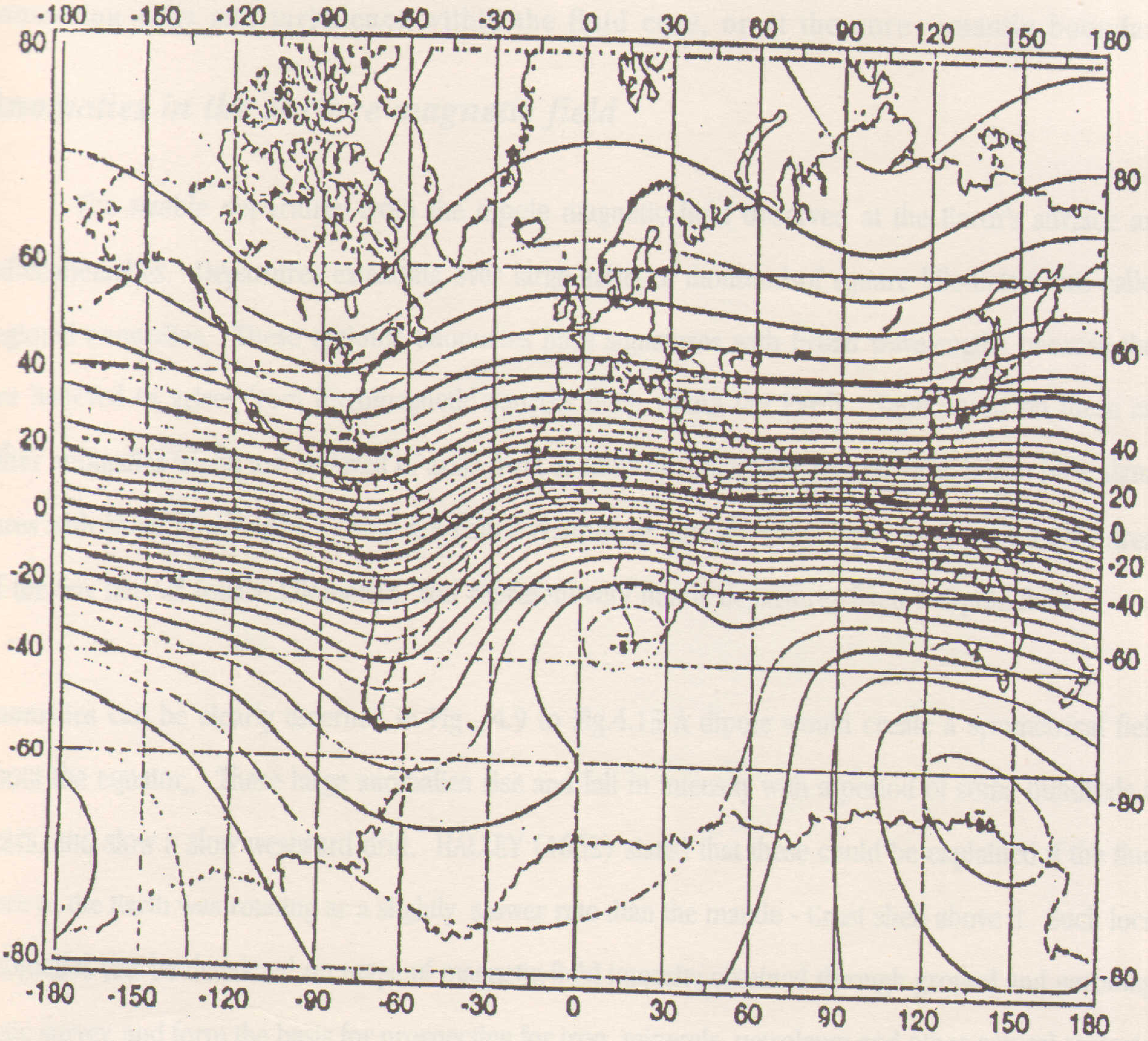


of their innner cores have shown that the following relationship holds good for Venus, Mars and Jupiter, as for Earth

(observed magnetic moment) = (Volume of Fludi core) x (Rate of diurnal rotation)x (Cosine of precession angle of Planet)

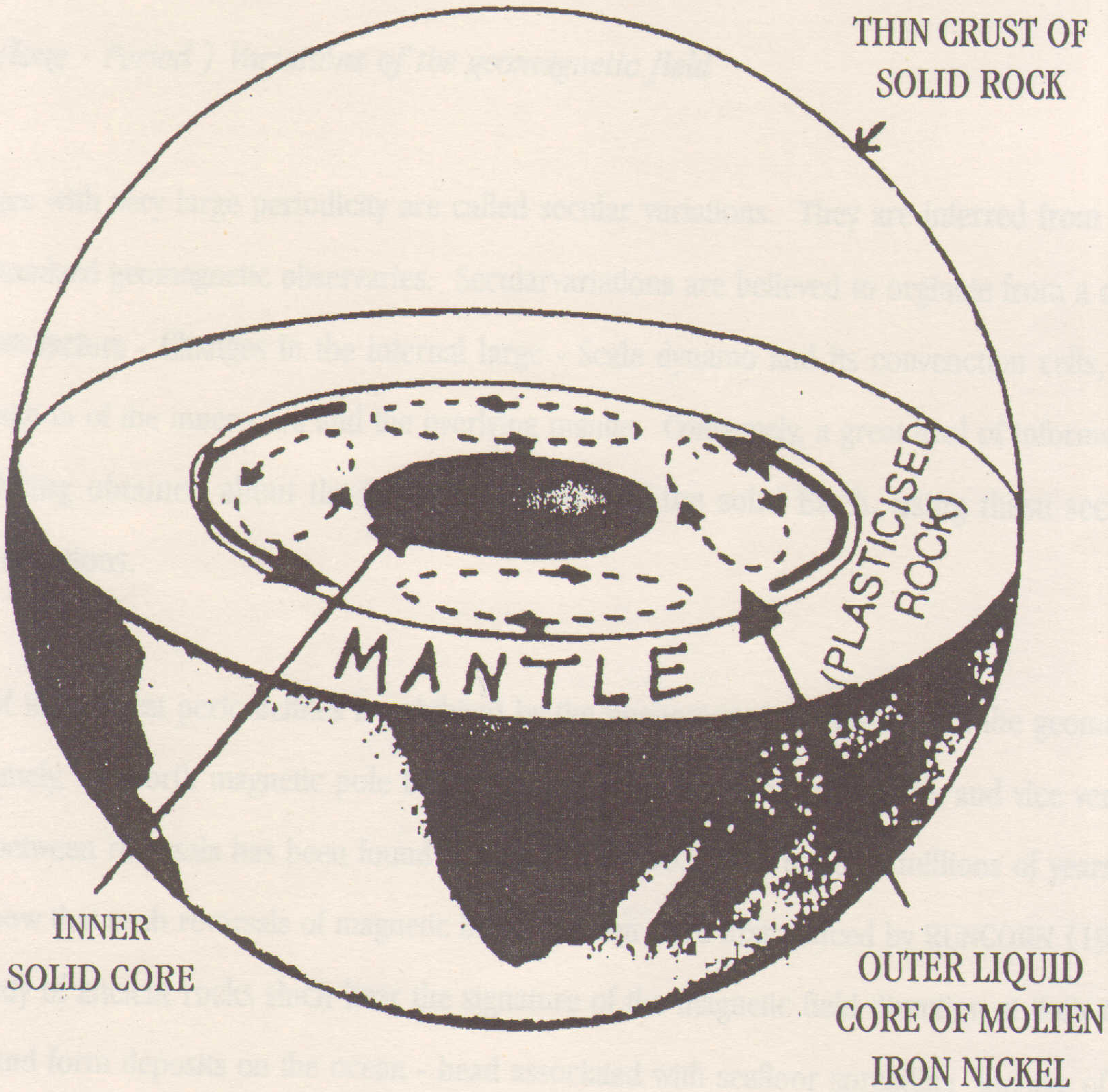
While the origin of the internal field is yet to be understood clearly, it is believed the large - scale rotation of the molten core forms a self - exciting dynamo, and generates the regular part of the main field. Irregularitees or anomalies observed in the main field are understood as being caused by smaller convection cells and turbulence within the fluid core, or at the core - mantle boundary

Anomalies in the surface magnetic field

The sizable departures from the dipole magnetic field observed at the Earth's surface are calledanomalies. Departures extending over large areas of thousandsof square kilometers are called regional anomalies. These regional anomalies have signatures with broad wavelengths because they are believed to arises from ferromagnetic sources deep within the Earth. Superposed on these are other anomalies which are believed to arise from shallow ferromagnetic souces, and hence have signatures with short wavelengths. These are called residual or surcace anomalies. They extend over areas of the few tens of square kilometers, and represent very minor departures from a dipole field.

Anomalies can be clearly dicerned in Fig . 4.9 to Fig.4.13 A dipole would create a symmetrical field about the equator,, These large anomalies rise and fall in intensity with a period of some hundreds of years, and slow a slow westward drift. HALLEY (1662) stated that these could be explained if the fludi core of the Earth was rotating ar a slightly slower rate than the mantle - Crust shell above it. Such local anomalies can be detedcted on maps of magnetic field intensity obtained through ground and aeromagnetic survey, and form the basis for prospecting for iron, minerals, petroleum and other natural resouces (DOBRIN 1952). Surface anomalies normally constitute a few per cent of the ambient field,

but in the vicinity of deposits of natural iron, They can even exceed that field.


THIN CRUST OF
SOLID ROCK
MANTLE
(PLASTICISED
ROCK)
INNER
SOLID CORE
OUTER LIQUID
CORE OF MOLTEN
IRON NICKEL

Periodicities in the Geomagnetic Field : Long - term and Short - term

Cyclical changes in the geomagnetic field can be due to two causes. One is changes in the Earth's Liquid core which manifest themselves as periodicities ranging from tens to thousands of years. The other is change in the Earth's ionised upper atmosphere which is governed by the magnetic activity of the sun.

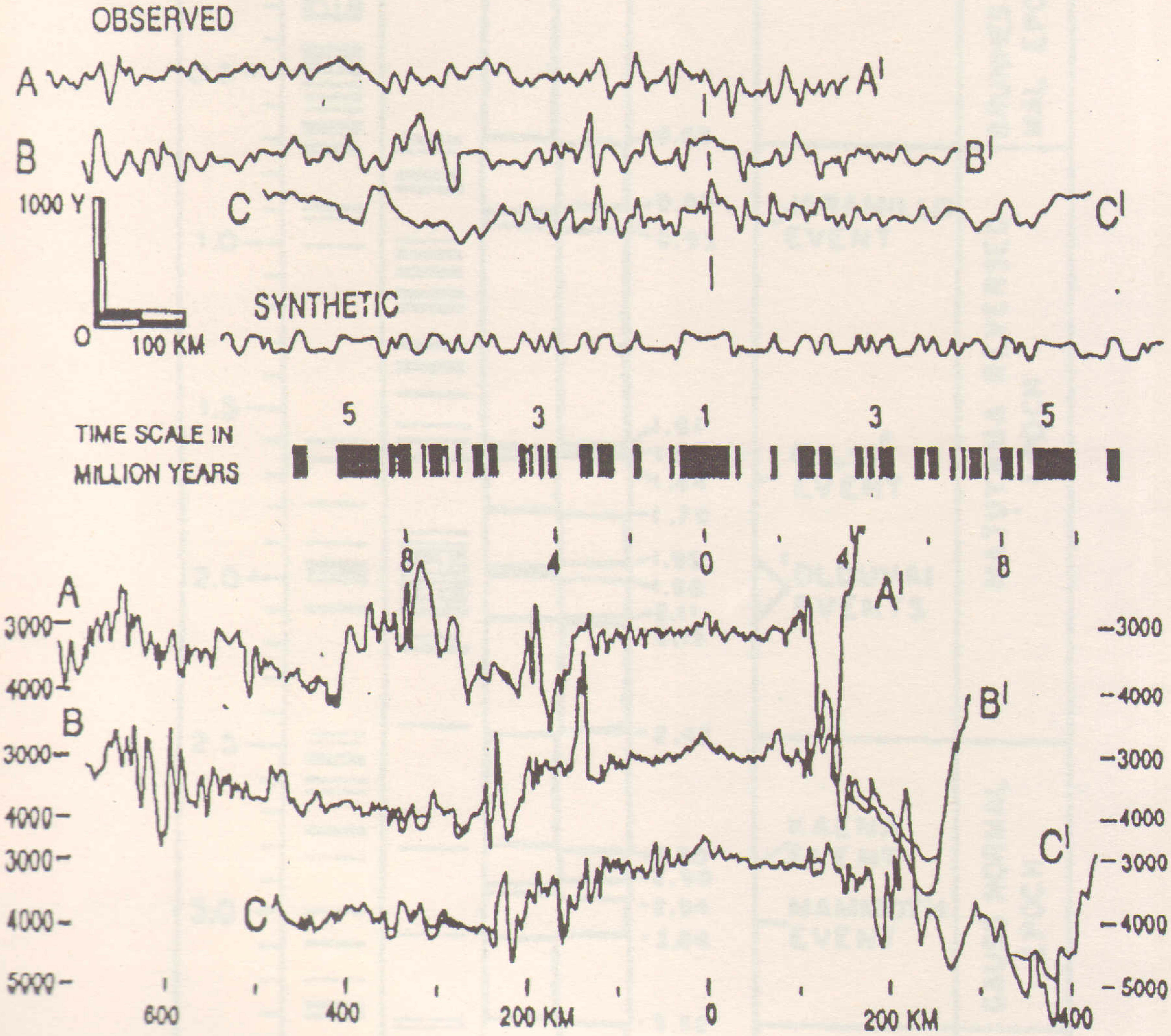
(a) Secular (long - Period) Variations of the geomagnetic field

Changes with very large periodicity are called secular variations. They are inferred from data recorded at standard geomagnetic observaries. Secularvariations are believed to orginate from a combination of two factors - Changes in the internal large - Scale dynamo and its convenction cells, and differential rotation of the inner core and the overlying mantle. Conversely, a great deal of information is currently being obtained about the internal structure of the solid Earth, using these secular geomagnetic variations.

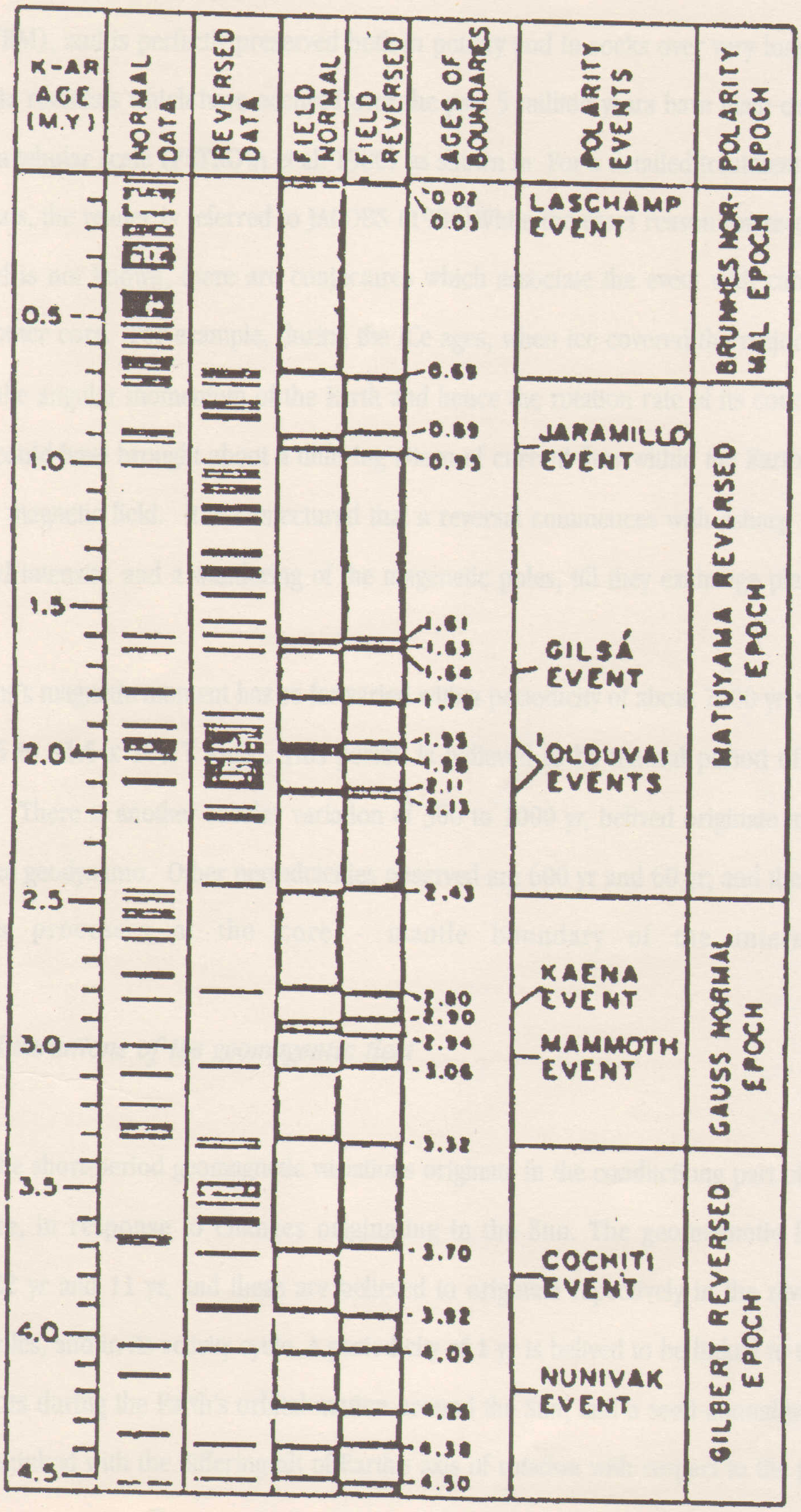
One of the longest periodicitites is exhibited by the phenomenon of reversals of the geomagnetic field, namely, the north magnetic pole being repalced by a south magnetic pole, and vice versa. This interval between reversals has been found to extend from 10,000 yr to some millions of years and studies show that such reversals of magnetic field direction were first noticed by RUNCORN (1956) during the study of ancient rocks shich bear the signature of the magnetic field direction at their time of formation and form deposits on the ocean - bead associated with seafloor spreading the age of the rocks and the ocean - sediments can be readily estimated through radiactive dating techniques.

Seclar changes are investigated in brances known as Archaeomagnetism - ancient magnetic field in historic time - and a Palaeomagnetism-magnetic field in geological time. Both these depend on the fact that natureal rock or earthern pottery contain samall amounts of ferromagnetic material such as magnetite, haematite, etc. When these materials are subjected to high temperatures exceeding 8000C

OBSERVED



OBSERVED
A
A'
B
B'
1000 Y
C
C'
0
100 KM
SYNTHETIC
TIME SCALE IN
MILLION YEARS
5
3
1
3
5
8
4
0
4
8
A
A'
B'
B
C'
C
3000
4000
3000
4000
3000
4000
5000
600
400
200 KM
0
200 KM
400



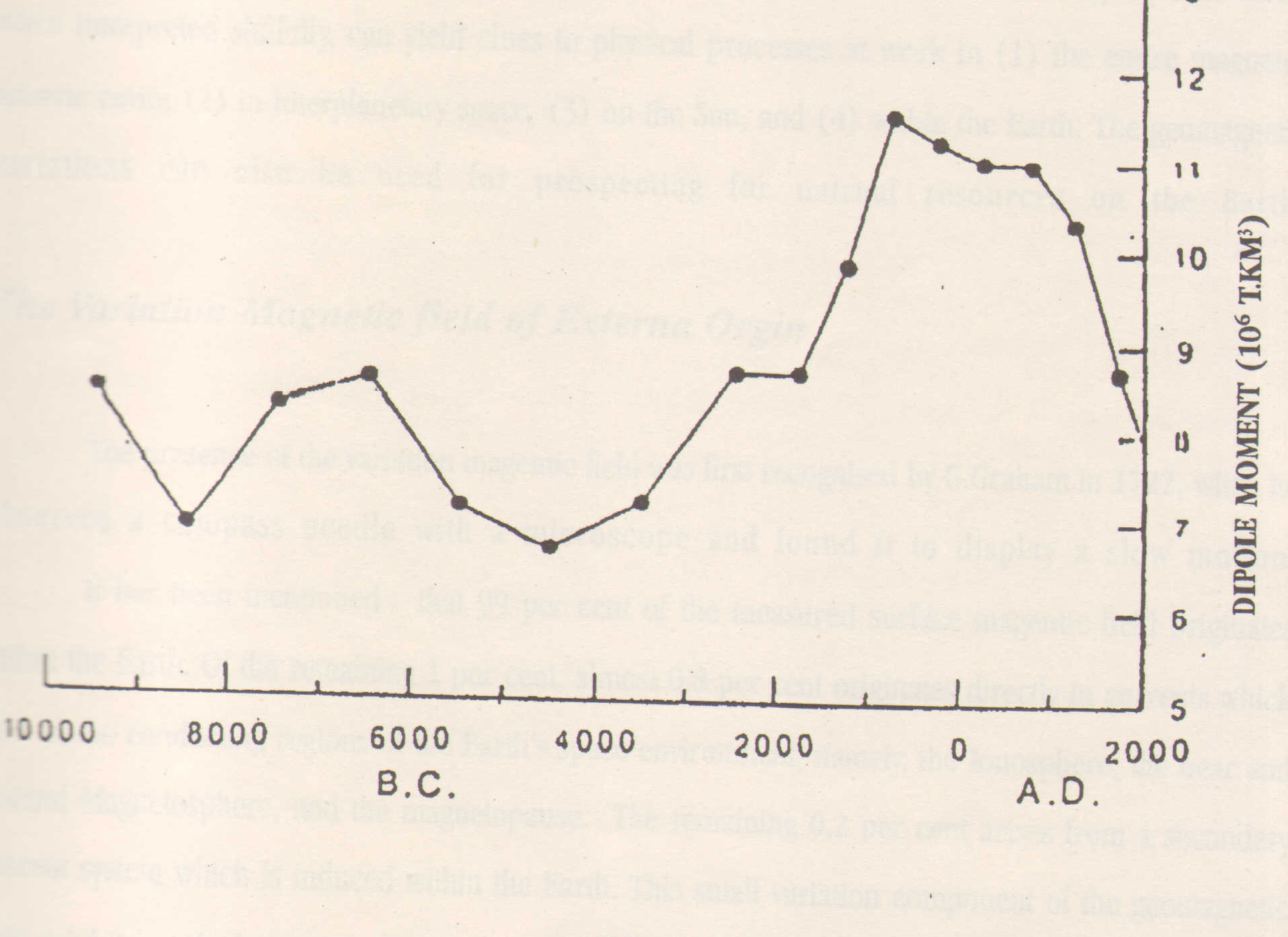
K-AR AGE (M.Y)
NORMAL DATA
REVERSED DATA
FIELD NORMAL
FIELD REVERSED
AGES OF BOUNDARIES
POLARITY EVENTS
POLARITY EPOCH
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0.02
0.03
0.69
0.89
0.95
1.61
1.63
1.64
1.79
1.95
1.98
2.11
2.13
2.43
2.80
2.90
2.94
3.06
3.32
3.70
3.92
4.05
4.25
4.38
4.50
LASCHAMP EVENT
JARAMILLO EVENT
GILSÁ EVENT
OLDUVAI EVENTS
KAENA EVENT
MAMMOTH EVENT
COCHITI EVENT
NUNIVAK EVENT
BRUNHES NORMAL EPOCH
MATUYAMA REVERSED EPOCH
GAUSS NORMAL EPOCH
GILBERT REVERSED EPOCH

they melt; while cooling, as they cross the Curie temperature, the ferromagnetic material takes up the direction of the prevailing magnetic field, and retains the same . This is called Thermo Remanent Magnetisation (TRM), and is perfectly preserved both in pottery and in rocks over very long periods of time. Geomagnetic reversals which have occured over the past 5 million years have been classified into events placed in a tabular scale (PETROVA et al. 1980) as shown in For a detailed treatment of geomagnetic field reversals, the reader is referred to JACOBS (1984)While the exact reason for reversals of the geomagnetic field is not known, there are conjectures which associate the event with cahnges in the internal molten outer core. For example, during the ICe ages, when ice covered the major part of the Earth's surcace, the angular momentum of the Earth and hence the rotation rate of its core could have changed . This could have brought about a differing attern of current flow within the Earth, and could have changed its magnetic field. It is conjectured that a reversal commences with asharp decrease in the magnetic field intensity, and a wandering of the magenetic poles, till they exchange places.

The Earths's magnetic moment has so far varied with a periodicity of about 7000 yr, with vcalues ranging from 6.5 to 11.5 x 106 T km3 . This period is believed to be natural period of the Earth's internal dynamo. There is another secular variation of 300 to 1000 yr, belived originate in convective motions within the geodynamo. Other periodcicities observed are 600 yr and 60 yr; and the attribute to inhomogeneous processes at the core - mantle boundary of the internal Earth.

b) Short -Period variations of the geomagentic field

Most of the short-period geomagnetic variations originate in the conductiong part of the Earth's upperatmosphere, in response to changes originating in the Sun. The geomagnetic field shows periodicities of 22 yr and 11 yr, and these are believed to originate repectively in the reversal of the Sun's magentic poles, and in its activity cycle. A periodicity of 1 yr is belived to be linked to the different Sun-Earth distances during the Earth's orbital motion around the Sun, and a semi-annual periodicity is understood to be ;inked with the differing tilt of Earth's axis of rotation with respect to the plane of the ecliptic.



DIPOLE MOMENT (10⁶ T.KM³)
13
12
11
10
9
8
7
6
5
10000
8000
6000
4000
2000
0
2000
B.C.
A.D.
YEAR

At the faster end of the spectrum are: (1) the 27-day variation connected with solar active regions rotating with the Sun's period of rotation; (2) the 24-hr variation and its sun-harmonics connected with sunrise and sunset (referred to as the sq; variation); (4) the variation asdsociated with the growth and decay of substorms; (6) periodicities of a few minutes to an hour which are set up due to (a) Xrays from solar flares, or (b) decreased currents in the ionosphere caused by rapid recombintion of ionisation during a solar eclipse; and finaly (7) pulsations with perods ranging from 0.3 sec to 30 min, which originate in the distant magnetosphere, but are yet to be understood cleraly. Atmospheric lighting too leaves an oscillatory signature with periods of <0.1 sec.

The variations in the geomagentic field recorded on the ground or in the magnetpheric cavity, when interpreted skilfully, can yield clues to physical processes at work in (1) the entire magnetospheric cavity, (2) in interplanetary space, (3) on the Sun, and (4) within the Earth. The geomagnetic variations can also be used for prospecting for natrual resources on the Earth.

The Variation Magnetic field of Externa Orgin

The presence of the variation magentic field was first recognised by G.Graham in 1722, when he observed a compass needle with a microscope and found it to display a slow motion.

It has been mentioned that 99 per cent of the measured surface magentic field originates within the Earth. Of the remaining 1 per cent, almost 0.8 per cent originates directly in currents which flow in the conducting regions of the Earth's space environment, namely, the Ionosphere, the near and distand Magnetosphere, and the magnetopause. The remaining 0.2 per cent arises from a secondary current system which is induced within the Earth. This small variation component of the geomagnetic field exhibits marked variations of both regular and irregular kind, and it can be as small as 100 nT in a background total field of about 40,000 nT. The variation field is namily caused by (1) thermal tidal forces in the atmosphere caused by solar heating,(2) interaction of the Earth's gaseous and plasma environment with charged particles, and wave radition intermitently emitted by the Sun, and (3) gravitational tidal pulls exerted on the Earth's gaseous environment, predominantly by the Moon, and to a lesser extent by the Sun.

Variations during Solar Quiet periods

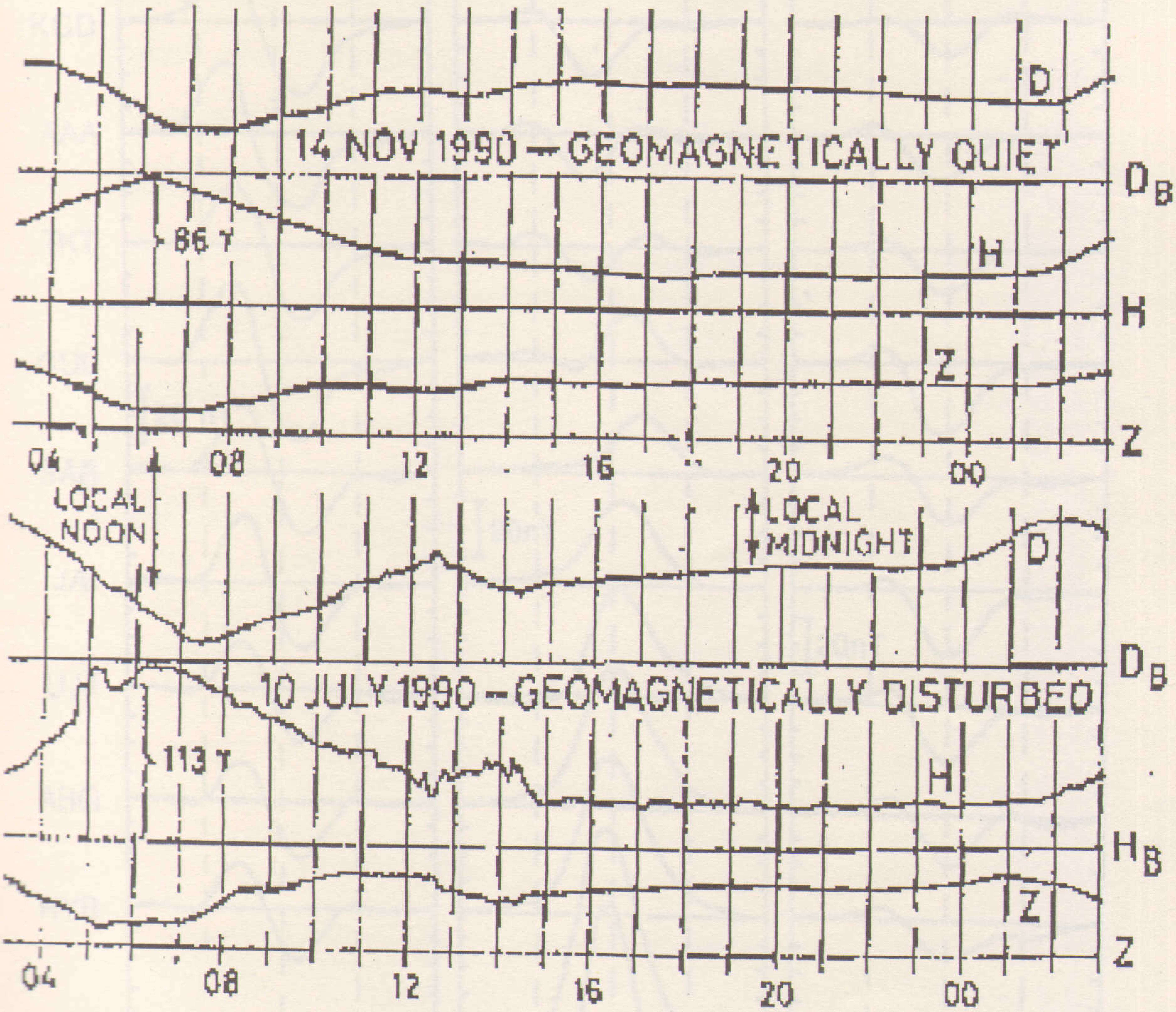
The Quiet (sq)variation - role of the Earth's ionosphere

At the most places on the Earth, during what are called Solar quiet (sq) days, the measured geomagentic field starts rising in value at about 06 hr LT, reaches a peak at 11-12 LT, and regains low levels at 17-18 LT. Thereafter, it remains at almost the same level all night, or it can show a slight decrease till 23 LT. This variation is called the sq (Sloar Quiet) variation. It is caused by the factthat as the Earth rotates, its gaseous atmosphere on the dawn side starts coming under the influnce of solar Extreme Ultra Violt (EUV) radition. This EUV radition is selectively absorbed at different altitudes above 60-80 km by the gases which comprise the Earth's upper atmosphere.

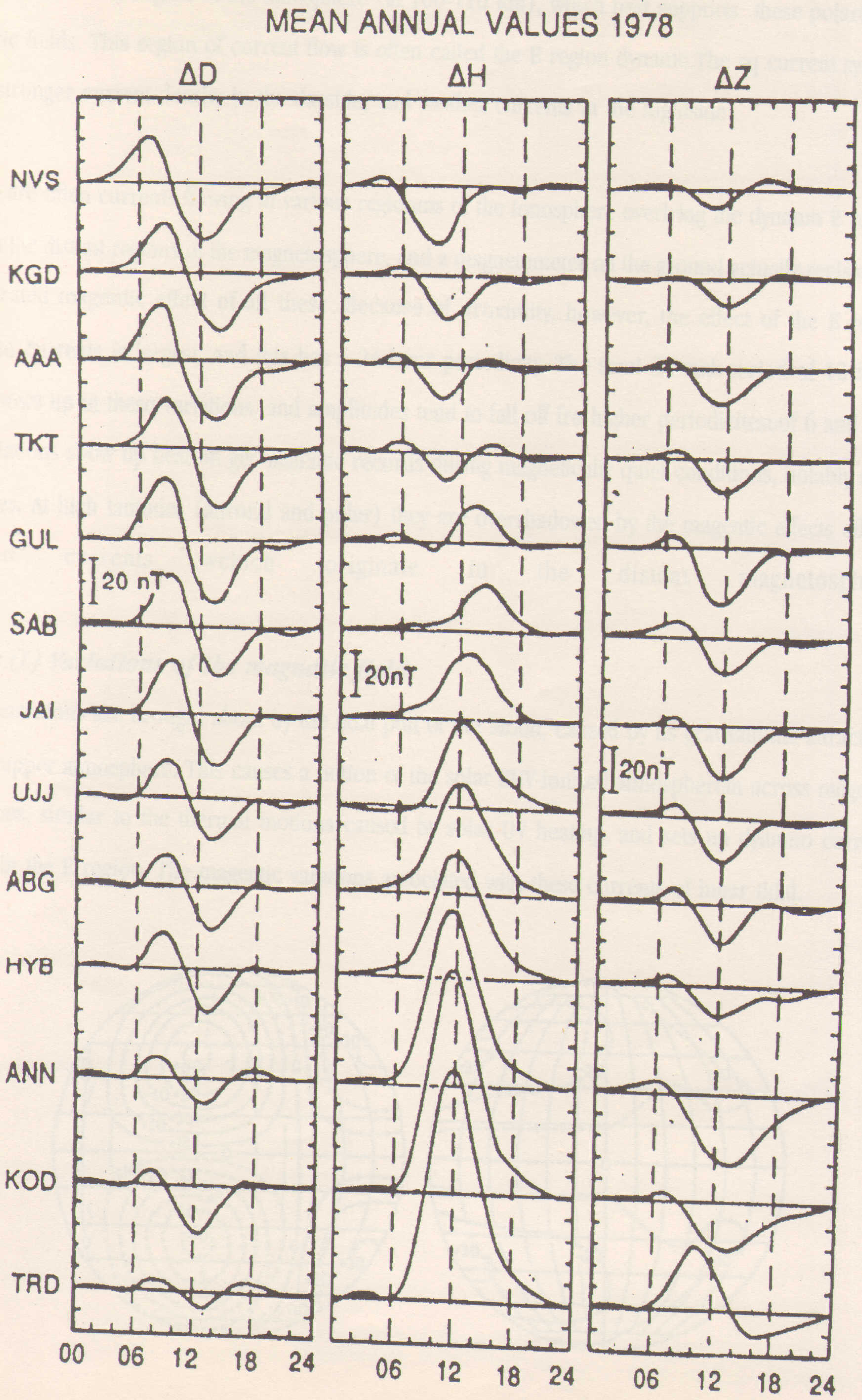
This causes ionsation of the gases,so that a conducting medium of free electrons and ions (mainly postive at altitudes> 90km, negative at altitudes<90km), is formed, and electrical currents flow in the region. This region is called the ionosphere, and the vertical profile of the obsreved electorn density classifies it into the D,E,F,(F_1 and F_2 by daytime) regions, and the Topside Ionosphere.One of the [ractical uses of the ionosphere generated a great deal of research interest over the first seven decades of the twentieth century. After satelite communications in the CH_z range has become relatively less important, although it is still importat in commercial broadcasting.

The sq variation is belived to originate in thermal tides, rather than in gravitational tides, because if the latter were to be responsible, the variation field causded by the Moon would be for lager than that due to the Sun. However, this is not observed to be the case. The sq cariation originates in currents which are set up in the conducting ionosphere. The EUV component of solar radiation on the dayside, apart from ionising the atmosphere, causesw thermal heating of the same. Pressure gradients are set up, and thermal tides pull all three constituents of the atmosphere - neutral, ion and electron - along and across the magentic field ;ines. This dynamo-like action gives rise to currents which flow a right angles to the directions of both the charged particle motion and the magentic field. Currents in avertical direction are less easily sustained (except at high latitudes,. and in a narrow belt in the

ALIBAG RECORD OF GEOMAGNETIC ELEMENTS



MEAN ANNUAL VALUES 1978

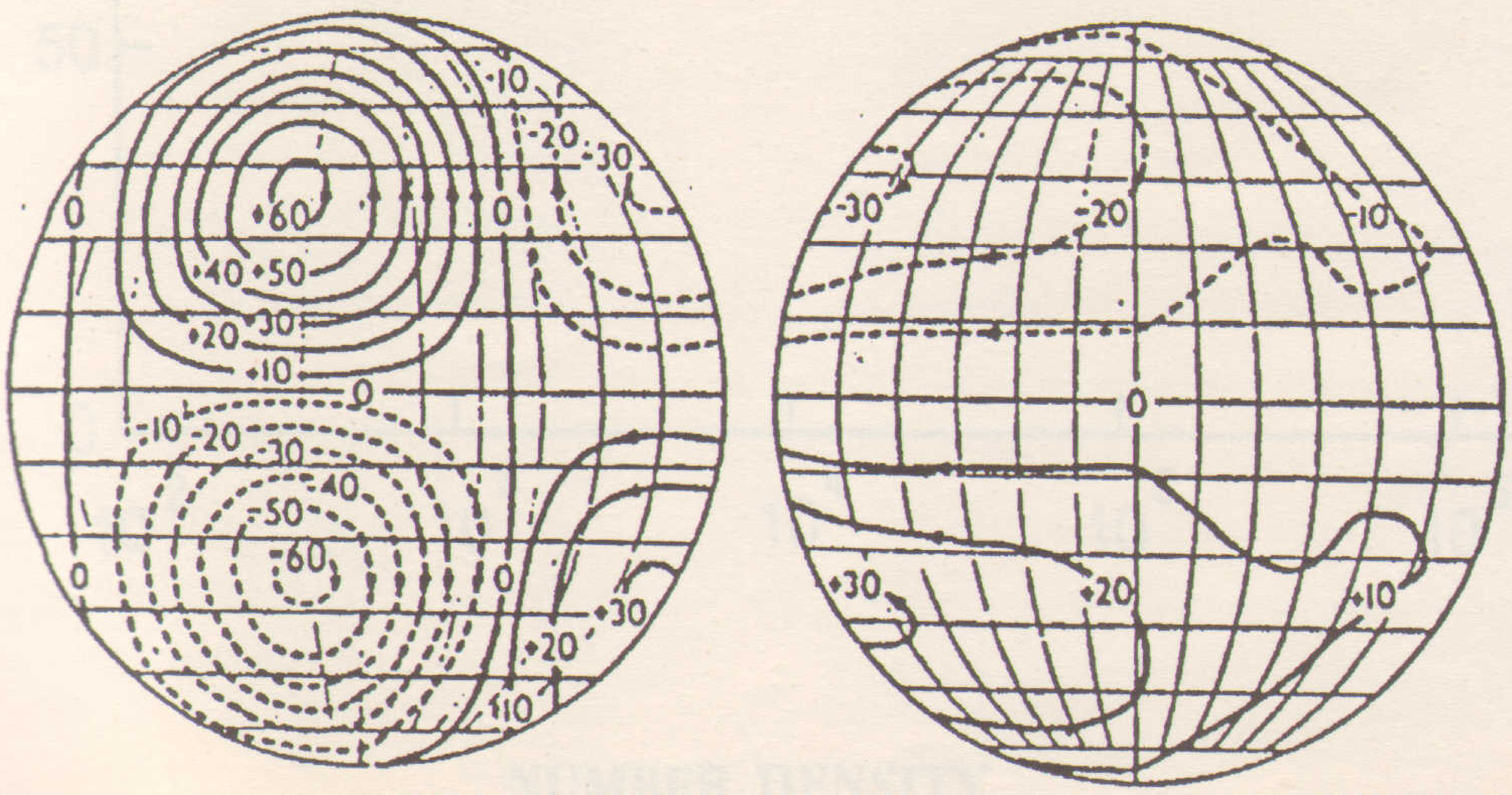


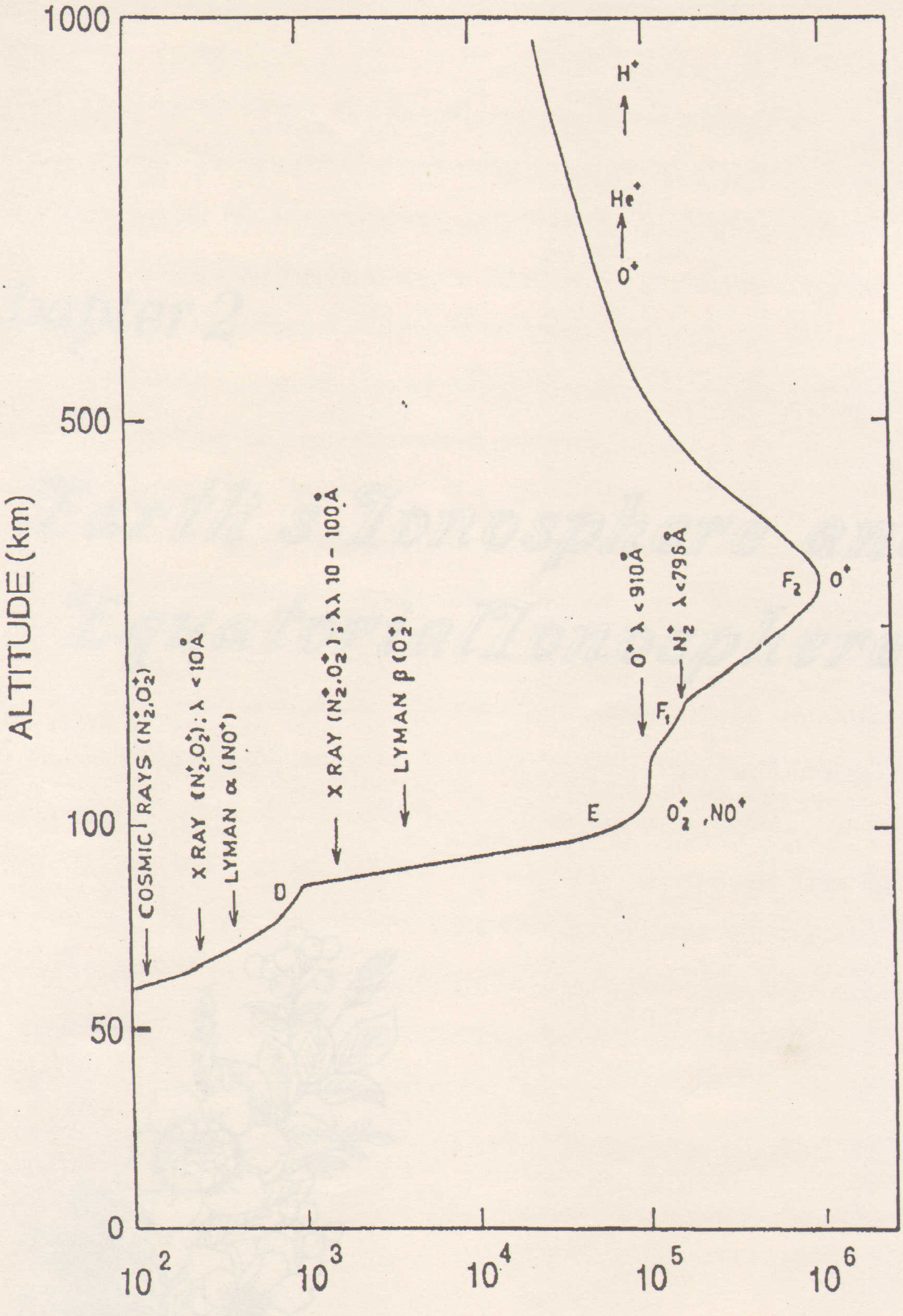
inclined magentic field lines. Most of the currents therefore flow in the north-south and east-west directions in the E region of the ionosphere (at 100-110 km), which best supports these polarisation electric fields. This region of current flow is often called the E region dynamo.The sq current system , with stronger current density in the dayside, and weaker currents in the nightside

There are often currents flowing in various regionms of the ionosphere overlying the dynamo E region, and in the distant regions of the magnetosphere, and a magnetometer on the ground actually registersthe intergrated magentic effect of all these. Because of proximity, however, the effect of the E region dyanmo currents is largest, and this has a 24-hour periodicity. The semi-diurnal period of 12 hours also shows up in thesq variations, and amplitudes tend to fall off fro higher periodicitesnof 6 and 3 hr. sq cariations show up best on geomagentic records during magnetically quiet conditions, notably atlow latitudes. At high latitudes (auroral and polar) they are overshadowed by the magentic effects offield-alinged currents wchich originate in the distant magnetosphere.

Lunar (L) Variations of the magnatic field

These variations are brought about by the tidal pull of the Moon, caused by its gravitational attractions on the upper atmosphere. This causes a notion of the solar EUV-ionised atmospherem across magentic field lines, similar to the thermal motions caused by solar UV heating, and sets up dyanmo currents mainly in the E region. The magentic varations associated with these currents of lunar tidal.





NUMBER DENSITY

Chapter 2

Earth's Ionosphere and Equatorial Ionosphere

Earth 's Ionosphere

Introduction

The ionosphere is the part atmosphere where electron density is sufficiently to affect the propagation of radio waves. The conventional ionosphere starts from of height of about 50 km and extends to about 100 km. However. the outer ionosphere extends far out into space electron density (el.cm-3) still exceeds 10^4 at 5000 km, and remains as large as 10^2 at 100,000 km. As a plasma medium the ionosphere consists of equal numbers of positively and negatively charged particles. The positive charges are carried by positive ions but relatively few negative ions also exits in some parts of ionosphere. Overwhelming part of negative charge is carried by electrons.

One of the ways of defining ionospheric regions of the spices of ions that compose them. In ascending order of height the following regions of the ionosphere may be recognized: D,E,F (subdivided in F_1 and F_2 in daytime), heliosphere and protonosphere. The D region extends from about 50-90 km altitude. The positive ions are dominantly NO^+. The negative charge is carried not only by electrons but also partly by O-2 and partly by some other negative ion species. In the E and F_1 regions electrons carry b practically all the negative charges while the positive ions are mostly O^+_2, NO^+ . The E region is form about 90 150 km and the F_1 regions from about 150-200 km height . In the F_2 region the heliosphere and protonosphere the negative charges are carried almost entirely by electrons. The dominantly positive ions are O^+ in F_2 region is not clear but the region may be considered as lying between 200 and 500 km. Thereafter, the heliosphere and protonosphere follow in that order but the boundaries are ill-defined.

In any part of the ionosphere the electron density N_c is determined by equation of continuity for electrons.

$$dNe/dt = P(Ne) - L(Ne) - V.(NeV),$$

Where $P(N_c)$ is the rate of production of electrons, $L(N_c)$ is the rate of loss of electrons mostly thought chemical processes, div(Nc V) is the rate of outward transport of electrons, and V is the mean velocity of electrons. Similarly, the continuity equations for positive and negative ions may be written by replacing Nc with N+ or N-. Below we consider the three terms which determine that rate of electron density after the other.

Production of Ionospheric Plasma

Outside the polar regions the predominant source of plasma production in the ionosphere is photoionization. In this process, a constituent atom or molecule X in the earth's atmosphere is ionized on the absorption of a photon hv of Solar radiation and it releases as electron e,

$$X + hv \rightarrow X^+ + e$$

The solar radiation principally consists of ultraviolet and X-rays but the full range will be discussed below. Also high temperature can cause some production through chemical processes like collisional excitation, dissociation and ionization.

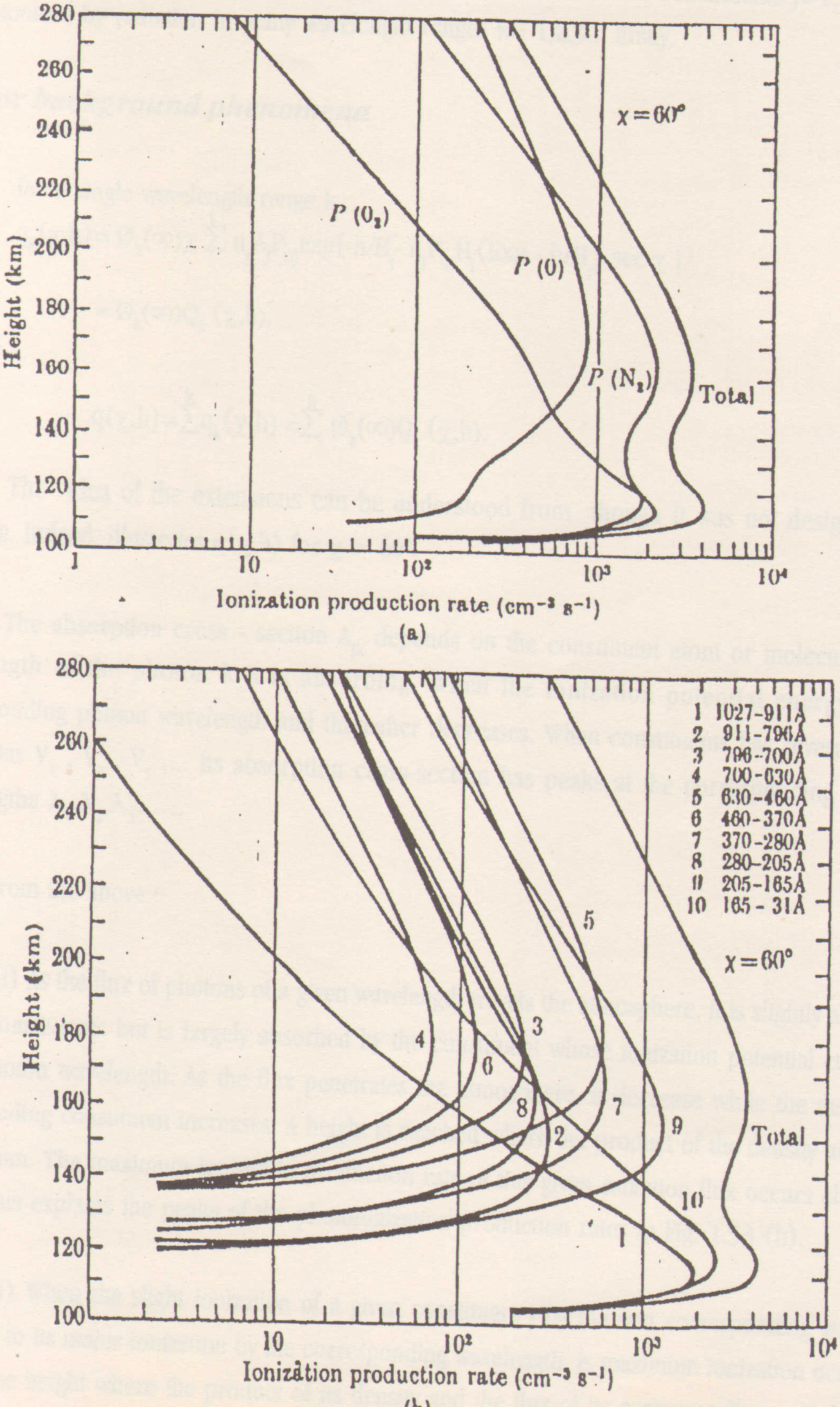
$$X + M \rightarrow X^+ + e + M,$$
$$X + Y \rightarrow XY^+ + e,$$
$$X + Y + Z \rightarrow X^+ + e + YZ,$$
$$WY + XZ \rightarrow WX + YZ^+ + e.$$

However, these processes are relatively rare and consequently low in their yield. In the polar regions a significant source of ionisation is the precipitation of energetic particles from magnetospheric sources.

We now outline the spectrum of solar electromagnetic radiation responsible for the ionization is the precipitation of energetic particles form magnetospheric sucroses.

We now outline the spectrum of solar electromagnetic radiation responsible for the ionization of the upper atmosphere. the major wavelength regions of interest are:

(i) The broad Schumann continuum from 135-175 nm, the far-ultraviolet responsible for the dissociation of O2.


Height (km)
280
260
240
220
200
180
160
140
120
100
P (O2)
P (0)
P (N2)
Total
χ = 60°
1
10
10²
10³
10⁴
Ionization production rate (cm⁻³ s⁻¹)
Height (km)
1 1027-911Å
2 911-796Å
3 796-700Å
4 700-630Å
5 630-460Å
6 460-370Å
7 370-280Å
8 280-205Å
9 205-165Å
10 165 - 31Å
χ = 60°
Total
10
10²
10³
10⁴
Ionization production rate (cm⁻³ s⁻¹)

(a)

(b)

This theory developed ny Chapman (1931) has been found very useful in the study of the ionosphere, especially the E region ever since then. Fig (1,52) shows the distribution of ion production $q(\chi,z)$ q_o as a function of reduced height z for different values of solar zenith angle x. It is easy to extend the photoionization rate to the case of several consituients j=1, 2,3, ... being photoionized by radiation in many wavelength ranges k= 1,2,3,.. firstly,

Major background phenomena

for a single wavelength range k,

$$q_k(\chi,h) = \varnothing_k(\infty)\chi \sum^{j} n_j A_J P_{0J} \exp[-h/H_j - A_J P_{0J} H_j (\mathrm{Exp} - h/H_j) \sec \chi].$$

$$= \varnothing_k(\infty) Q_k(\chi,h).$$

Finally,

$$q(\chi,h) = \sum^{k} q_k(\chi,h) = \sum^{k} \varnothing_k(\infty) Q_k(\chi,h).$$

The idea of the extensions can be understood from though it was not designed for that purpose. Indeed, illustrates $q(\chi,h)$ for $\chi = 60^0$.

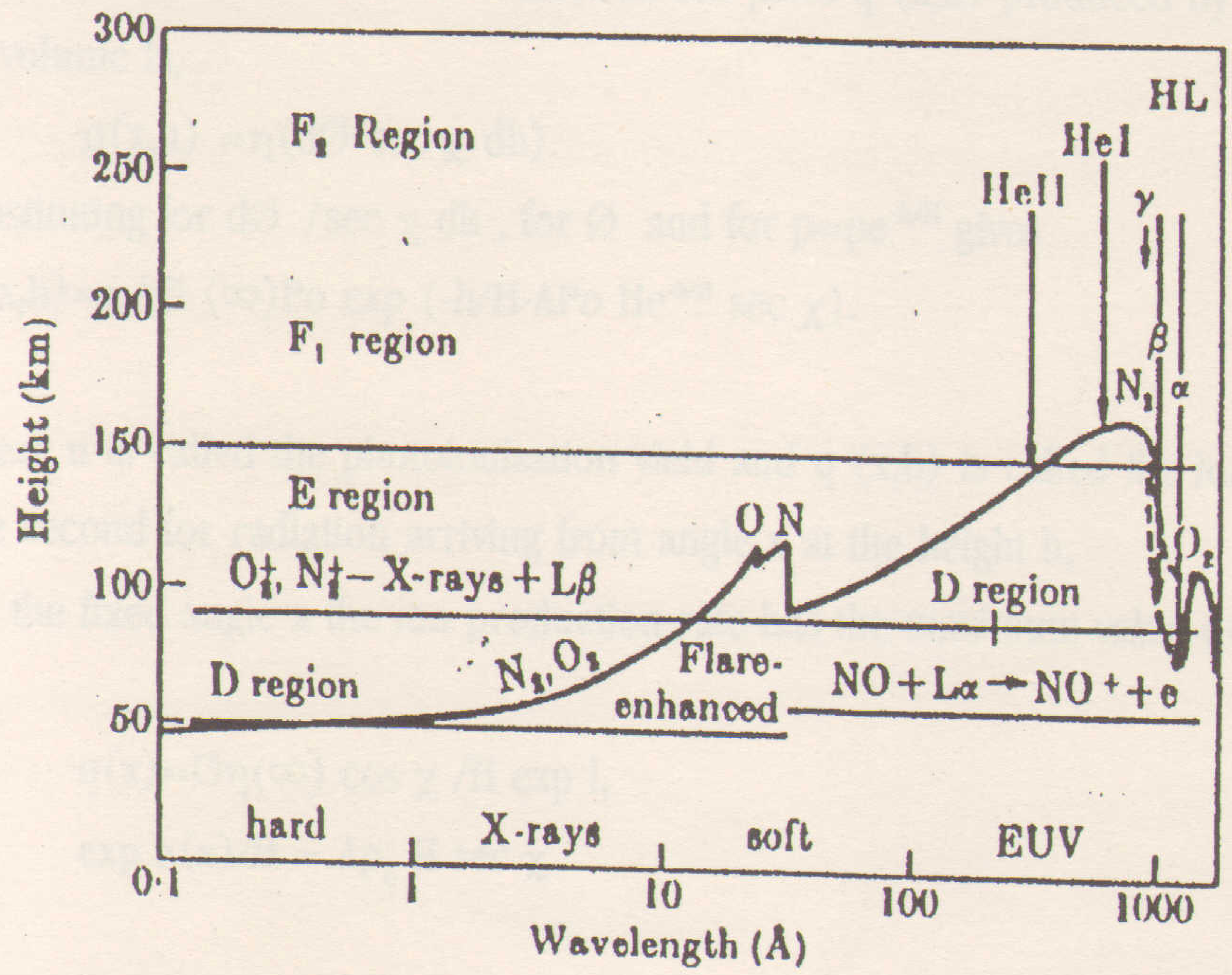
The absorption cross - section A_{jk} depends on the constituent atom or molecule j and the wavelength of the photon k it is absorbing. When the ionization potential energy eV of the corresponding photon wavelength and thereafter decreases. When constituents has several ionization potentillas V_1 , V_2 , V_3 ,... its absorption cross-section has peaks at the corresponding photon the wavelengths $\lambda_1,\lambda_2,\lambda_3$......

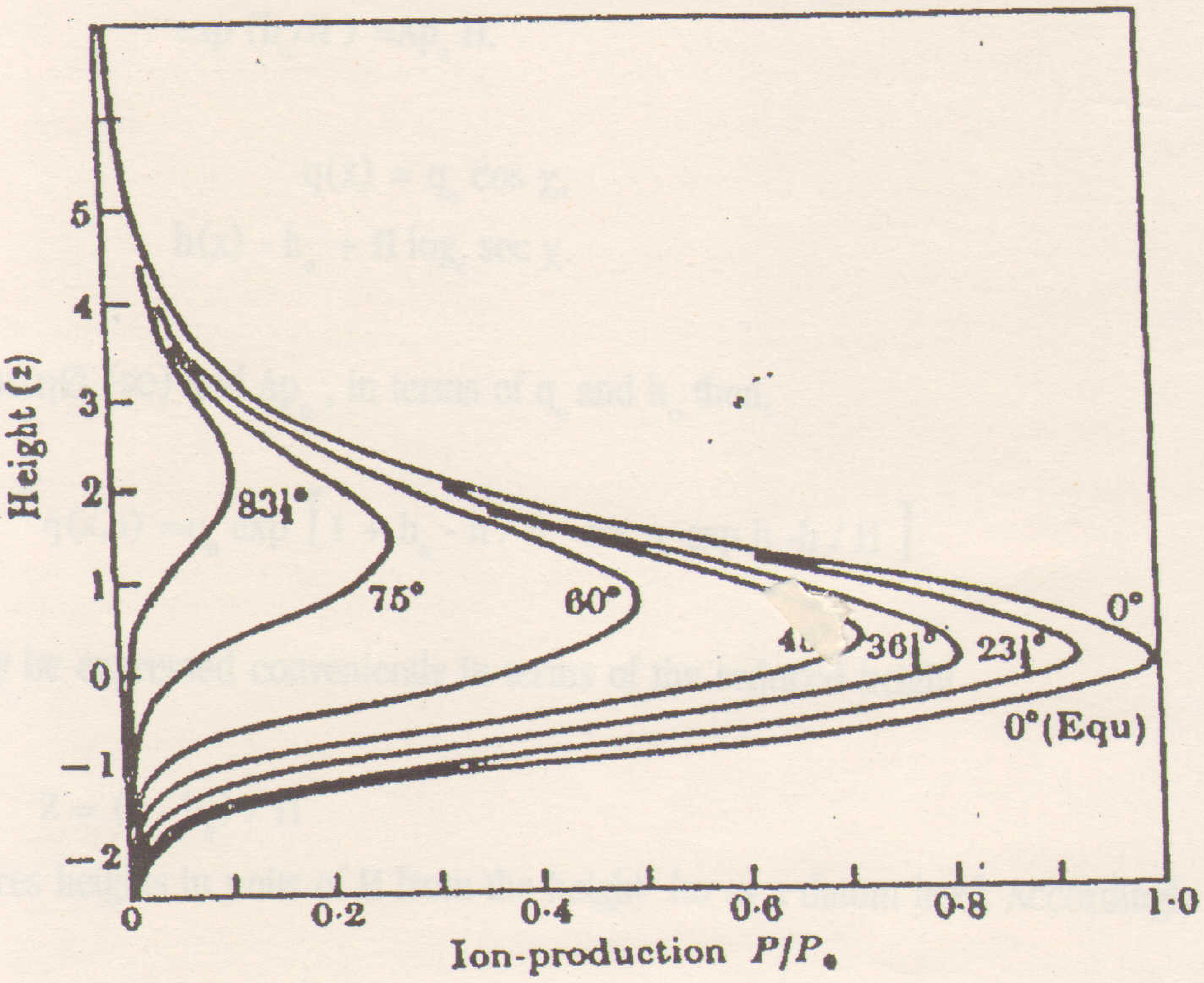
Arising from the above :

(i) As the flux of photons of a given wavelength travels the atmosphere, it is slightly absorbed by several constituents but is largely absorbed by the constituent whose ionization potential corresponds to the photon wavelength. As the flux penetrates the atmosphere, it decrease while the density of its corresponding constituent increases. A height is reached where the product of the density and the flux is maximum. The maximum ionization production rate of this given radiation flux occurs close to this height. This explains the peaks of the photoionization production rates in Fig. 1.53 (b).

(ii) When the slight ionization of a given constituent j by the non corresponding wavelengths are added to its major ionization by the corresponding wavelength, is maximum ionization occurs close to the same height where the product of its density and the flux of its corresponding wavelength is a maximum. Thus the peaks of the total ionization production rate Fig. 1.53 (a) obtained by adding the ionization production rates due to different wavelength ranges.

MAJOR BACKGROUND PHENOMENA





A is the absorption cross-section with the dimension of area. The value that absorbed do is sec χ dh and therefore the solar radiation energy absorbed per unit volume is d o sec χ dh. Let n be the number of electron - ion pairs produced by the absorption of unit quantity of radiation energy in the unit volume. Then the total number of electron-ion pairs q (x,h) produced by the radiation absorbed in the unit volume is,

$$q(x,h) = \eta(d\emptyset \sec \chi \, dh).$$

Substituting for $d\emptyset$ /sec χ dh , for $\emptyset$ and for $p=pe^{-h/H}$ gives

$$q(x,h) = \eta A\emptyset(\infty)Po \exp(-h/H - APo\, He^{-h/H} \sec \chi).$$

Where n is called the photoionization yield and q (x,h) is called the ion production rate per unit volume second for radiation arriving from angle x at the height h,

For the fixed angle x the ion production rate has the maximum value q(x) at the height h(x) where

$$q(x) = \emptyset\eta(\infty) \cos \chi / H \exp 1,$$

$$\exp h(x)/H = Ap_0 H \sec \chi.$$

The equatorial electrojet

Let the values of q(x) and h (x) doe x =0 be q_o and h_o when the sun is overhead. Then

$$q_o = \eta\emptyset(\infty) H \exp 1,$$

$$\exp(h_o/H) = Ap_o H.$$

Combining,

$$q(x) = q_o \cos \chi,$$

$$h(x) - h_o + H \log_c \sec \chi.$$

substitute for $\eta\emptyset$ (∞) and Ap_o , in terms of q_o and h_o then,

$$q(x,h) = q_o \exp \left[1 + h_o - h / H - \sec \chi \exp h_o - h / H\right]$$

Thus this may be expressed conveniently in terms of the reduced height

$$Z = (h - h_0) / H$$

which measures heights in units of H from the height ho as a datum level. Accordingly

$$q(\chi,h) = q_o \exp(1 - z - e^{-z} \sec \chi$$

It is seen that the reduced height z(χ) at the maximum value q (χ) is

$$z(\chi) = 1 \text{ nsec } \chi$$

These peaks of total ionization rates are related to the classical ionospheric regions. Although the loss and transport terms of Eq.(1.36) are yet to be taken into account, we begin to see how the Chapman photoionization theory explains the basis of ionospheric layer formation.

The calculation for D region needs to take into account the ionization production rate by galactic and solar comic rays. Cosmic rays are not electromagnetic radiation. Consequently, Mitra (1987) has recommended the following empirical expression for the estimate of the ionization production are q (CR) due to cosmic rays:

$$q(CR) = 1.5 \times 10^{-8} \left[1 - 3\times 10^{-3}(F_{10.7} - 70)\right] (M) \cos^4 0,$$

Where is the particle density of the atmosphere at the altitude z, 0 is geomagnetic latitude and $F_{10.7}$ is the flux of solar 10.7 radiation.

INTRODUCTION

The equatorial ionosphere os unique in many ways. Global scale action, i.e., generations of currents by electromotive forces due to tidal winds result in the generations of the planetary scale, east-west electric fields at low latitudes around the dip equator. These electric fields, in combination with the north-south magnetic fields result in different geophysical phenomena peculiar to the equatorial region. They are: (1) equatorial electrojet, (ii) the equatorial ionization anomaly (EIA or Appleton Anomaly) and the generations of plasma density irregularities. The generation of plasma density irregularities and the various plasma instability mechanisms that are responsible for them will be covered by fellow authors. Here, we restrict ourselves to the (i) equatorial electrojet and (ii) the equatorial ionization anomaly. (EIA or Appleton Anomaly)and the generation of plasma density irregularities. The generation of plasma density irregularities and the Various. Here, we restrict ourselves to the (i) equatorial electrojet and (ii) the equatorial ionization anomaly.

Equatorial Electrojet

Historically, the first observation of the daily variation in the earth's magnetic field by Graham [1724]and the proposal of the dynamo theory by Steward [1882] marketed the beginning. Chapman [1919] subsequently put dynamo theory by into mathematical form, assuming semidiurnal tidal motions as inferred by the pressure variations at the ground. The second breakthrough was provided by Breit and Tuve [1925] and Appleton and Barnett [1925] with the discovery of the conducting layers. With the installation of extensive ground-based network of magnetometers, thediscovery f enhanced variations of earth's magnetic field over the equator was made and later explained by Egedal [1974] to be due to enhanced east-west current flow in a narrow latitudinal belt of = 3 around thdip equator. This was later named by Chapmn [1951] as the 'equatorial electrojet'. The explanation for the electrojet was offered on the basis of basic electrodynamics of a horizontally stratified ionosphere with anisotropic conductivities in a horizontal magnetic field. In a magnetoplasma with the mutually perpendicular electric (E) and magnetic fields (B) Pedersen currents flow parallel to E and Hall currents perpen dicular to both E. and B. In the presence of almost nonconducting boundary above and below the dynamo region (80-140km), the flow of Hall currents are inhibited. Under such circumstances, the east-west conductivities are enhanced, increasing the flow of currents, namely, the 'equatorial electrojet'.

The next milestone in the understanding of the equatorial electrojet was marked by Untiedt [1967] who pointed out that the vertical current flow is indeed not totally inhibited over the equator in an electroject model which is mathematically self-consident. Permiting the vertical current flow resulted in a doubling of the equatorial northward magentic variation over the 'thinshell' value. The physics of the equatorial electroject was investigated in detail including thev vertical current flow, local time variations, longitudinal difference and the effects of local winds in the electrojet by Sugiura and Poros [1969]; Richmond [1973a,b]; Forbes and Lindzen [1976b]; Anandarao and Raghavarao [1979a,b;1987]; Raghavarao and Anandarao [1980]; and Reddy and Devasia [1981].

The initial investigations on the phenomenon of equatorial electrojet were either morphological or by synoptic studies of ground magnetic variations. Omwumechilli [1967] has reviewed these aspects. Forbes [1981] has comprehensively reviewed the state of our understanding giving emphasis to the more recent accomplishments.

Morphological Features:

The important points with regard to the electrojet (EJ), inferred from the ground magnetic variations are:

(i) The maximum contribution to the geomagnetic variation by the electrojet coincides with the dip equator [Onwumechilli, 1967; Fambitakoye and Mayaud,1975], the true center of EJ to be coincident with the average location of the dip equator within any 30 longitude sector.

(ii) There is no seasonal dependence for the EJ center.

(iii) The latitudinal extent is inferred to be about 600 km.

(iv) The EJ is wider over Peru by about 30% that over Nigeria.

(v) The day-to-day variability in the width of the EJ has been shown to about 20% [Burrows,1970].

(vi) The strength of EJ has been shown to vary with longitude and it seems to have an inverse relation to the earth's magnetic field B [Rastogi, 1962; Rastogi and Trivedi, 1970; Gupta,1973].

(vii) The equatorial amplitudes of the diurnal and semidiurnal harmonics of the ground magnetic (H)varaitions increase linearly with the Zurich sunspot number [Rastogi and Iyer, 1976]. The solar activity control is further brought out from the observations of the local times of maxima which increase from 1110 hrs LT for the dirunal phase and form 1120 hrs to 1220 hrs LT for the semidiurnal phase as R increase from 0-200. The net effect is that at sunspot maximum, the daily maximum in 'H' is at 1100 LT while at sunspot minimum it is 1200 hrs LT.

Rocket and Satellite Observations

One of the major breakthroughs in the understanding of EJ is by in situ measurements which became possible after the advent of sounding rockets and suitable measuring techniques. The intensity, altitudinal structure, their possible diurnal and day-to-day variabilities and the latitudinal width of EJ have been investigated by rocket-borne magnetometers.

Important Results

(1) The current density (J) profile at the dip equator is narrower and occurs about 5 km higher(107km) than 100-200km away.

(2) Measurements from India revealed significant day-to-day variabilities in amplitude but exhibit similar shapes at the same altitude of 104-106 km as opposed to 108 km from Peru.

(3) Presence of secondary current maxima have been recorded over Peru and India

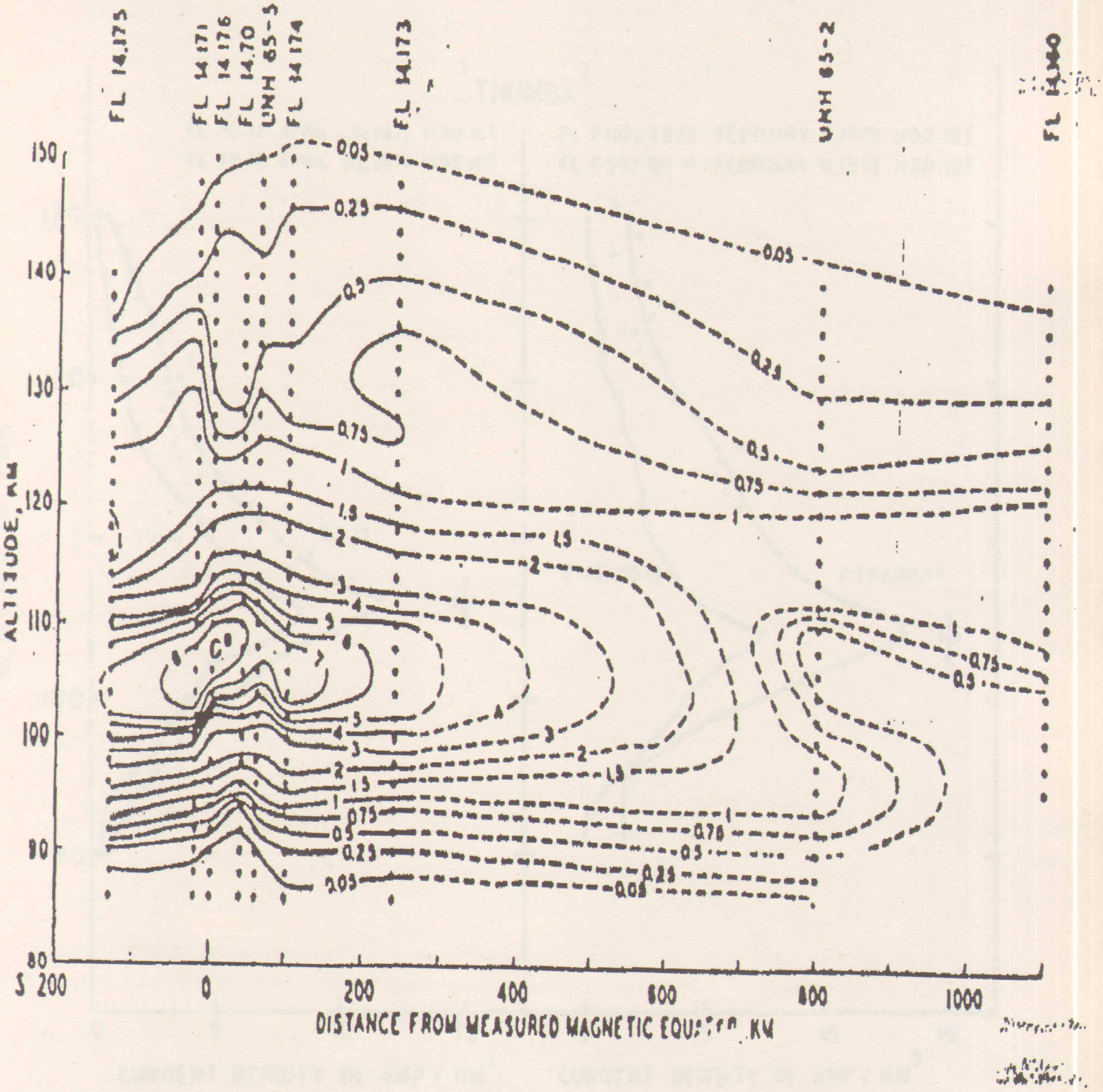
(4) Meridional currents of twice the amplitude of that predicted by Untied's model were detected. Recent model investigations by Anandarao and Raghavargo [1987] reveal that such enhancement is possible with meridional winds.

1.7 Counter Electrojet

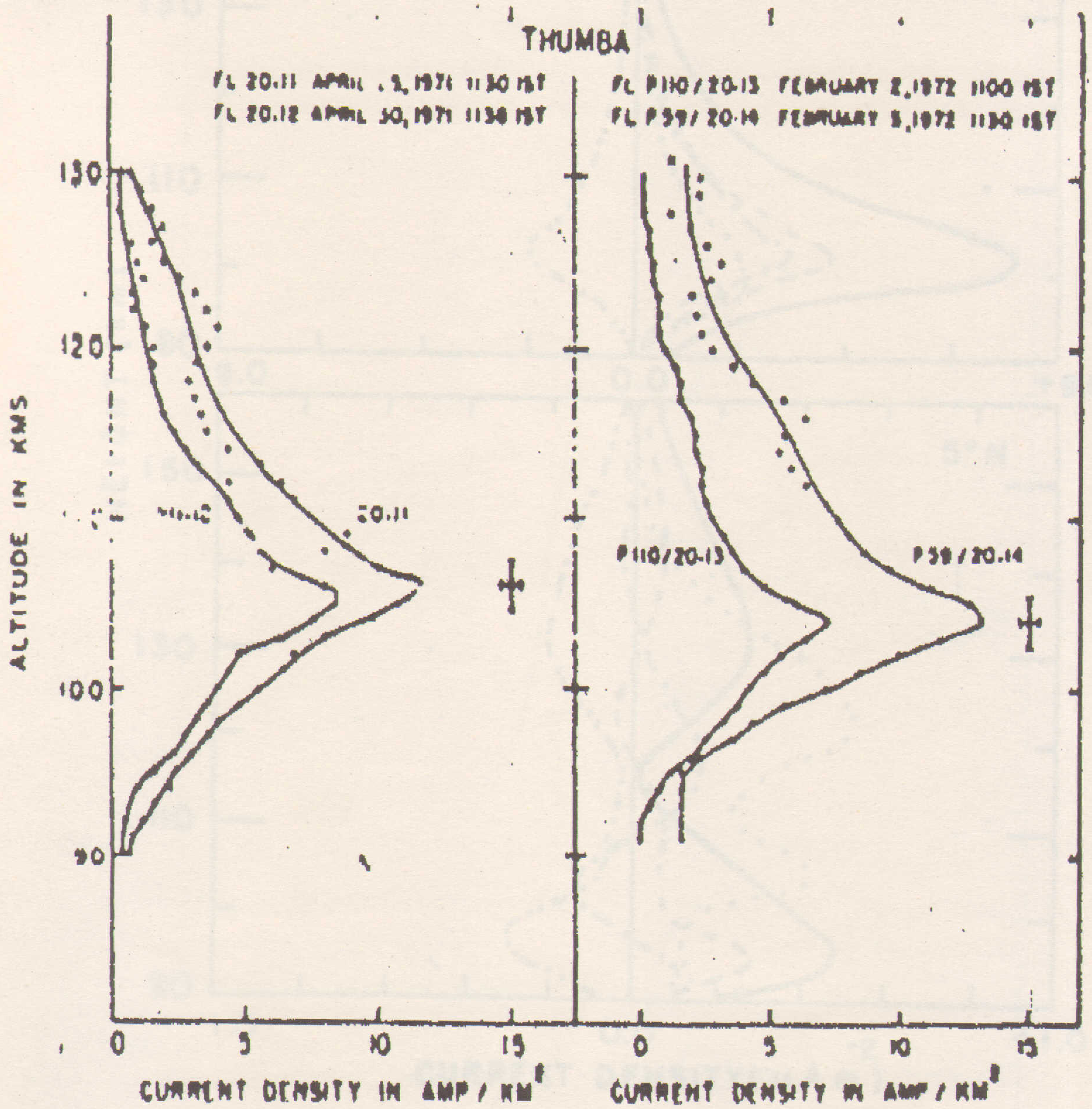
Continues monitoring of ground magnetic observations revealed that on certain days the AH showed negative depressions. As there events are apparently associated with the reversals in the daytime eastward currents of the EJ, it was known to be called as the 'counter electrojet' [Gouin and Mayaud, 1967]. Rastogi [1974] analyzed many CEJ events. The main characteristics of CEJ can be summarized as follows:

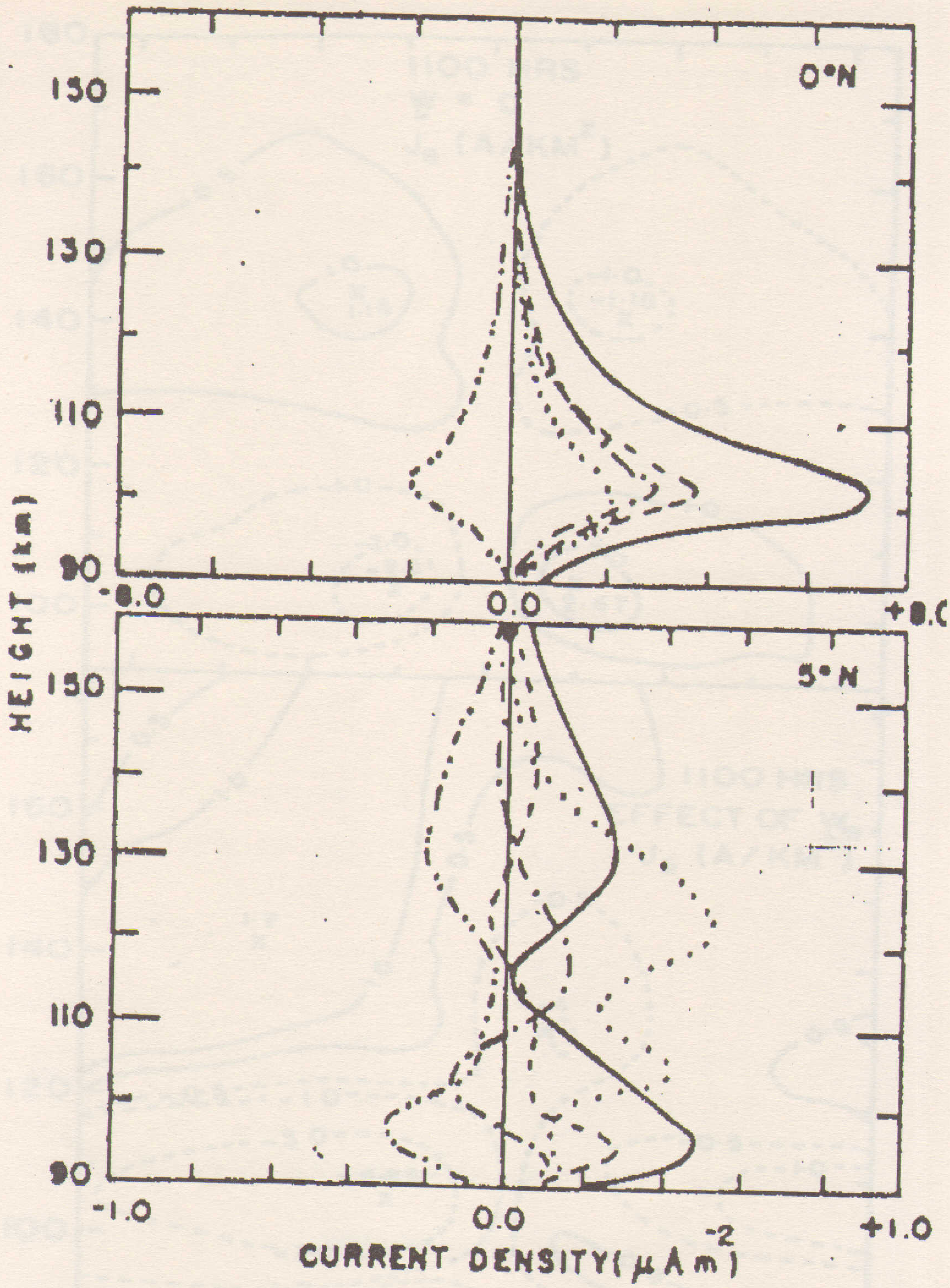
(1) These event occur during sunrise (0600-0800hrs) and in the afternoon hours (1400-1800 LT) with peak occurrence around 1500 hrs. On certain occasions, the depression in the afternoon period can be as large as that daytime peak value of AH.

(2) The occurrence of afternoon CEJ is more frequent during solar minimum periods and inversely varies with sunspot cycle. The morning CEJ occurrence does not reveal any such systematic behavior.

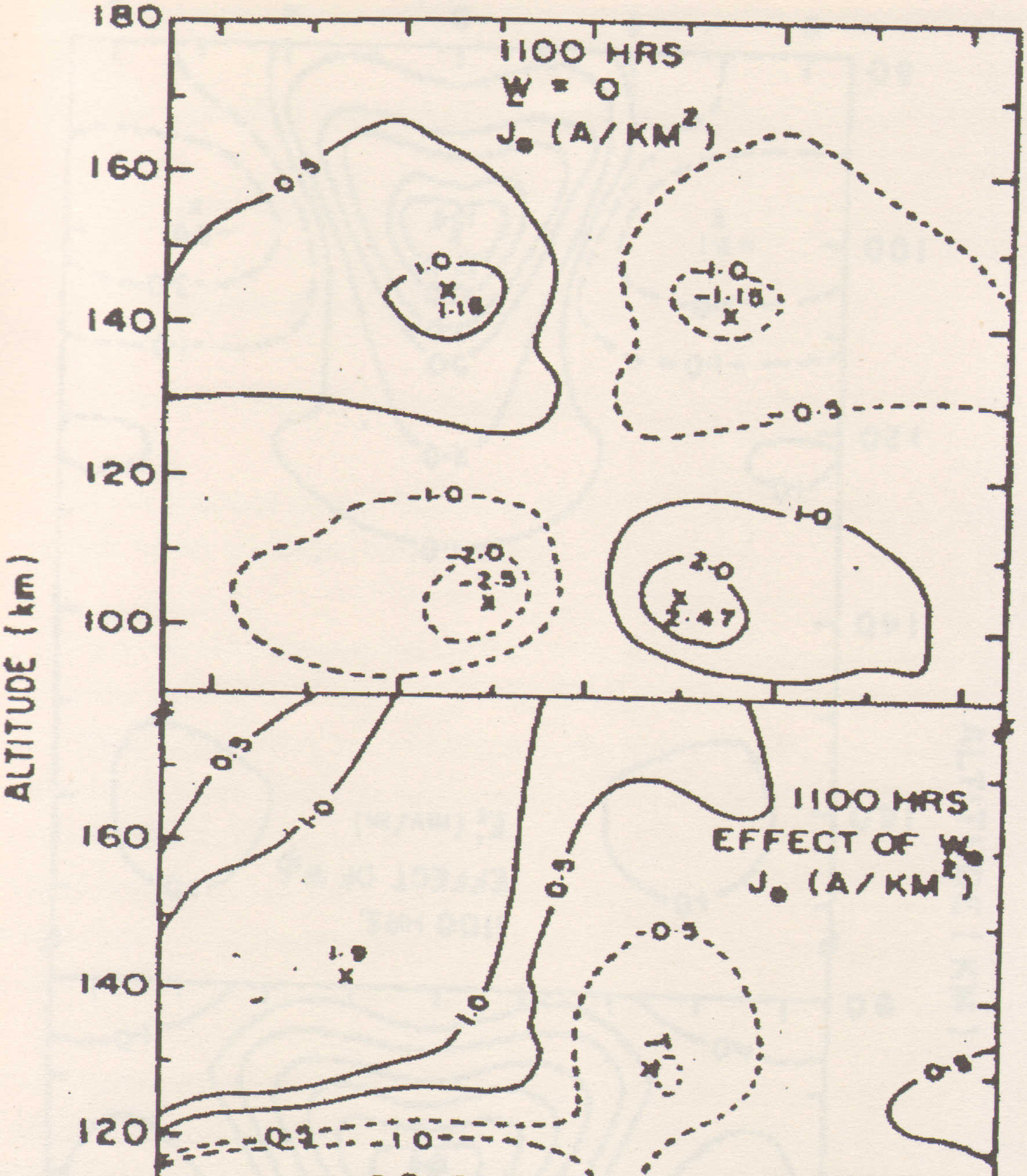


DISTANCE FROM MESURED MAGNETIC EQUIPMENT

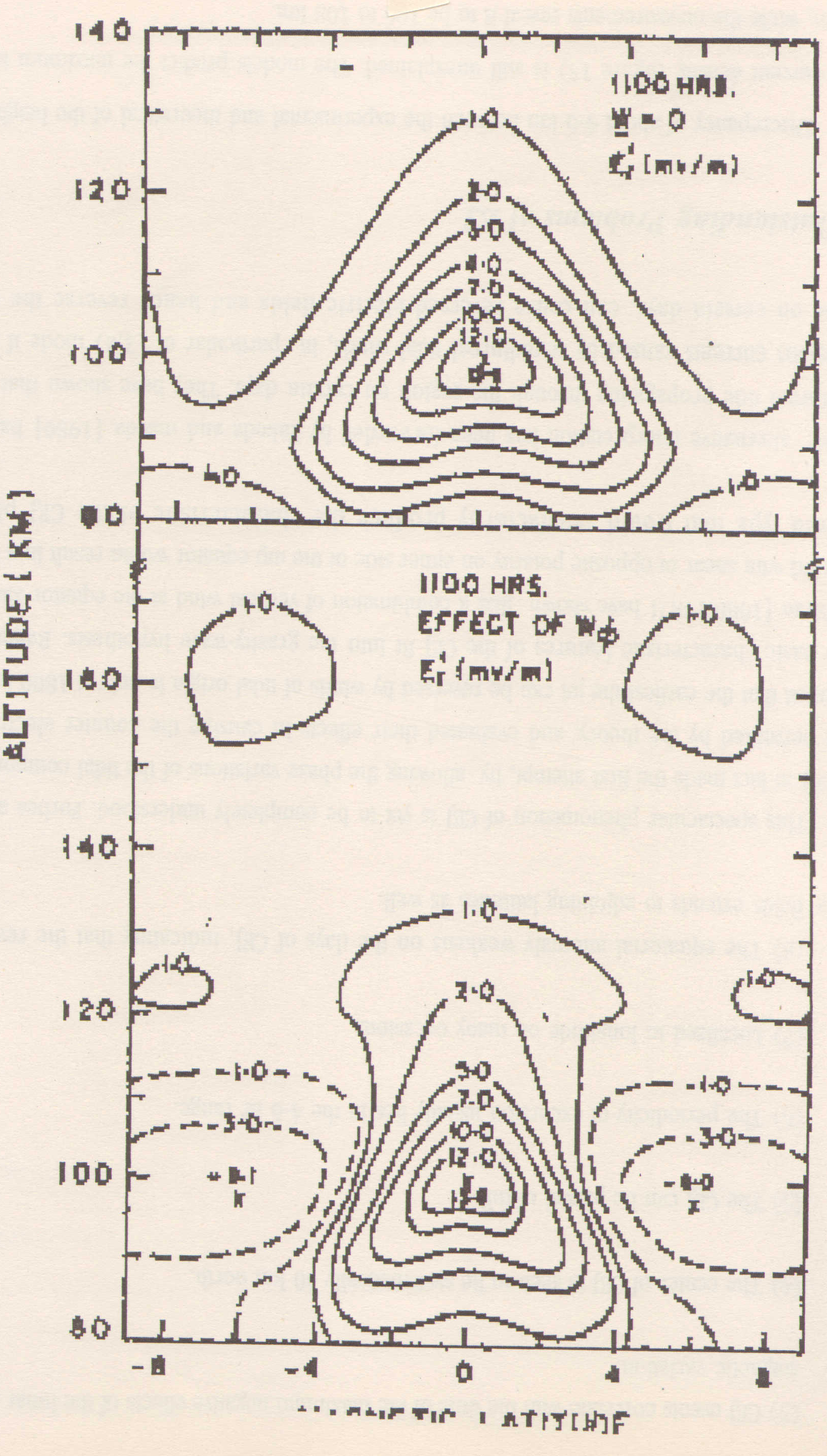

THUMBA
FL 20.11 APRIL .3, 1971 1130 IST
FL 20.12 APRIL 30, 1971 1130 IST
FL P110/20.13 FEBRUARY 2, 1972 1100 IST
FL P59/20.14 FEBRUARY 5, 1972 1130 IST
ALTITUDE IN KMS
20.11
P110/20.13
P59/20.14
CURRENT DENSITY IN AMP / KM²
CURRENT DENSITY IN AMP / KM²



CURRENT DENTSITY



1100 HRS
W = 0
J_ϕ (A/KM^2)
0.5
1.0
1.18
-1.0
-1.18
-0.5
-1.0
-2.0
-2.5
1.0
2.0
2.47
1100 HRS
EFFECT OF W_ϕ
J_ϕ (A/KM^2)
0.5
1.0
1.9
-0.5
-1.0
-3.0
-4.65
-0.5
-1.0
0.5
ALTITUDE (km)
MAGNETIC LATITUDE
180
160
140
120
100
80
-8
-4
0
4
8



MAGNETIC LATITUDE

(3) CEJ events correlate with the time of the maximum negative effects of the lunar semidiurnal magnetic variation.

(4) The center of CEJ is seen to lie systematically 40 km north.

(5) The CEJ can be partial of full.

(6) The periodicity of excursion usually lies in the 4-6 hr range.

(7) Localized in longitude on many occasions.

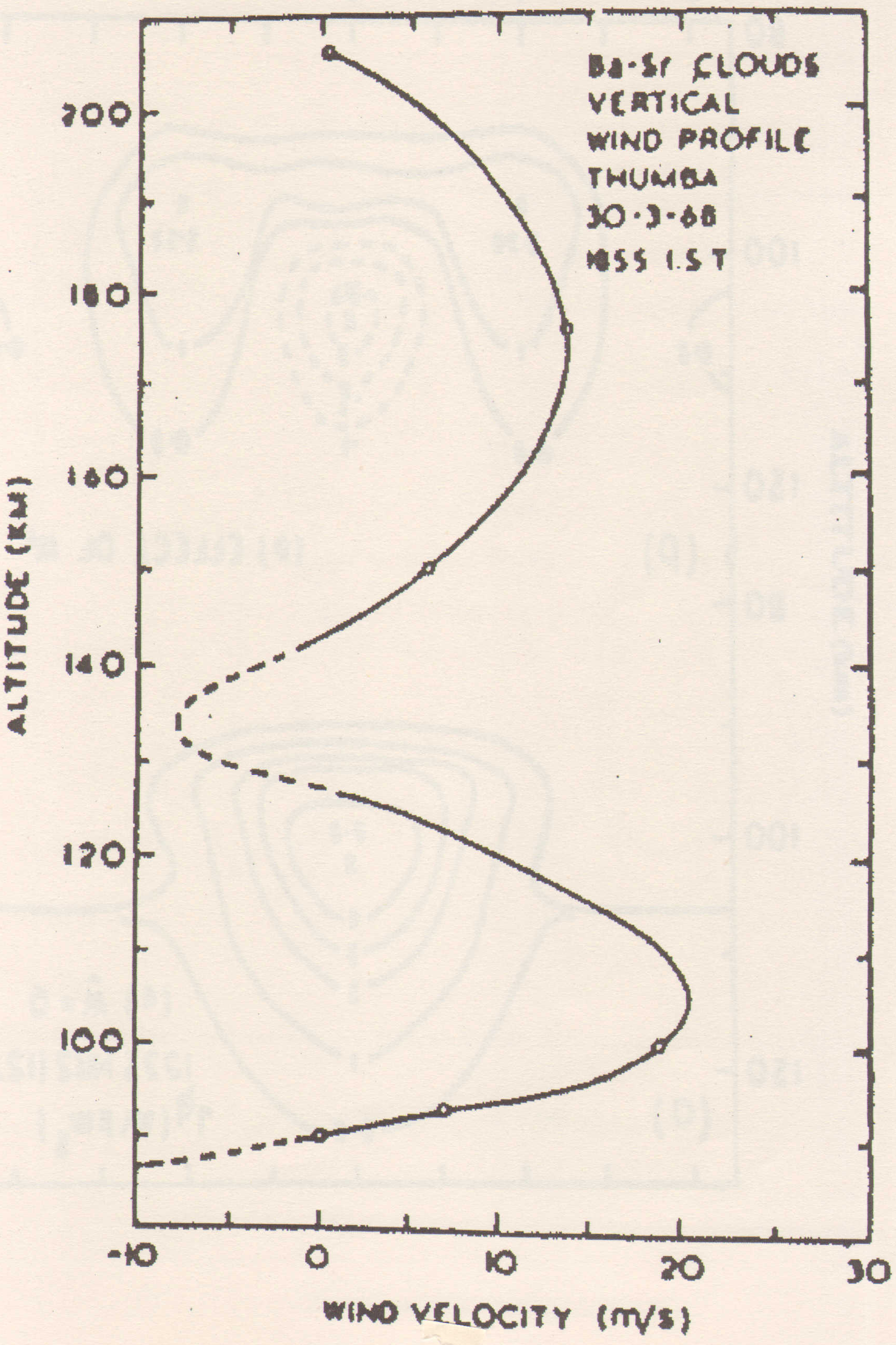
(8) The equatorial anomaly weakens on the days of CEJ, indicating that the reversal of sq electric fields extends to adjoining latitudes as well.

This spectacular phenomenon of CEJ is yet to be completely understood. Forbes and Lindzen [1976b] in fact made the first attempt, by allowing the phase variations of the tidal components to the extent permitted by the theory, and evaluated their effects in causing the counter electrojet . They concluded that the earliest the jet can be reversed by winds of tidal origin is only at 1800 hrs LT. Many of the basic characteristic features of the CEJ fit into the gravity-wave hypothesis. Raghavarao and Anandarao [1980.1987] have shown that a combination of vertical wind at the equator and a meridional wind with shear of opposite polarity on either side of the dip equator would result in a wave of the required type that would satisfactorily produce the characteristic of the CEJ phenomena

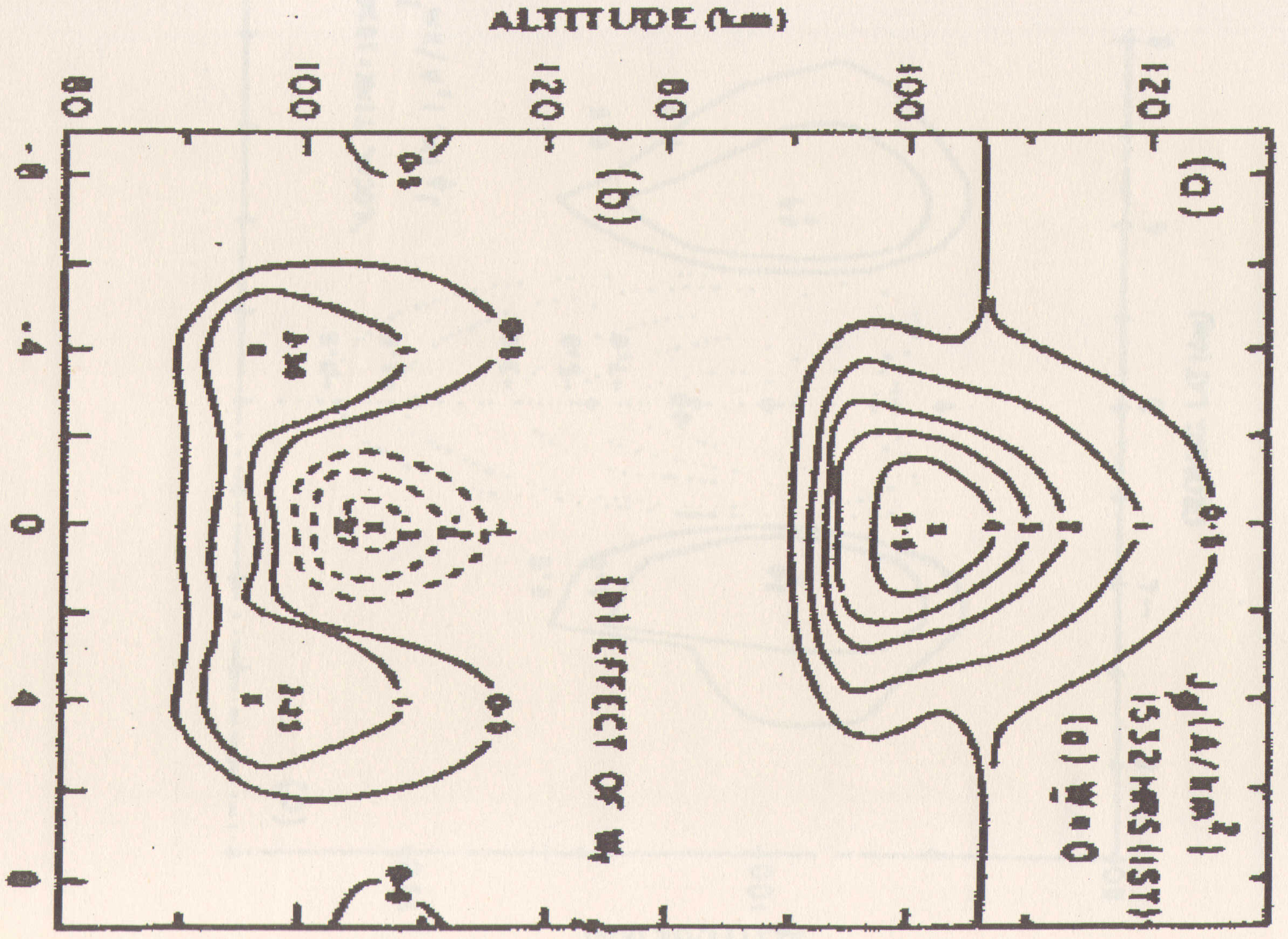
Another alternative interpretation has been forwarded by Takeda and maeda [1980] based on the semidiurnal tide propagating through the region on certain days. They have shown that the three-dimensions currents caused by semidiurnal tidal winds, in particular of (2,2) mode if sufficiently intense on certain days, can cause reversed electric fields and hence reverse the electrojet.

1.9 Outstanding Problems of EJ

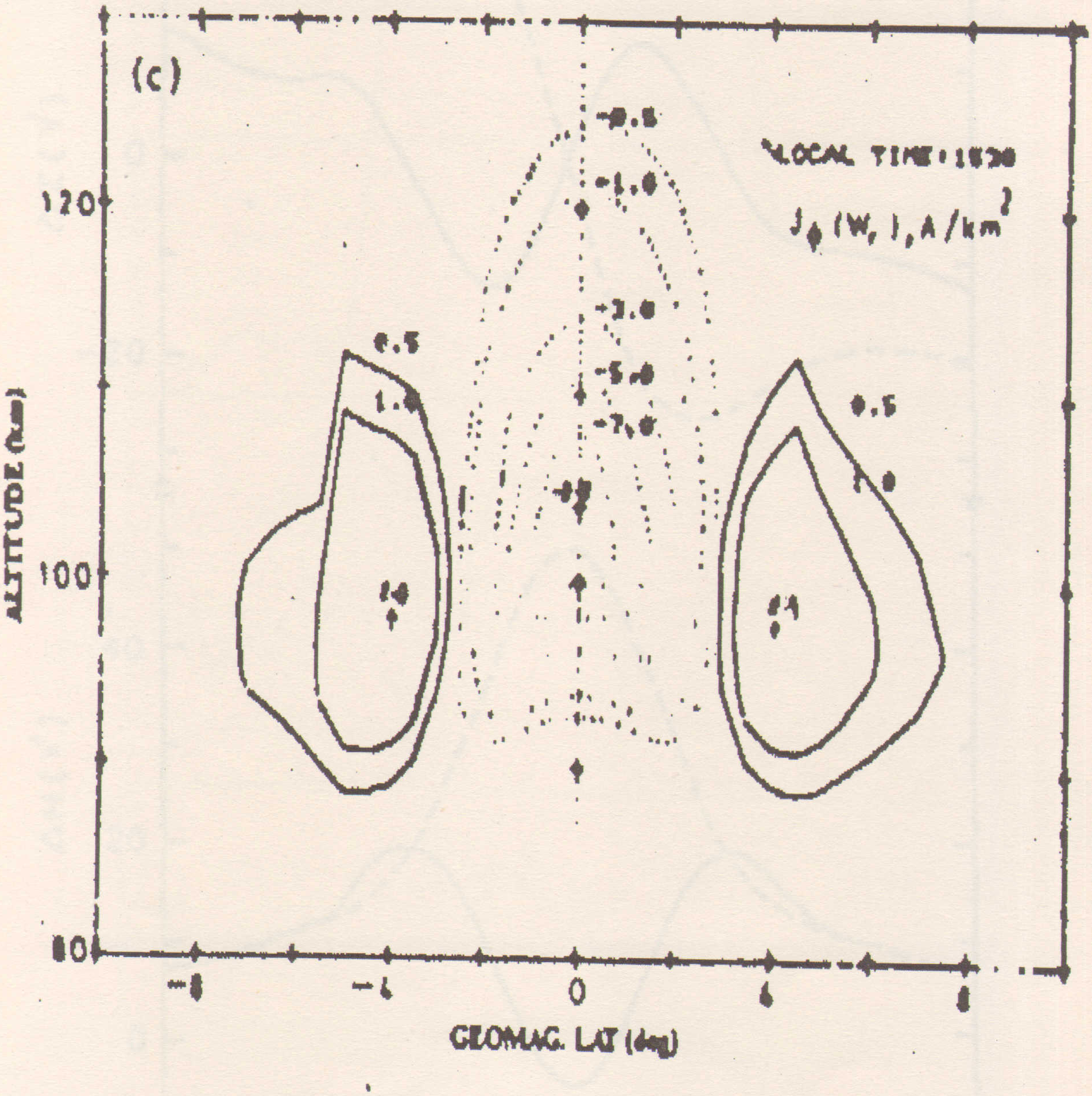
Discrepancy of about 4-6 km between the experimental and theoretical of the height structure of the current density (figure 15) is still unexplained. The models predict the maximum to be about 102 km, while the measurements reveal it to be 106 to 108 km.

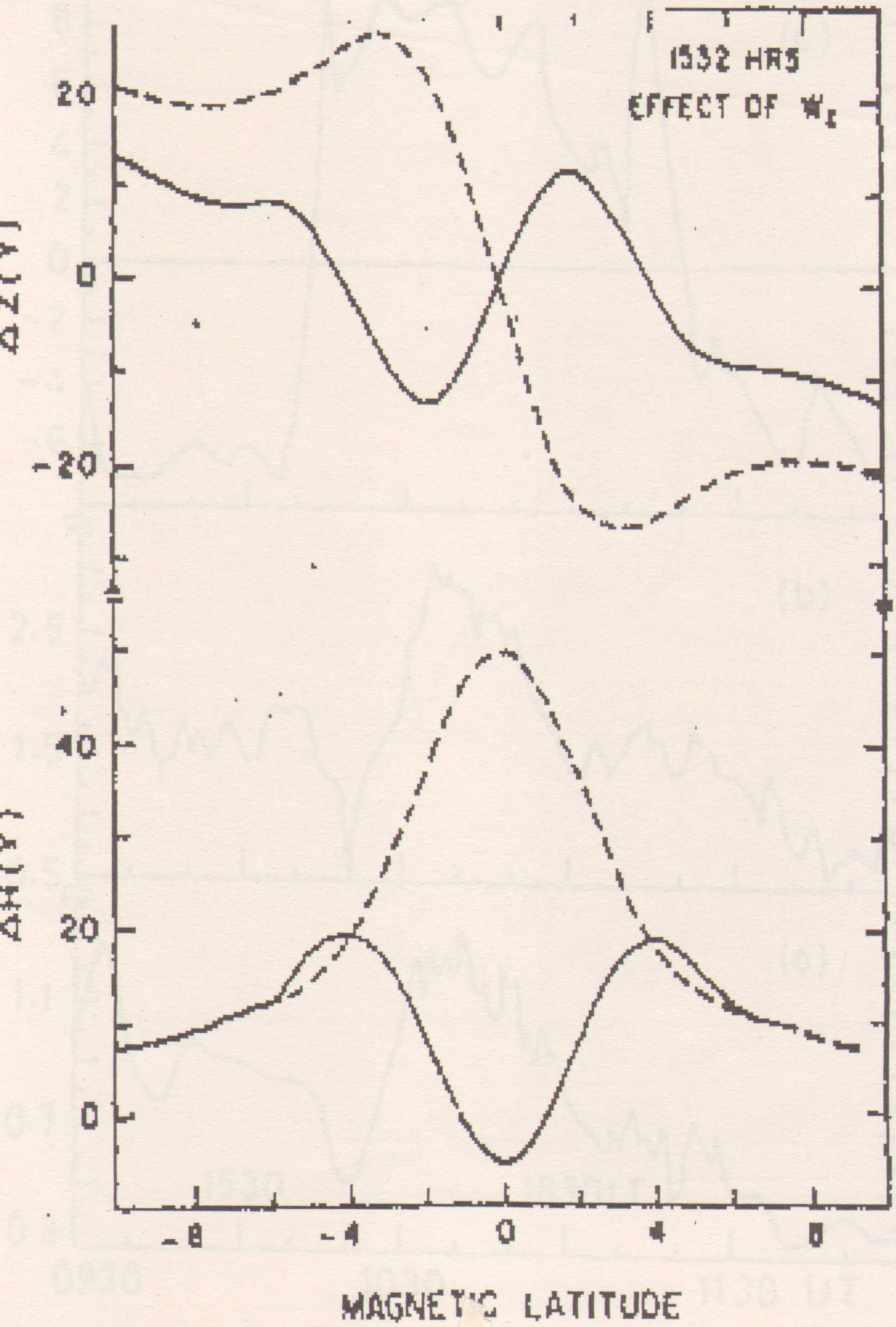


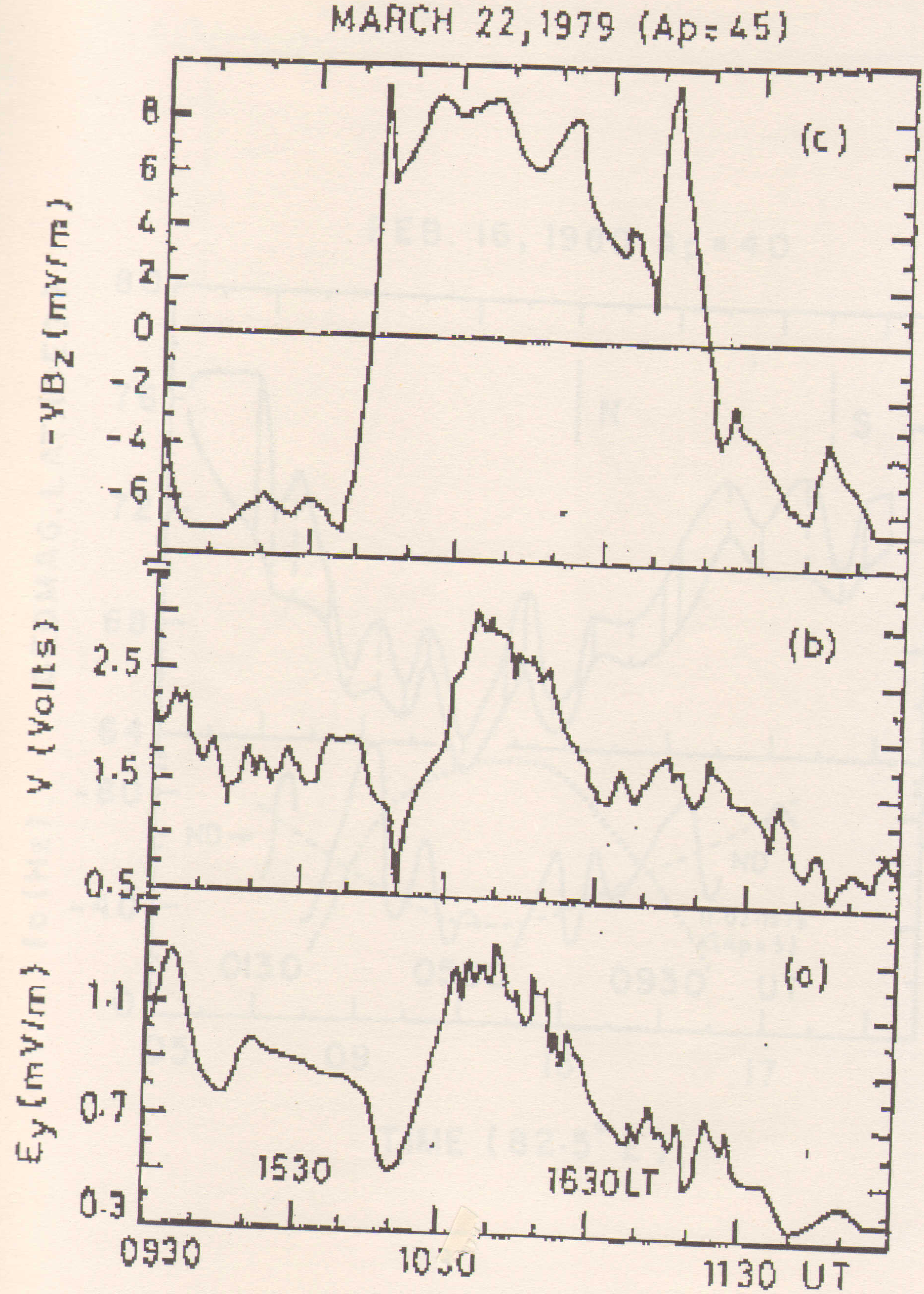
WIND VELOCITY

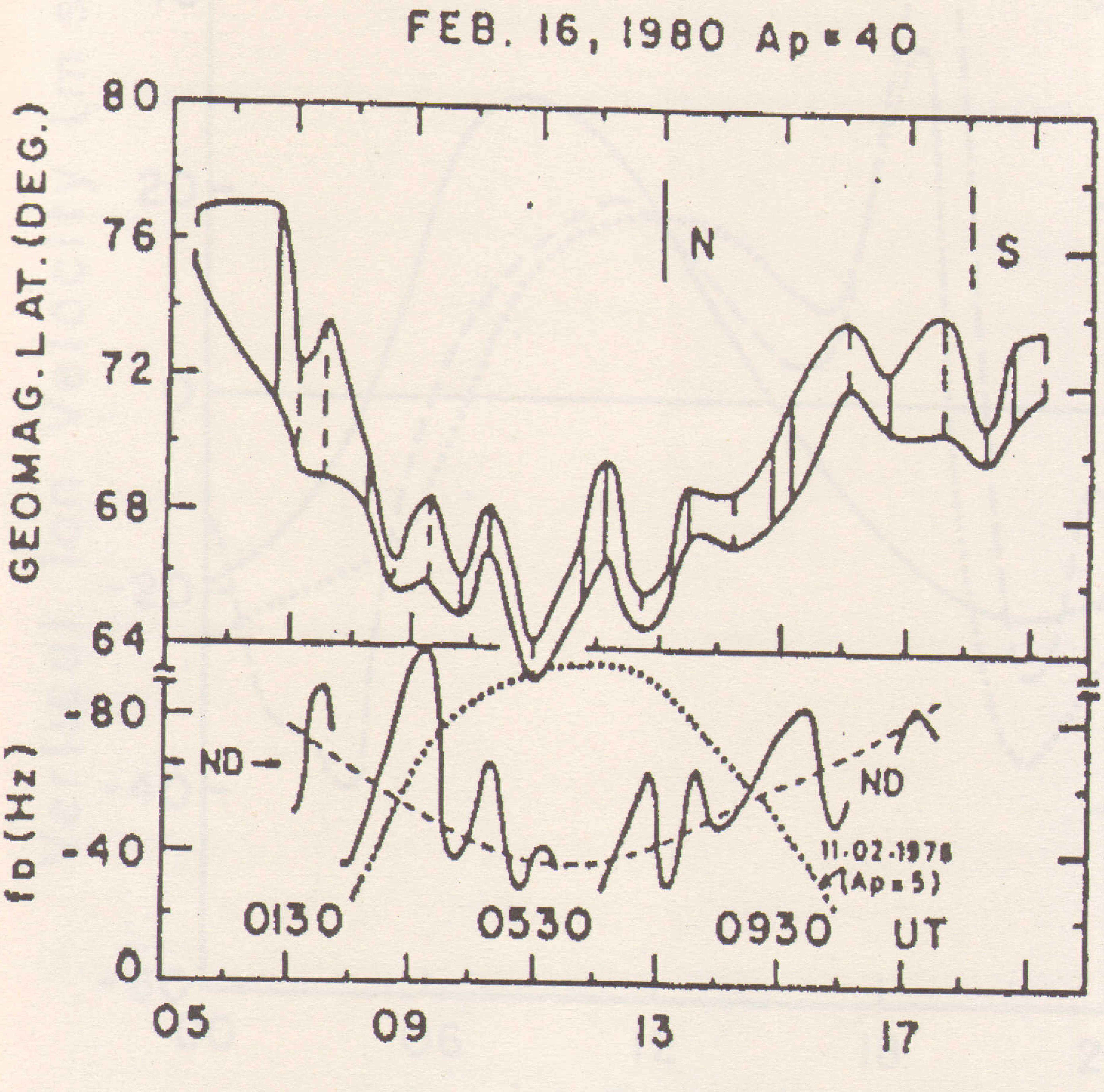


ALTITUDE (km)
80
100
120
80
100
120
-8
-4
0
4
8
(a)
(b)
(b) EFFECT OF W
J (A/km²)
1532 HRS (IST)
(a) W = 0

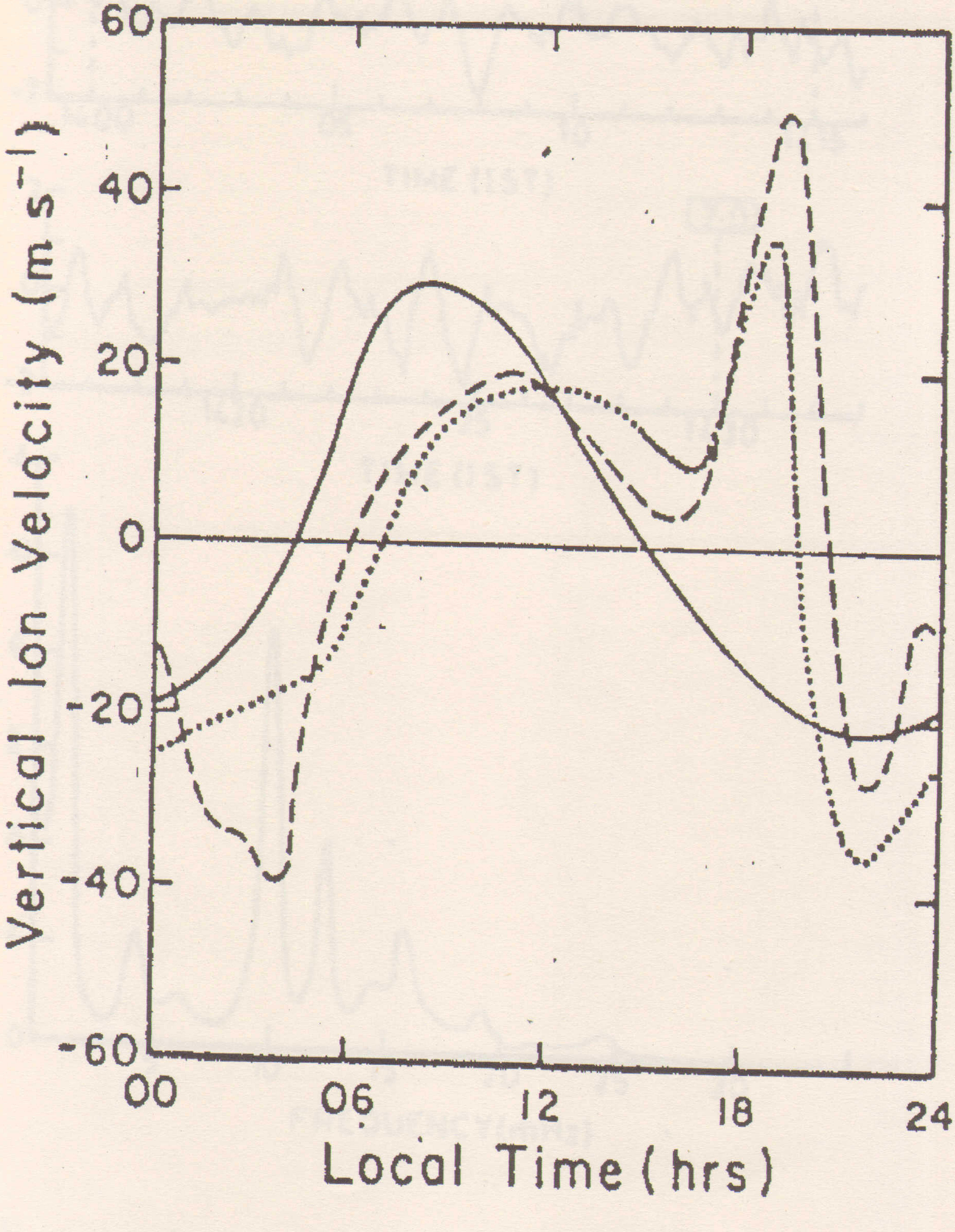

(c)
LOCAL TIME
$J_\phi (W_r)$, A/km^2
-0.5
-1.0
-3.0
-5.0
-7.0
0.5
1.0
0.5
1.0
ALTITUDE (km)
120
100
80
-8
-4
0
4
8
GEOMAG. LAT (deg)


1532 HRS
EFFECT OF W
ΔZ(γ)
20
0
-20
ΔH(γ)
40
20
0
-8
-4
0
4
8
MAGNETIC LATITUDE

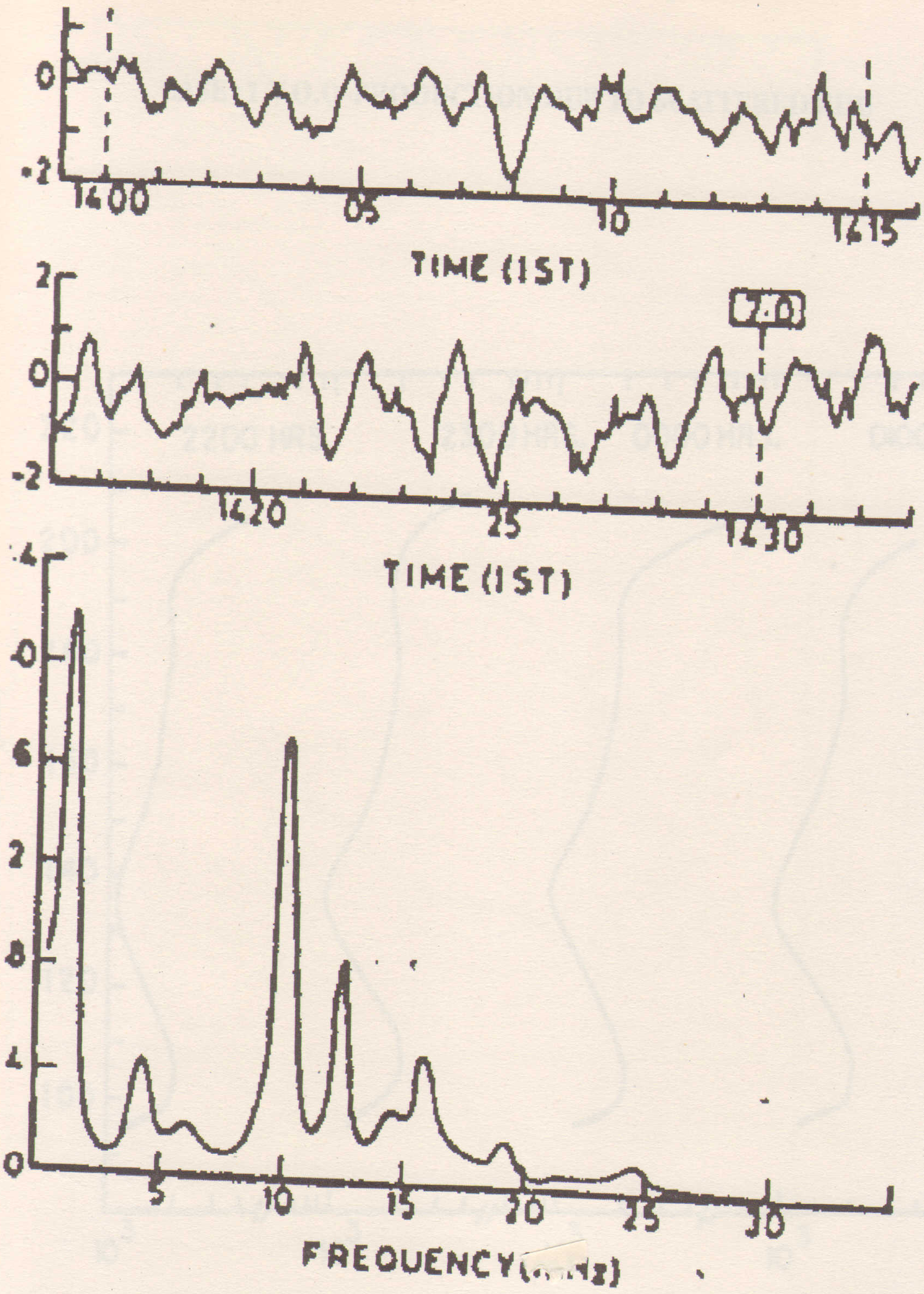

MARCH 22,1979 (Ap=45)
(c)
(b)
(a)
$-VB_z$ (mV/m)
V (Volts)
E_y (mV/m)
8
6
4
2
0
-2
-4
-6
2.5
1.5
0.5
1.1
0.7
0.3
1530
1630LT
0930
1030
1130 UT

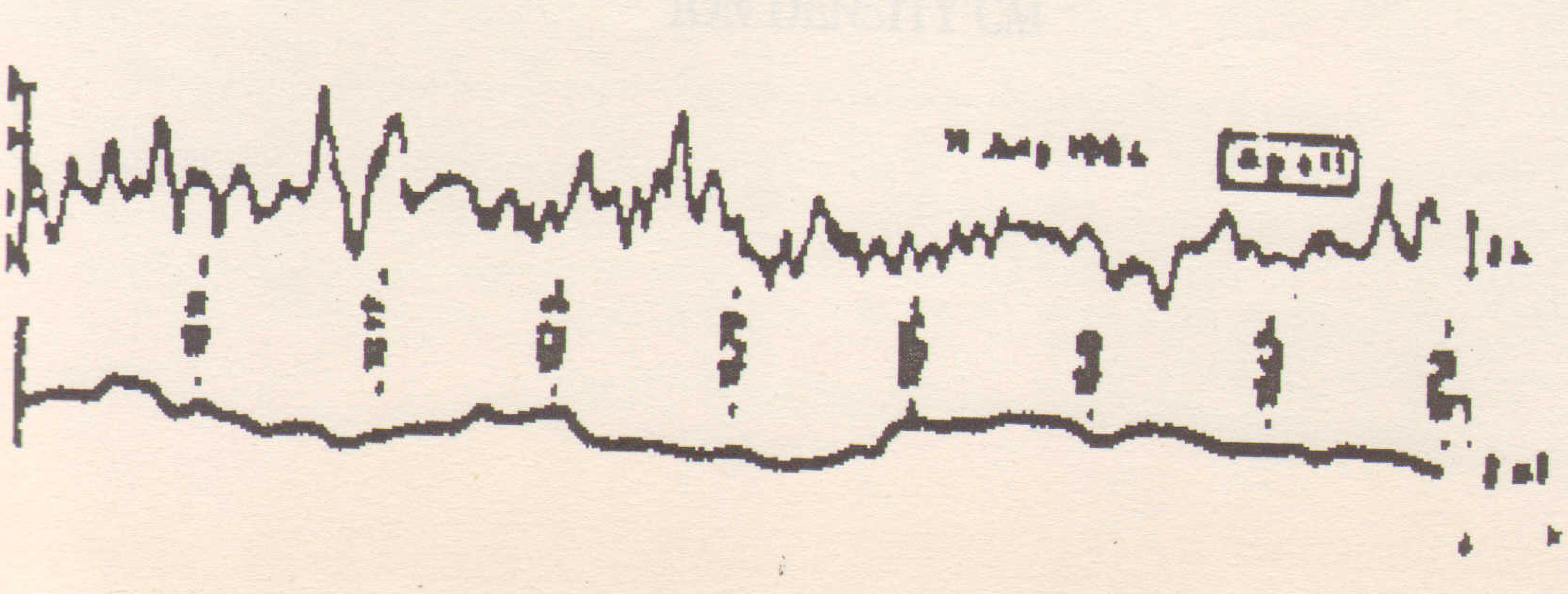


FEB. 16, 1980 Ap = 40
80
76
72
68
64
GEOMAG. LAT. (DEG.)
N
S
-80
-40
0
fD (Hz)
ND
ND
11.02.1978
(Ap = 5)
0130
0530
0930
UT
05
09
13
17
TIME (82.5° E)

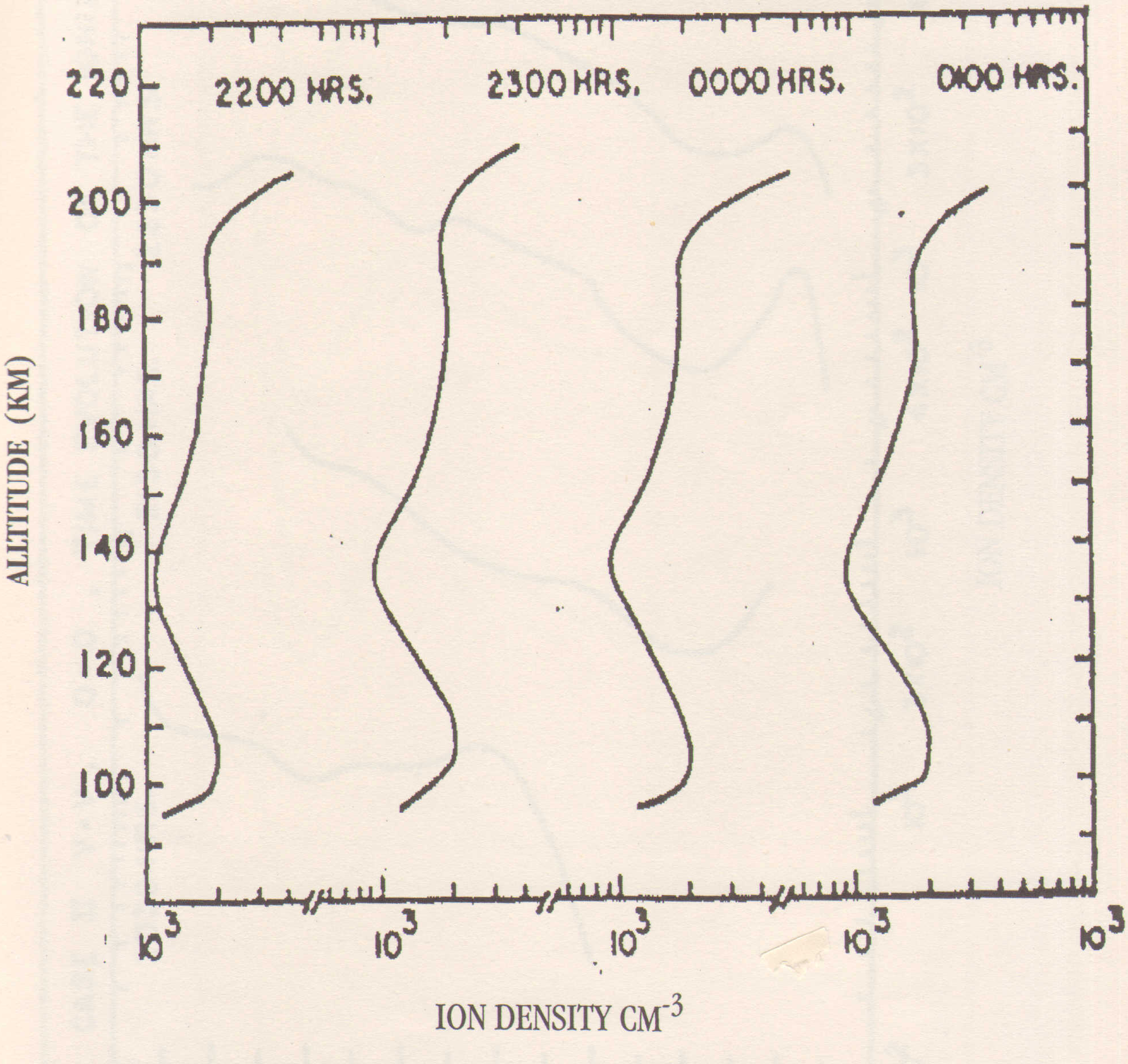


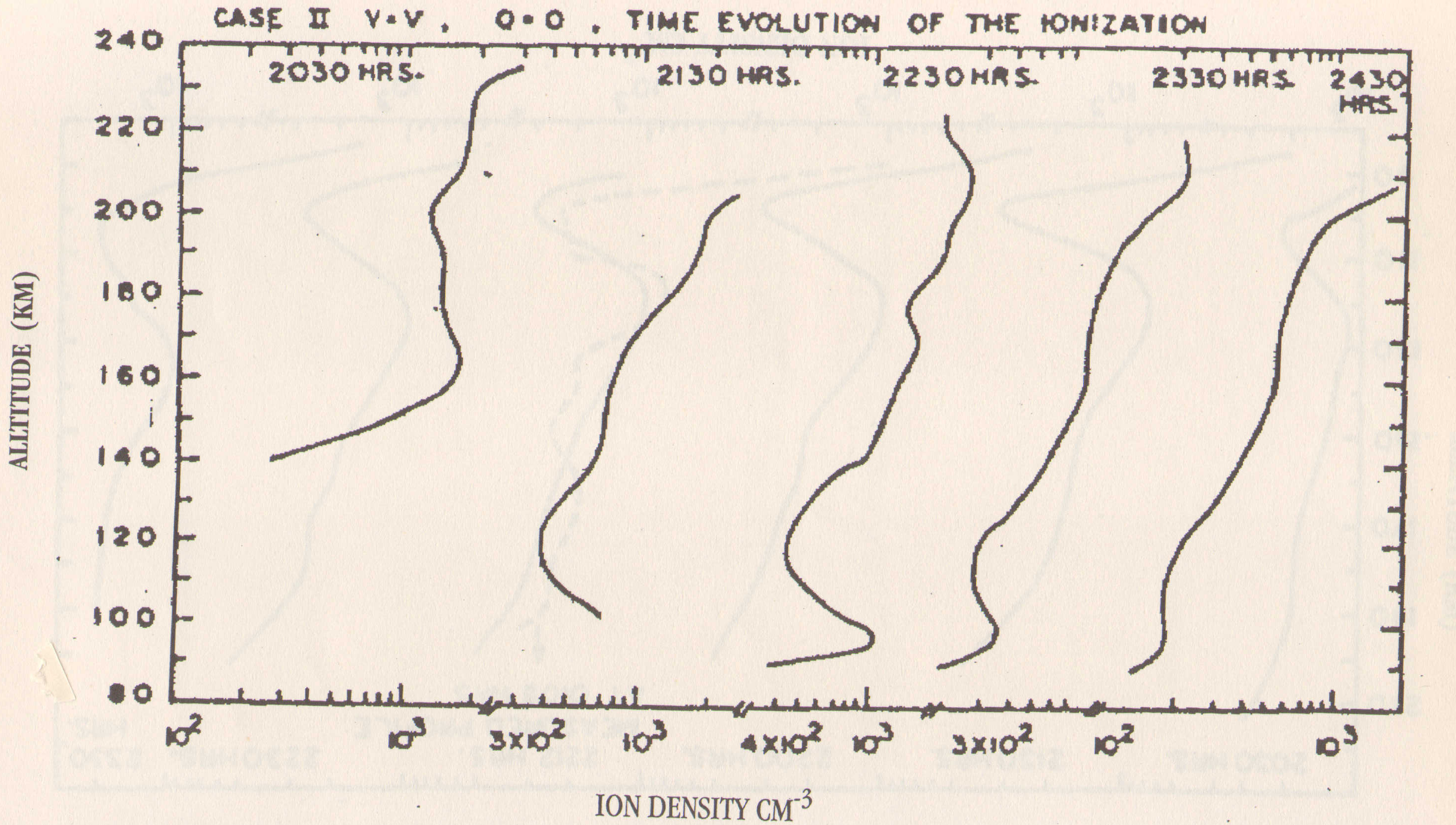
60
40
20
0
-20
-40
-60
Vertical Ion Velocity (m s⁻¹)
00
06
12
18
24
Local Time (hrs)


0
-2
1400
05
10
1615
TIME (IST)
2
0
-2
1420
25
1430
TIME (IST)
0
2
4
6
8
5
10
15
20
25
30
FREQUENCY



CASE :1 V.O.Q-PRODUCTION DUE TO SCATTERED EDU





CASE II V-V , O-O . TIME EVOLUTION OF THE IONIZATION
2030 HRS.
2130 HRS.
2230 HRS.
2330 HRS.
2430 HRS.
240
220
200
180
160
140
120
100
80
10²
10³
3×10²
10³
4×10²
10³
3×10²
10²
10³
ALLTITUDE (KM)
ION DENSITY CM⁻³

Chapter 3

Geomagnetic Field Measurements.

Geomagnetic field elements and their measurment

The Geomagnetic Elements

The earliest form of geomagnetic instrument was possibly a piece of lodestone, shaped into a cylinder and freely suspended at its centre. The direction it came to rest in would have depended on the location of the observation point on the globe. Later (around the 11th century) the lodestone may have been replaced by a bar of magnetised iron or steel suspended from a fibre. The first generation of geomagnetic instruments, which were used till the 1950s (when nuclear resonance instruments came into use), were improved versions of this simple system.

A freely - suspended magnet at a typical mid - latitude location in the northern hemisphere would set itself along the line OD depicted in with its north magnetic pole dipping downwards. The plane in which it sets itself is called the Magnetic meridian, and this in many places makes an angle D east or west of the geographic meridian, i.e.., the plane containing On. The angle D in Fig is called the Declination. The magnetic field which sets the magnet at an angle inclined to the horizontal is the total magnetic field vector F. The vector F can be resolved into two vectors, ON in the horizontal plane with an intensity II, and OV in the vertical plane with value Z. The angle I made by OD with OA is called the Dip or Inclination. Oa in turn can be resolved in two directions, On pointing northwards with value X, and OE pointing eastwards with magnitude Y, Each of these vectors and angles is called a geomagnetic element , and the following relationships exist between them :

$H = F \cos I$

$Z = F \sin I$

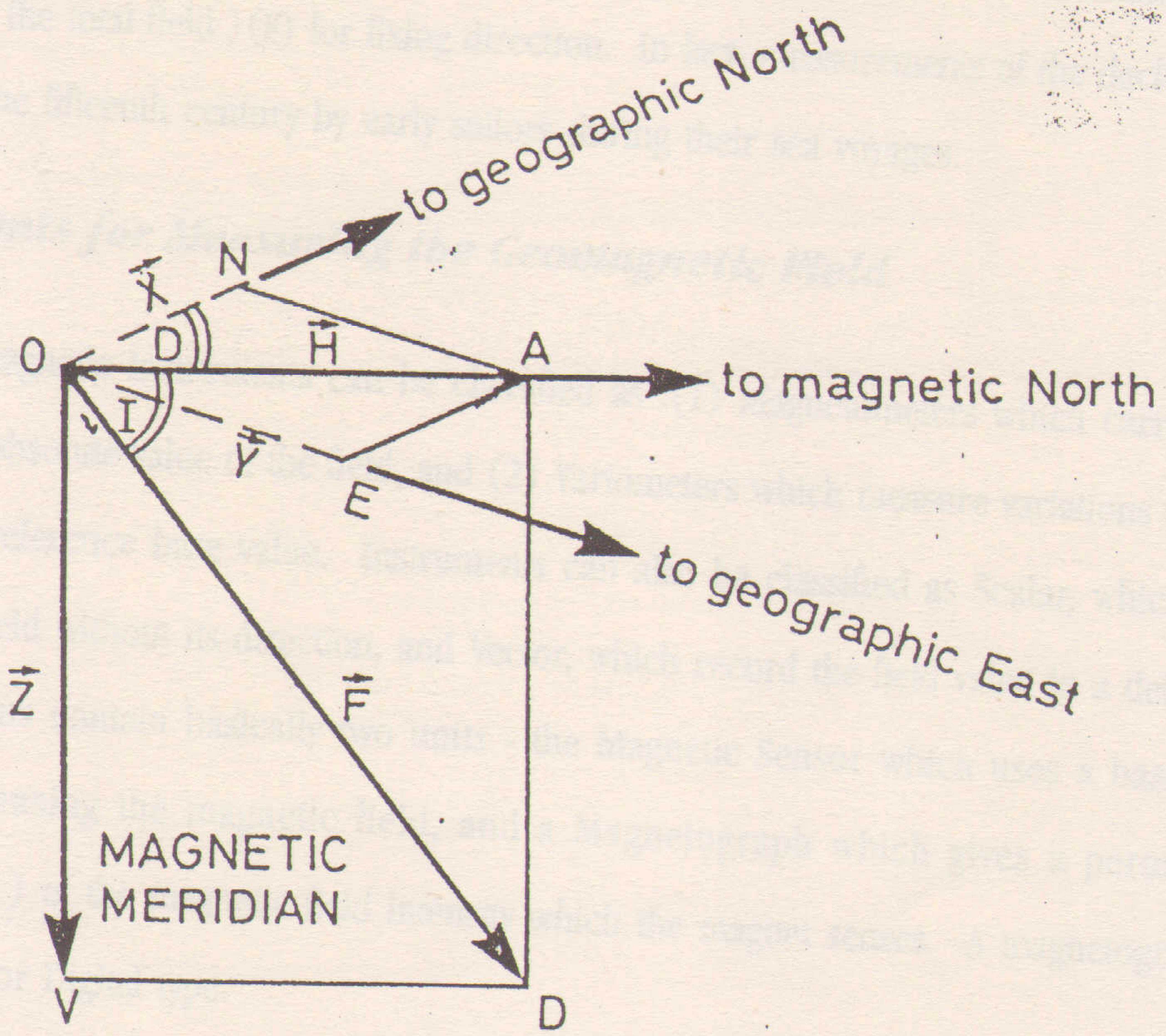
$Z/H = \tan I$

$H = (x^2 + Y^2)^{1/2}$

$X = H \cos D$

$Y/X = \tan D$

$F = (H^2 + Z^2)^{1/2} = (x^2 + Y^2 + z^2)^{1/2}$



F - TOTAL FIELD

H - HORIZANTAL FIELD

Z - VERTICAL FIELD

X- NORTH (GEOGRAPHIC COMPONENT)

Y - EAST (GEOGRAPHIC COMPONENT)

D - DECLARATION ANGLE

I - INCLINATION ANGLE

precautions, it is still usual magnetogram is usually 50 cm in length, with the drum rotating at a speed of 2 Cm/hr. At high latitudes, especially in the auroral zone, it is necessary to run the records at f2-24 times this speed, in order to obtain 'rapid run' records which capture the fast variations of the magnetic field so common in these regions. At these high latitudes it is a practice to measure the variations X,Y,Z, along the geographic north - south, east - west, and vertical , rather than H,D and Z, because the presence of field - aligned currents causes very rapid fluctuation in D.

A magnetograph is expected to yield a complete record of the daily variations of the magnetic field without missing traces. Apart from mechanical failure, a missing trace can occur for other reasons also. For enable, during a very serve disturbance, the field variation can be large enough to turn the magnet to such an extent that the light point moves completely off the drum. This can be overcome by: (1) having two magnetographs with different sensitivities, one with high sensitivity for operation during quiet times, the other with low sensitivity for operation during times, or (2) having auxiliary prisms between the source lamp and the variometers, with spacing such that if the reflection from one prism takes the light point off its allowed range on the paper, a second prism moves into place, and restores the reflection back to the same allotted range. It is the latter arrangement which is preferred at observatories worldwide.

The magnetic sensors used in most existing instruments can be classified as : (1) Torsion type, (2) Nuclear magnetic resonance type, (3) Core saturation type, (4) Induction type, and (5) Superconductivity or Cryogenic type.

(b) Torsion Instruments

These are classical instruments which (barring a few improvements) date back to 1841, when Gauss thought of attaching a tiny piece of mirror of the sensing magnet, so that a light beam reflected off it would effectively amplify the deflection of the magnet. In 1847, a way was, found to record the reflected light beam on on a rotating drum carrying photographic paper-this is how the Royal instruments being in operation.

Greenwich Observatory started recording the geomagnetic elements. Their use for over a century has proved that these classical variometers have great reliability and stability. They are being used at most magnetic observations operating worldwide even today, despite later generations of more sophisticated

In Torsion instruments the magnet is freely suspended at the end of a torsion fibre such as quartz. The principle underlying this is that a magnet with moment (m) when freely suspended in a field (H) is subjected to a magnetic torque T given by

$$\tau \alpha \left(\overline{\mathbf{m}} \, X \, \overline{H} \right)$$

A position of equilibrium is reached when this magnetic is just balanced by a restoring torque in the suspension fibre. In the determination the of the elements H and D, the fibre is oriented along the z axis while the magnet is free to move in the x-y plane. A very fine fibre with little torsion is used in the D variometer, and magnet freely aligns itself along the magnetic meridian. In the instrument for detecting H, the suspension fibre is thicker with higher torsion, and the magnet is initially placed in a perpendicular the magnetic meridian by deliberately rotating the torsion head of the suspension fibre. The magnetic torque T_m is balanced by the fibre torsion thus.

$$\tau m = (\mu / 4\pi) \left| \mathbf{m} \, X \, H \right| = \tau\theta$$

Where H is the horizontal component of the Earth's magnetic field;

M is the magnetic moment;

u is the permeability of the magnet;

t is the torsion constant of the fibre; and

o is the angle through which the fibre is twisted.

In the case of the Z variometer the magnet moves in they-z plane about a horizontal axis. This achieved by either suspending it from a horizontal fibre, or by letting it balance freely on a knife-edge. In its position of equilibrium, the magnetic torque T_m is balanced by the force due to the weight of the magnet. In the Z variometer of the La Cour type, the knife-edge, the reflecting mirror, and the magnet are all fabricated from a single piece of steel. In order to free nit from the influence of variations in H, the magnet in the Z variometer is deliberately placed in the magnetic east-west plane.

The deflection suffered by a magnet is affected by temperature, because of (1) a change in the magnetic moment, and (2) changes in the torsion constant.

Some from of compensation is prided for these thermally induced changes In some set-ups. for the required compensation., auxiliary magnets are positioned carefully so as nullify the ambient field. In other instruments, the light-beams forming the trace are made to pass through prisms suspended on bimetallic stirps-changes in the deflection on the magnet due to temperature, are compensated for by

The Quartz Horizontal Magnetometer (QHM) and the Balance Magnetometrique zero (BMZ) come under the class pf Absolute instruments, used for determining Absolute value of the H and Z components repetitively. They form the Baseline Values (BLV) with respect to which the variations are recorded. Both the QHM and BMZ need to be calibrated periodically to check that the constants of the instruments as specified by the manufacturer have not changed.

While freely suspended magnets are very suitable for use in magnetic observatories, they are unsuitable in the field. For the latter, more rigid suspensions (quartz fibres) are used. The optical feedback type of variometers are even more suitable for field use. In these, the variations in the ambient field H are instantaneously translated by electronic feedback into an almost equal and opposite field H_0 which serves to oppose H. The residual field ($H-H_0$) is sufficiently small to keep the sensing magnet practically at rest. What is measured is the current which creates the opposing field H_0. Being a null method, the values measured have high accuracy.

Nuclear Resonance Magnetometers

The most widely used in this class of instruments is the Proton Precession Magnetometer (PPM) . It was the first reliable instrument to replace the classical Torsion magnetometers. The PPM can serve as a variometer, and so long as the associated electronics stable, as an Absolute instrument too. The PPM can a;lso measure the vector components of the magnetic field by cancelling out one of the components by means of a Helmholtz coil. Then it is called a vector Proton Precession Magnetometer (VPPM). The sensor of the PPM is basically a bottle of about 500 cc capacity, containing a proton-rich fluid such as water or benzene. A coil with a few hundreds of turns of wire is wound on it, so as to provide a magnetic field when the current is passed through. The principle of the PPM is described below. The fundamental building blocks of matter (electrons and protons) are both known to have magnetic moment; this parameter has a larger value for protons. This property causes protons to align their magnetic axes in a direction which is parallel or anti-parallel to the ambient magnetic field (in this case the Earth's field F.) A current passed through the coil wound on the bottle is directed so as to create a magnetic field B which is perpendicular to F. This causes the magnetisation in the sample to be re-directed along B. Removal of this polarisation field B causes the net magenetisation vector of the protons to return to the original direction F, but they cannot do so instantaneously. They return to the original direction F by precessing about F (much like what the toy 'top' shown in fig 1.2 does about the vertical axis). The signal induced in the coil as a consequence of this is the Larmor Precession frequency w of the proton, given by

$$F=(2\pi/\gamma\rho)\omega=23.487\omega$$

Where F is expressed in units of n T (nanotesla) and r_p is the gyromagnetic ratio (Magnetic moment /Angular ment) of the proton, given by q (2mc).

The PPM is an accurate instrument because the precession frequency is solely dependent on the field intensity, and on gyromagnetic ratio which is an atomic constant. Typically for an ambient field of 0.50 gauss. w =2128.8 Hz.

There are two disadvantages amongst the many advantages of a PPM. Firstly, measurements of fields < 15,000n T is difficult because of a low signal-to-noise ratio. Secondly, the readings pf the PMM are discrete, not continuous. This is because the field produced in the coil for polarising the protons has to be on for typically 2 to 3 sec, and no readings can be taken within this time. The simplest way to make the readings continues. Is to use two PPMs functioning at alternate intervals. Other methods use physical principles to achieve continuity. One method by OVERHAUSER (1953) uses coupling between the spin energy of protons and electrons. The other method is optical pumping which is used in another popular type of instrument, namely the Rubidium Vapour Magnetometer.

They optically pumped magnetometer depends on the Zeeman spliting of the atomic energy levels into sub-levels, in the presence of a magnetic field. The separation between the energy sub-levels depends on (1) the intensity of the magnet field, and (2) the alignment of the magnetic moment of the atoms relative to this field. The transition frequency generated is proportional to the energy separation levels, and it is this which is monitored. For details on the working of such instruments, the reader is referred to PARSONS and WIATR (1982).

Both the PPM and the Rubidium Vapour Magnetometers can measure vector field components instead of the total field, by using sutiable bias fields. This is done by using a coil of current which will generate an axial field of known magnitude in the required direction. For vector field measurements in a particular direction, the coil is positioned in such a way that the axial field it generates just cancels the field in the direction perpendicular to the required vector field. The relationship between the current in the coil / and the axial field generated
F, is given for the Helmhotz -Gauagin coil by

C is called the coil constant; it is directly proportional to N, the number of turns in the coil, and inversely proportional to R, the coil radius which is also the coil separation. The Helmhotz-Gaugain coil comprises two coils of equal radius, separated by a distance equal to the coil radius, and connected in serious. This ensures: (1) a homogeneous field at the center, and (2) coincidence of the magnetic and geometric axes. These Helmhoz-Gaugain coils form an integral part of the instrumentations at all observatories for generating (1) fields for calibration, (2) fields for compensation, and (3) additional fields.

$$F=89.92\ NI/R=CI$$

(d) Saturable Core Magnetometer: the fluxgate type

The best known amongst the saturable core instruments in the Fluxgate Magnetometer. Along with the PPM, it constitutes the two instruments most widely used for field and survey work because of their (1) ruggedness, (2) reliability, (3) low power requirement, and (4) amenability to automatic digital recording, Fluxgates have worked very well in arrays, for long periods of time, in conditions of adverse terrain and hostile climate such as are found in Greenland and Antarctica.

The basic principle of working of the Fluxgate Magnetometer is as follows, A coil of wire carrying current is wound around a core of high permeability, which is capable of reaching saturation quickly. It is placed with is axis directed along an ambient field F (in this case the geomagnetic field), and an AC current is fed to the coil, the abient field is alternately enhanced and an AC current is fed to the coil, the abient field is alternately enhanced and diminished by a quantity H cos wt, which is also directed along the axis of the coil. The effective magnetic field therefore is given by

$$B= \mu (F \pm H \cos \omega t)$$

where u is the permeability of the core.

So long as the core does not go into saturation, and hysteresis is small, a voltage is generated in the winding, due to the changing magnetic field, and is given by

$$V=NA(dB/dT)$$

Where N is the number of turns in the coil; and

A is the area of the coil

If the ambient field and the induced field combine to bring about magnetic saturation in the core, the core goes through a hysteresis and magnetisation cycle. If μ . has a high value, then the major contribution to the flux density can come from the lern μ.F. The core can then saturate earlier in one half of a cycle, and later in the other half, when the ac field H cos ωt is applied. This is found to cause an asymmetric voltage in the coil, whcih ultimately results in even harmonics of the excitation frequency ω, with the secibd garmonic being notably measurement of this second harmonic.

They are many aspects about the configuaration of the Fluxgate Sensor, its activation, the detection of the second harmonic , and the errors to whcih the instrument is prone.

(e) Induction Magnetometers

It is well known principle of physics that when the magnetic flux through a coil changes, a voltage is induced within the coil. This is the principle used in the induction magnetometer. There are two ways of bringing about this chang in magnetic flux - a dynamic one in which the coil is bodily rotated about one of its diameters, and a static one in which the coil is kept stationary and the magnetic flux density is deliberately changed. In the dynamic case,the induced voltage is given by

$$V = FAN \cos \omega t$$

where

F is the magnetif flux normal to the axis of rotation

A is the area of the coil

N is the number of turns in the coil : and

ω is the rotation rate in radians/sec

It is easy to determine the direction of F, because of the coil about an axis parallel to F will not yield any change in magnetic flux, and hence here will be no induced voltage in the coil

In the static case, where the Magnetic flux density, altered, the induced voltage is

$$V = -NA\,(dB / dT)$$

where dB/dt is the rate of change of magnetic flux, and the other quantities are the same as for This relationship assumes that the coil has every small resistance (R), inductance (L), and capacitance(C).

The efficiency of the Induction Coil magnetometer depends upon several factors which include the geometry of the coil, and the introduction of a core with high permeability. Air-core coils have been used for effectively recording even micropulsations. While air -core coils do not need much calibration, high permeability cores do require it, because the core properties can change with time.

The Induction Coil can be modified so as to make it a Null method for measuring the magnetic field. In this the voltages induced in the coil, by variations in the abient field, are back into circuit so as to compensate for the variation field.

(f) The QUID Magnetometer: Cryogenic type

The SQUID (Superconducting Quantum Inference Device) is also called a Cryogenic magnetometer because it operators at the low temperature of < 20 K required for the phenomenon of Superconductivity. The SQUID instruments are currently believed to be the most sensitive for accurate measurement of very small variations in the magnetic field of the order of 1 picotesla, i.e., 10^{-3} nT. Their working depends on the following principles:

(1) A ring of pure metal of a suitable alloy at temperatures of <20 K loses all electrical resistance and becomes a perfect conductor - it can then sustain a non-dissipative current almost indefinitely.

(2) At such low temperatures, the ring displays the Meissner effect, i.e., all magnetic flux is expelled from the ring. This is achieved by a current circulating in a thin surface layer called the skin layer; the magnetic flux associated with this skin current is such as to cancel any magnetic flux within the material.

(3) At temperatures below the critical temperature of <20 K, the super conducing ring displays a set of discrete, i.e., 'quantised' sates of angular momentum. The angular momentum of electrons in the ring is linked, not with the current which flows in the ring, but rather with the magnetic field associated with the current. This phenomenon is called Quantum Interference, and it results in magnetic flux through the ring being quantised in units of,

$$\phi = h/2e = (h/2\pi)/2e$$

Where h is Planck's constant, the quantum unit of angular momentum

(6.62×10^{-27} erg sec); and

2e is the charge of electron pair.

A change is the external abient field results in a change in the skin-layer currents, which causes the Meissner effect. Ideally the magnetic flux in the skin layer and the rest of therein should be isolated, and no interaction can occur. If however, for some reason, a 'weak link' is set up between the two regions of the ring, then the two regions can interact. A 'weak link' is defined as one which can support the circulating current I up to a critical value Ic.If $I > I_c$, then the Meissner situation brakes down, and magnetic quanta can once again enter and leave the ring. When this happens I becomes $< I_c$, and the ring becomes superinducing again, i.e., it is a self-adjusting situation.

Measurements with the SQUID magnetometer depend on the that there is define relationship between the circulating current I and the change in the abient field AF, which causes I to built upto the value I_c. Measurement of AF is made from the measurement of I, and this is done through the use of sutiable electronics.

Because of its very high sensitivity of I picotesla the SQUID finds great use in measurement of the magnetic properties of geological samples. The only handicap for its use as afield instrument is its requirements of very low temperatures, and hence of liquid helium.

Geomagnetic Observatories

The function of a permanent magnetic observatory is to continously and accurately record variations of three or more elements of the magnetic field (with a desirable resolution of 1 nT in magnidue and 1 minute in time), and relatethese to absolute values. A good observatory also makes its data avaliable in reasonably quick time to the scientific community. Many observations still record the varations on conventional photographic papaer as magnetograms. The magnetograms are scaled every hour for ordinates, which are then converted into hourly mean values; this is done by making use of the refreance Base Line Values (BLV), and a factor called the sensitivity or Scale Value (SV), which expresses the field in nanoteslas which would cause unit deflication in the magnetogram i.e., nT /cm BLV are expected to be accurate to about 1 nT, and SV to about 1 per cent. Permanent observatories are expected to send microfilm copies of their magnetograms and monthly tables of hourly values to the World Data Centers (WDC) at Boulder (U.S.A.), Mocow (Russia), Copenhagen (Denmark), and Kyoto(Japan),. The WDC establisdhments supply worldwide data to users on rtequest.

In recent years, many observatories have been turing over to digital modes of recording magnetic data. These are stored in the form of magnetic Tapes or Diskettes, and are redable by computer. This type of data from the recording observatories is stored at World Digital Data Centers (WDDC) at Boulder (U.S.A.), Edinburgh (U.K.), and Bombay (India). The WDC and WDDC have been established as aresult of international agreements on exchange of geophysical dat.

The first digital recording observatories were statred in the U.S.A. in 1960, and were called ASMO (Automatic Standard Magnetic Observatory) systems. They used the Proton Precession and Rubidium Vapour Magnetometers. Many of these have been replaced by the AMOS (Automatic Magnetic Observatory System), which use Fluxgate Magnetometers, and were developed in Canada. From the points of view of saving in data-storage space, amenability to mathematical treeatment of data with computers, and the decreasing cost of microprocessor chips with large solid atate memories, the digital method of recording has great advatages. Many observatories worldwide are turnig to these, although they continue to maintain an analogue record of magnetograms for instantaneous use

The operation of good geomagnetic obsrevatories is a demanding task which calls for a great deal of dedication. The requirments for a magnetic observatory are: (1) a site which does not have magnetic material in the vivinity; the building which houses the magnetometers must itself be constructed of non-magnetic material; (2) a site which is free of electrical noise especially from DC generators, and if possible AC genertors too; and (3) a buildinmg which, to the maximum extent posible, is kept free changes in temperature and humdity. The older torsion type instruments are externaly susceptible to tempreature variations, the baseline values showing thermally induced drift. The sensors of the other types of magnetometers-nuclear resonance, Fluxgate and SQUID - may be not be affected by thermal changes, but here the electronics has to be kept stable at low temperatures.

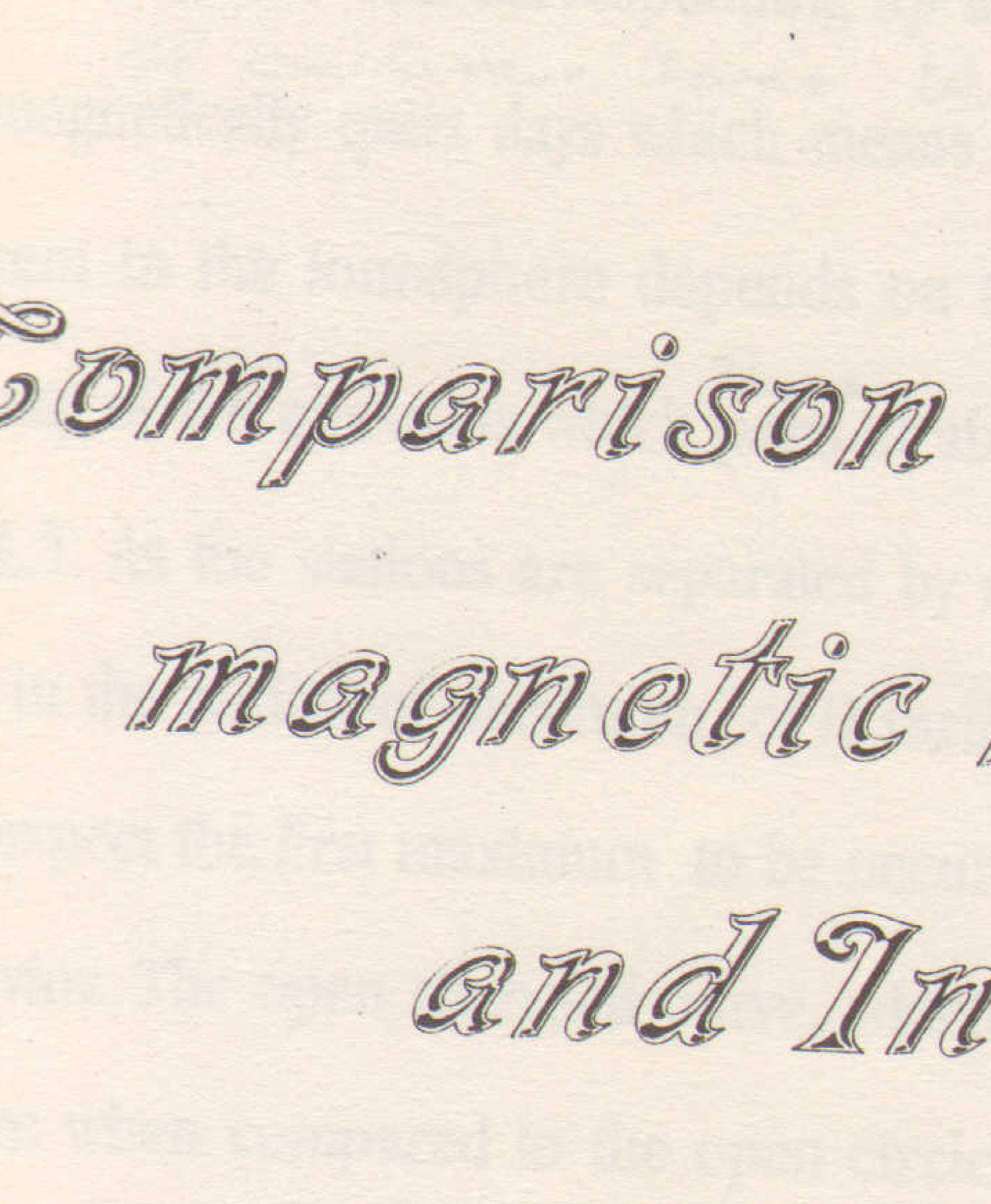
Other types Observatories

There are also temporary observatories involving closely-spaced ground magnetometer arrays, which are set up for specific studies. Examples are those set up during the First Polar Year (1882-1883), the Second Polar Year (1931-1933), the International Geophysical Year (IGY) (1957-1959), the International Quiet Sun Year (IQSY) (1963-19654), the International Manetoshperic Study (IMS) (1976-1979), and more recently the International Equatorial Electrojet Year (IEEY) (1991-1993), and the Solar Terrestrial Energy Program(STEP) over 1990-1997.

There can also be land and sea surveys of highly localized areas or regional areas to establish magnetic properties or subsurface electrical conductivities of the areas. These are often used fro mineral prospecting, or for archaeological and geological purposes. Most developed countries have already carried out national surveys of this type, which they repeat regularly at 5 to 10 yr intervals because of the changing nature of surface geomanetic vaiations. Aeromanetic surveys by aircraft are especially suited for discovering natural reources, but these data are not made public. Finally, there are satellite measurements of the surface field, the first of this kind having been made by the SPUTINK 3 in 1958. The COSMOS (1964-1970) and the POGO (1967-1971) series were the first to yield surface first values from pole-to-pole, with Proton Precession and Rubidium Vapour Magnetometers on board. The complete glopal coverage from these helped in formulating the IGRF (International Geomagnetic Refernce Field) of 1965 and of subsequent years. The MAGSAT was the first satellite which was totally dedicated to the measurement of the vector magnetic field in the Dawn-Dusk sector.

Chapter 4

Comparison of Equatorial Geo magnetic field in African and Indian sectors.



Results

The H component of the geomagnetic field variations taken at equatorial electrojet (EEJ) stations Addis Ababa (AAE,90.0 N,38.8 E geographic; 0.3 Ndip lat), east Africa and Trivandrum(TRD,8.5 N, 77.0 E geographic 0.3 S dip lat.)' India are considered here for comparison. The hourly averaged field variations of both stations during 10 May, 8 jun., 5 jul., and 26 sep. 1995 are shown in the fig : 1. The abscissa denotes hour in universal time (UT) and the ordinate denotes H variations in nT. The corresponding Ap indices of 6,3,3, and 4 respectively shows that these days are geomagnetically quiet days which means that the major contribution from magnetosphere. Since, the current in the ionosphere depends on the solar radiation flux which peaks at noon and the drift velocity of the electrons which parts at about 10 L.T one can expect the peak of the H variations near 11. L.T. As the stations are separated by about 38° in longitude it is obvious to expect an appreciable shift in the period of maximum of H variations. And also, when the earth rotates from west to east we can expect the first maximum to be occurred over India according to the UT Fig. I shows the expected behavior. The open triangled curve, which is for India, Shows its maximum approximately two hours before when compared to the open circled curve, which is for east Africa, in all these days. A slight change may happen to these maximum time periods due to the interaction of the local wind system with the ionospheric drift motions. So, for a 24 hour interval, a phase shift of about 2 hours for the stations separated by about 38° in longitude is accordingly to our expectation. If the local background wind system different in these longitudinal sectors one can expect the difference from 2 hour phase shift. For example, on 26 Sep. the phase shift is only about one hour. One can also notice that on 10 May, both the stations showed the noontime counter electrojet events (CEJ). And the period of the maximum negative peak (~ - 40 nT peak) is also separated by 2 hours which shows that the wind system in the mesospheric (60-90 km) and lower thermometric (90-130 km) region (MLT)is almost same. As a comparison one can also notice that the field variations are slightly larger in the African region (about 80 nT peak) than in the Indian region by about 20 nT except during the strong noon time CEJ day as in 10 May where the reverse is true.

Geomagnetic field variations at TRD and AAE

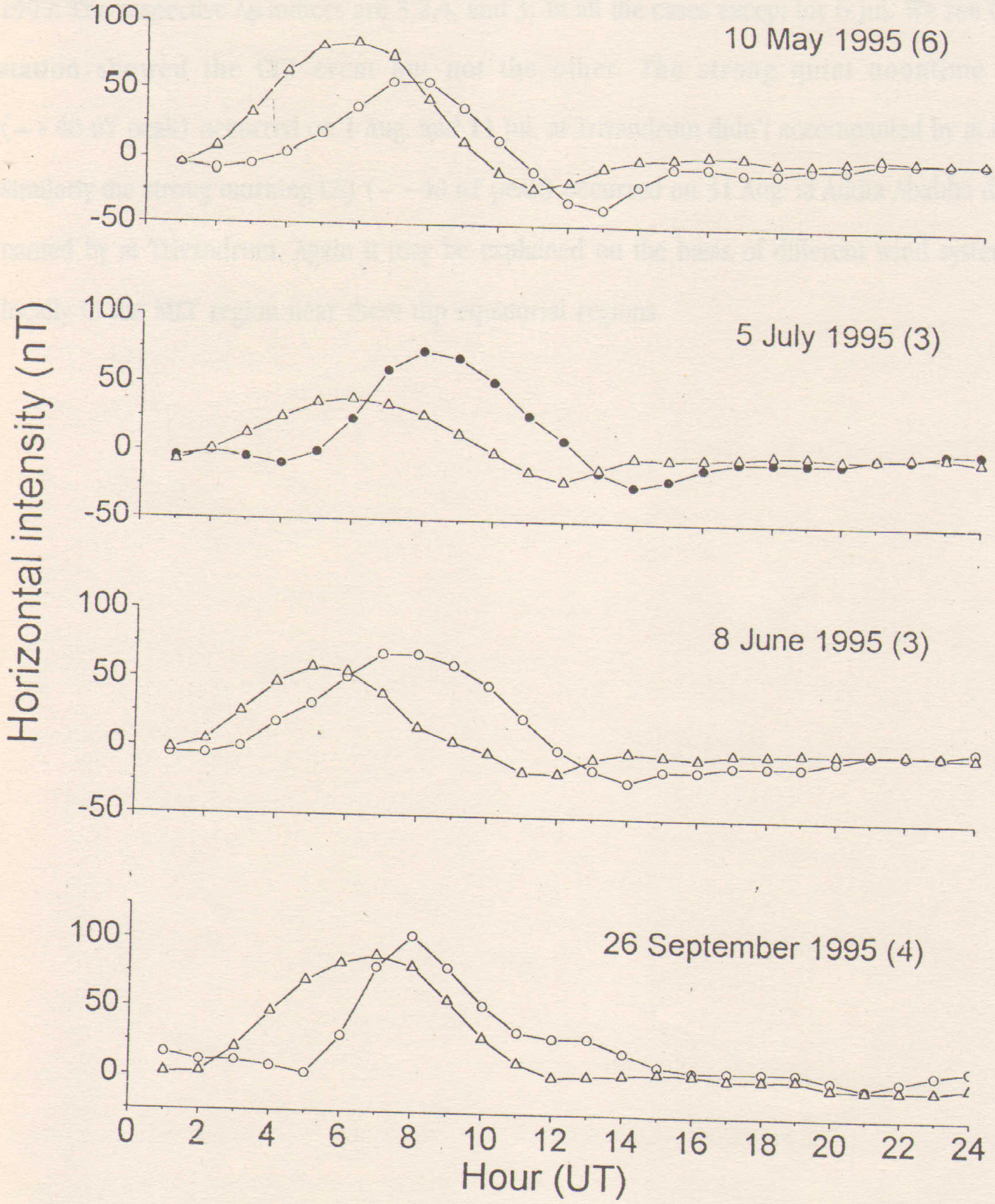


Fig 2 shows the same as in fig. 1 except that the days are changed to 6 and 11 Jul., and 1 and 31 Aug. 1995. The respective Ap indices are 3,2,4, and 3. In all the cases except for 6 Jul. We see that only one station showed the CEJ event but not the other. The strong quiet noontime CEJ events (~ - 40 nT peak) occurred on 1 Aug. and 11 Jul. at Trivandrum didn't accompanied by at Addis Ababa. Similarly the strong morning CEJ (~ - 40 nT peak) occurred on 31 Aug. at Addia Ababba didn't accompanied by at Trivandrum. Again it may be explained on the basis of different wind systems prevailed locally in the MLT region near these dip equatorial regions.

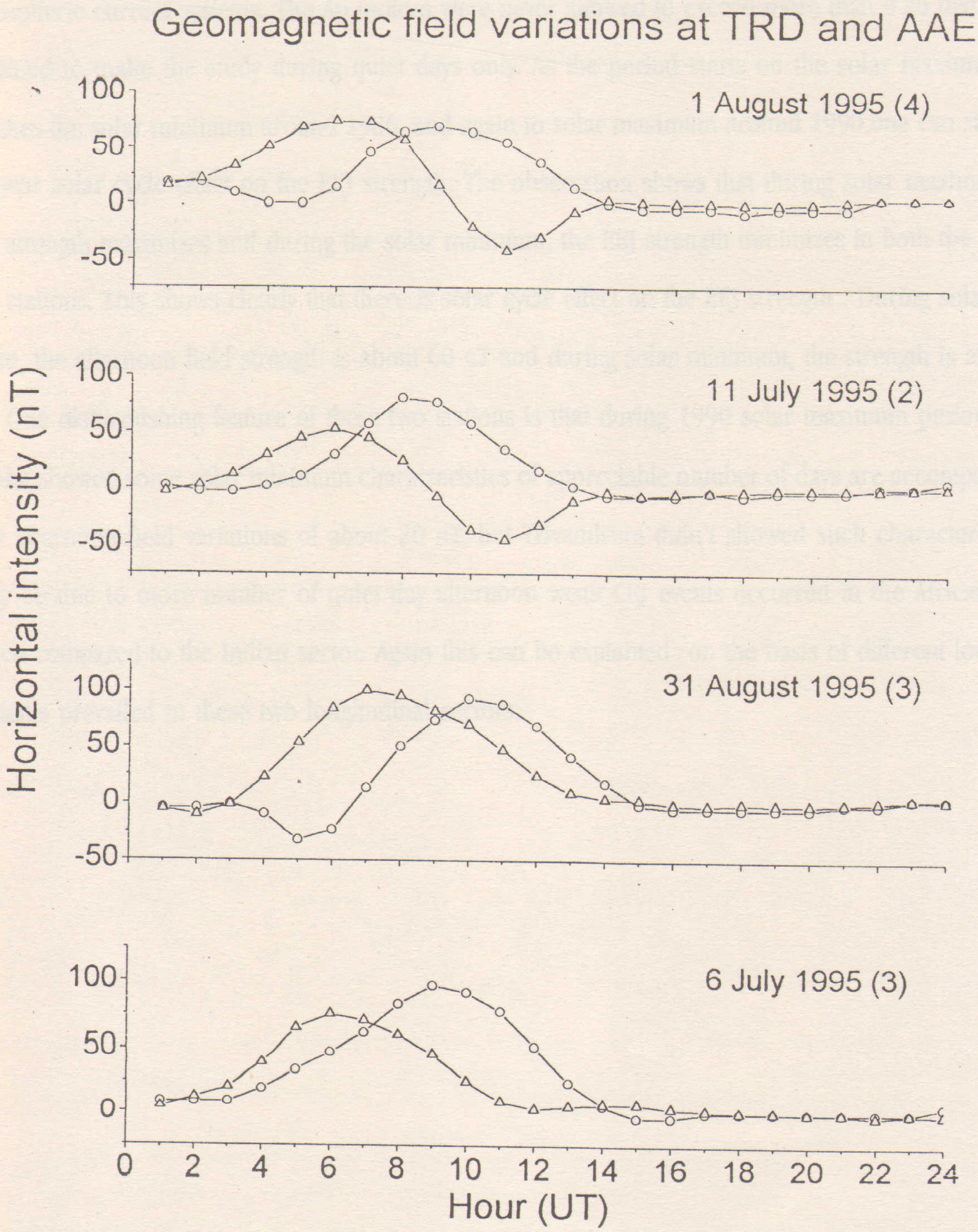
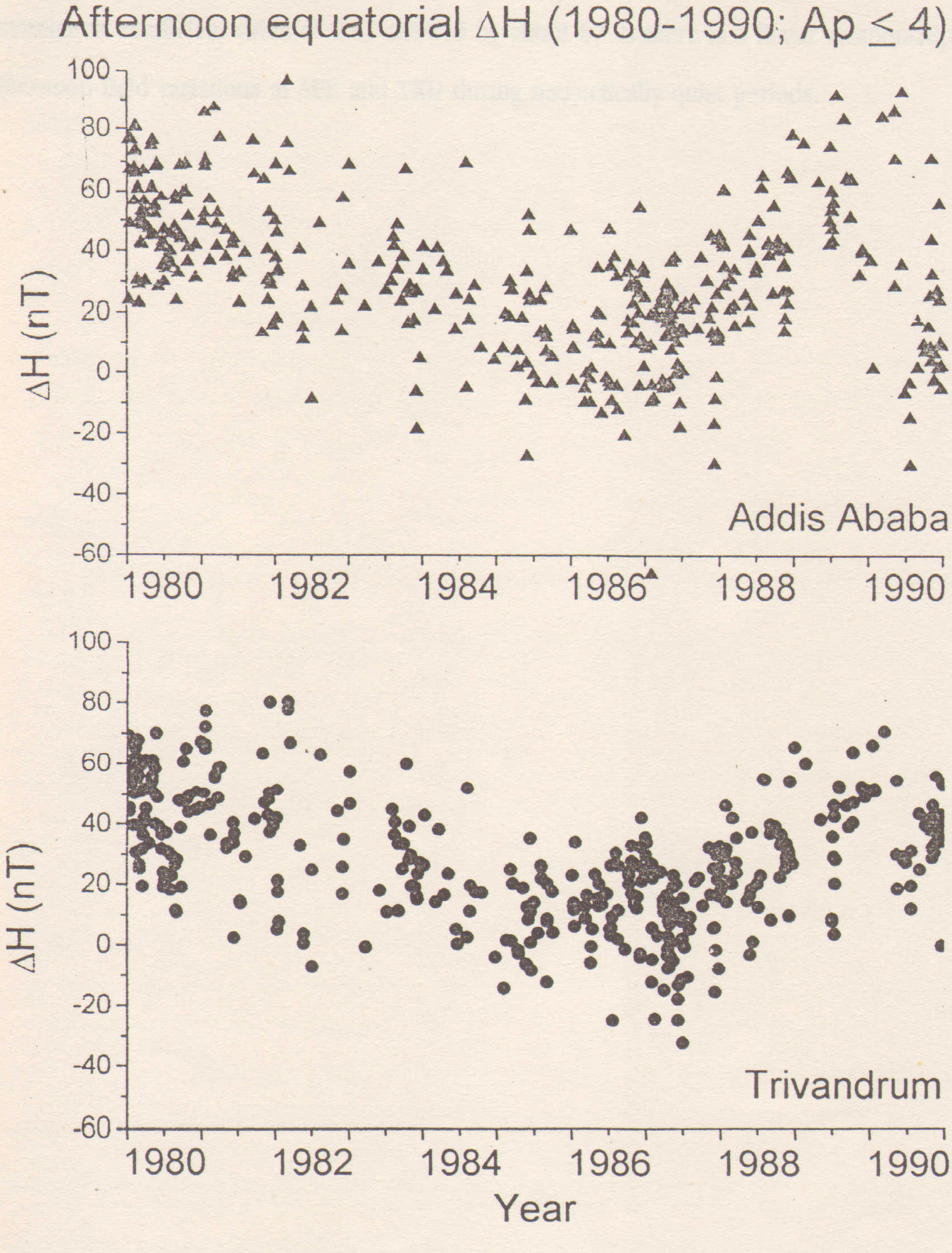

Geomagnetic field variations at TRD and AAE
1 August 1995 (4)
11 July 1995 (2)
31 August 1995 (3)
6 July 1995 (3)
Horizontal intensity (nT)
Hour (UT)
100
50
0
-50
0
2
4
6
8
10
12
14
16
18
20
22
24

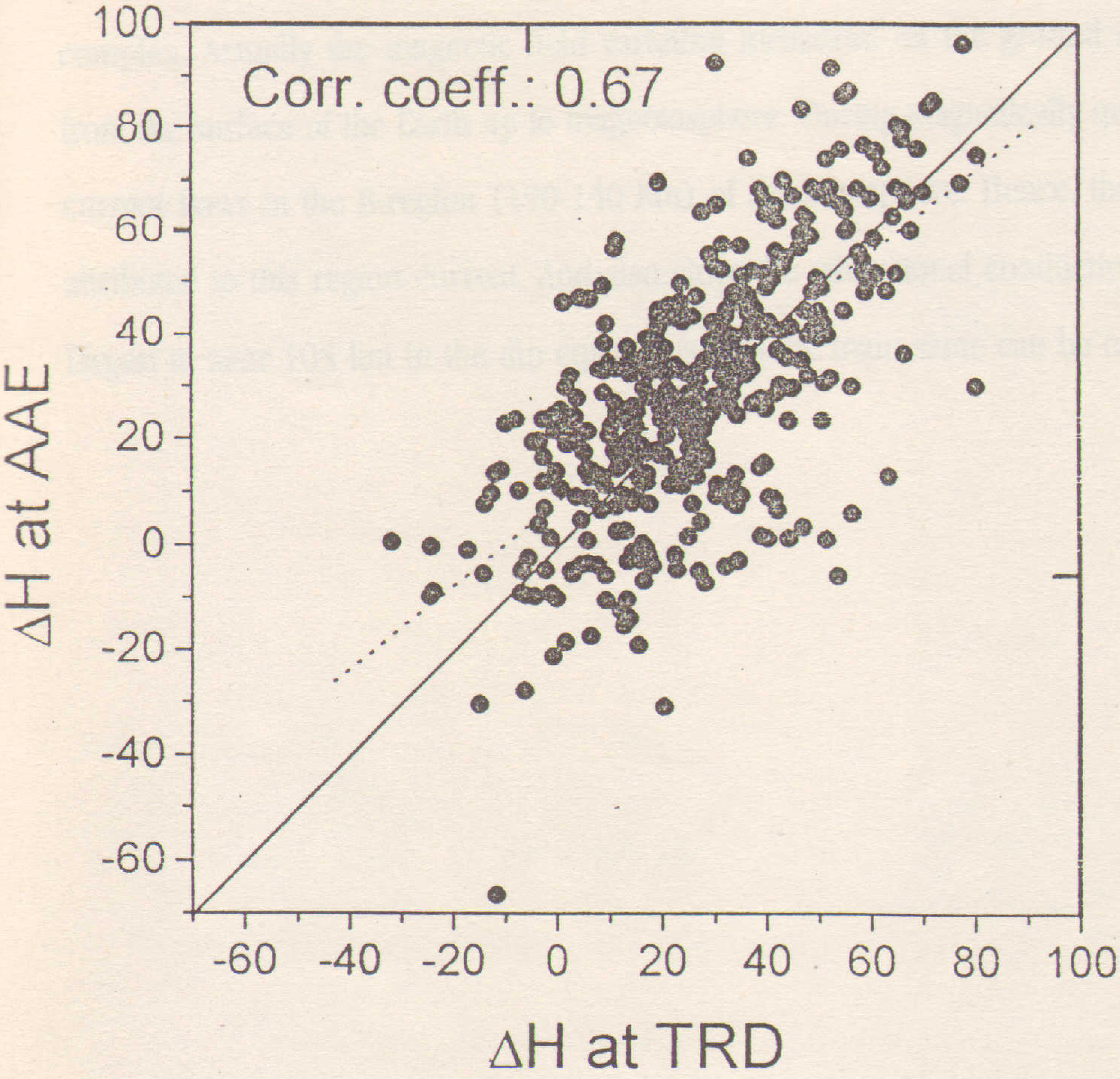
Fig .3 Shows the scatter plot of afternoon H variations, for a period of 11 years (1980 to 1990), for both the dip equatorial stations (TRV and AAE) to study the solar cycle effect on the equatorial ionospheric current systems. The Ap indices were never allowed to exceed more than 4 so that we are confined to make the study during quiet days only. As the period starts on the solar maximum and reaches the solar minimum around 1986, and again to solar maximum around 1990,one can study the 11 year solar cycle effect on the EEJ strength. The observation shows that during solar maximum, the EEJ strength maximizes and during the solar minimum, the EEJ strength minimizes in both the equatorial stations. This shows clearly that there is solar cycle effect on the EEJ strength . During solar maximum, the afternoon field strength is about 60 nT and during solar minimum, the strength is about 20 nT. One distinguishing feature of these two stations is that during 1990 solar maximum period, Addis Ababa showed some solar minimum characteristics of appreciable number of days are accompanied by low afternoon field variations of about 20 nT, but Trivandrum didn't showed such characteristics. It may be due to more number of quiet day afternoon weak CEJ events occurred in the African sector when compared to the Indian sector. Again this can be explained on the basis of different local wind systems prevailed in these two longitudinal sectors.



Afternoon equatorial ΔH (1980-1990; Ap ≤ 4)
ΔH (nT)
Addis Ababa
Trivandrum
Year
100
80
60
40
20
0
-20
-40
-60
1980
1982
1984
1986
1988
1990

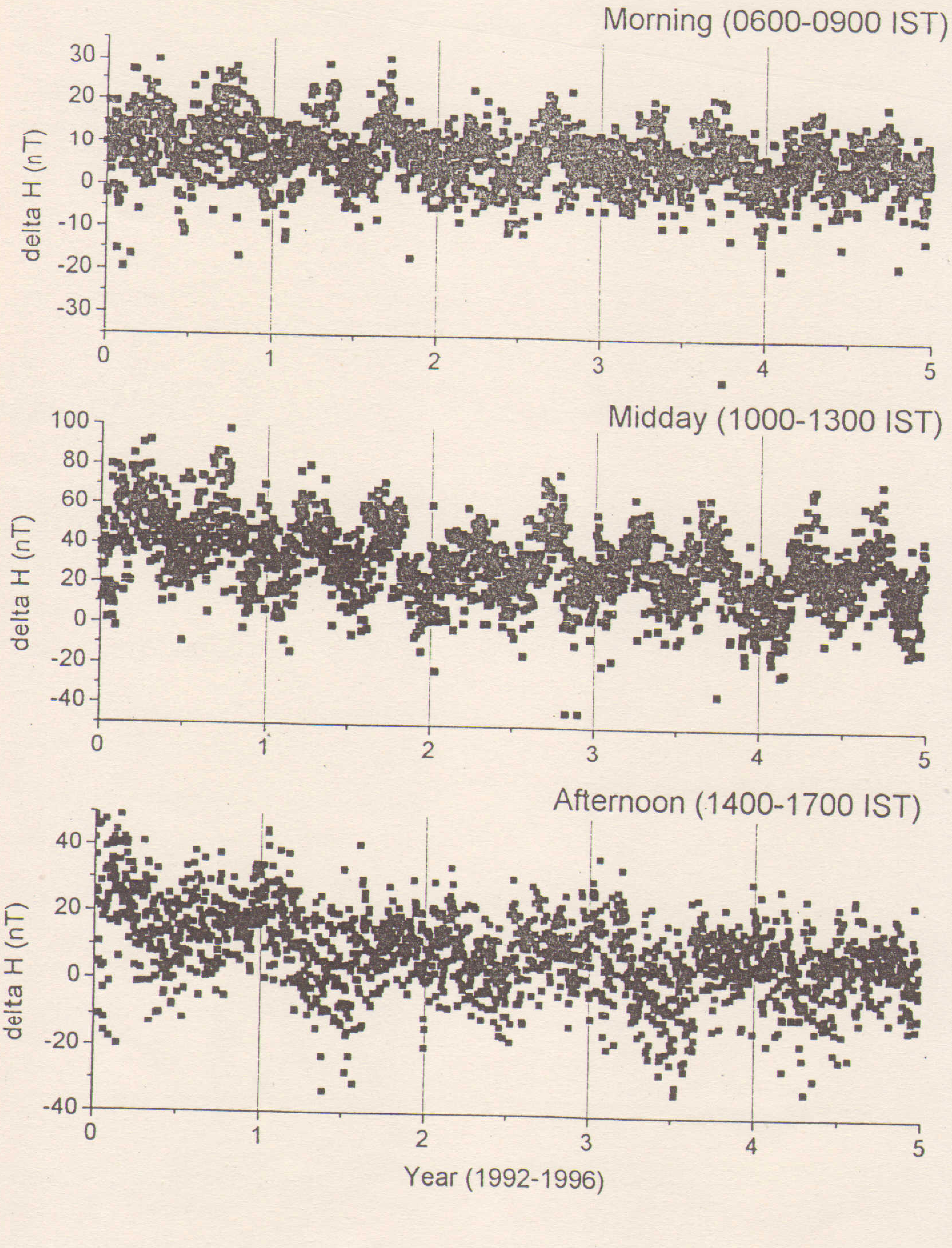
Fig. 4 Shows a single scatter plot along with the best fit straight line between AAE (y axis) and TRD(x axis) afternoon magnetic field variations corresponding to the period interval as in fig.3 The correlation coefficient value of 0.67 showed by about 67 % there is a linear relationship between the afternoon field variations at AEE and TRD during magnetically quiet periods.

Data used: 1980-1990 (all days with Ap $\leq$ 4)



These observations are only during magnetically quiet time periods. If we take all the times, including the disturbed periods of high Ap indices. into account. then finding a clear picture may be become complex. Actually the magnetic field variation measured on the ground is due to current integrated from the surface of the Earth up to magnetosphere. During magnetically quiet times (Ap$\leq$ 4) the major current flows in the E-region (190-140 km) of the ionosphere. Hence, the H field variations is mainly attributed to this region current. And also since the educational conductivity (counting conductivity) is largest at near 105 km in the dip equator region the main same can be narroued to this height range.

EEJ strength in different LT intervals



Note: Indian Standard Time (IST) = Universal Time (UT) + 1:30 hrs

AddisAbaba Africa Time = Universal Time (UT) + 3hrs.

Chapter 5

Summary

Summary

1. A comparison study of two dip equatorial region ground based geomagnetic field variations (H component) are presented in this work.

2. Stations such as Addis Ababa (AAE,90.0 N, 38.8 E geographic: 0.3 N dip lat.,) east Africa and Trivandrum (TRD, 8.5 N, 77.0 E geographic; 0.3 S dip lat.,), India are used for this purpose.

3. The current source of the field variations is mainly situated at about 103 km from the surface of the Earth.

4. The selected days are almost free from magnetospheric (above 3 Earth radii) current contribution. The Ap indices of these days are never allowed to exceed 4.

5. The observation shows that the peak of the H field variations, which depends upon the maximum solar radiation occurring near noon and the maximum drift velocity of the electrons at about 105 km occurring at about 10 LT, are separated by about 2 hours as expected since these stations are separated by about 38in longitude.

6. As India is first seeing the sun, the H field variations takes it maximum before at Africa and shown properly in the figures.

7. A slight change in the magnitude of the field variations between the stations can be explained based on the different conductivities prevailing there.

8. Sometimes both the stations shows the CEJ phenomenon and sometimes not can be explained on the basis of whether the coupling between the ionosphere with the MLT region neutral wind is a local or a global scale, If it is a global scale wind system, then we can expect similar behavior at both the stations.

9. Data for a period of 11 years have shown clearly the 11 year solar cycle influence on the EEJ strength, A perturbation accured in the Africa longitiude arround 1990.

10. There is about 67% linear relation between the H field variations at African and Indian longitudes.

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