INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392-I

H4.SMR.203 - 7

" SPRING COLLEGE ON GEOMAGNETISM AND AERONOMY "

(2 - 27 March 1987)

" Quiet day magnetic field at low latitudes "

presented by :

G.K. Rangarajan
Indian Institute of Geomagnetism
Dr. Nanabhoy Moos Road
Colaba
Bombay 400 005
India

Quiet day magnetic field at low latitudes

G.K. Rangarajan
Indian Institute of Geomagnetism
Colaba, Bombay 400 005

College on "Geomagnetism & Aeronomy" International Center
for Theoretical Physics, Trieste, Italy

March 2 - March 27, 1987

The atmospheric dynamo theory involving atmospheric tidal motions, ionospheric conductivity and the magnetic field of the earth is generally accepted as the mechanism responsible for quiet day magnetic field variations, other than at polar cap. A 2-dimensional dynamo theory describes all the basic features of Sq fields but does not fully explain some complex phenomena like N-S asymmetry, longitudinal dependence of seasonal variations etc. A 3-D theory incorporating field-aligned magnetospheric currents together with the ionospheric current has since been developed.

Using dynamo simulations using steady winds and both diurnal and semidiurnal winds Richmond et al (JGR 81, 547, 1976) conclude that (i) primary source of Sq currents are diurnal and semidiurnal winds in E and F retion driven by solar heating (ii) electric field variability on quiet days is due to variability in E-region winds and (iii) Magnetospheric sources are only of secondary importance to quiet-time ionospheric electric fields at least in day-time.

Sarabhai and Nair (1969, 1971) first proposed that the daily variation at low latitudes would be due to current system outside the ionosphere causing a depression of the field in the late evening/night hours. It is now conceded that at best this could be one of the sources contributing to Sq at low latitude. Olson (1970) estimated that magnetopause currents, tail currents and quiet time proton belt could together produce a daily variation whose magnitude at surface could be about one-third of the observed values.

Close to the dip equator, the range of daily variation in H increases abnormally due to narrow band of intense current called "Equatorial Electrojet". The cause was theoretically investigated by Hirono, Maeda, Baker and Martyn and many others. It was shown that the equatorial electrojet is due to enhanced conductivity brought about by the configuration of crossed electrical and magnetic fields. The magnetic field at dip equator is purely horizontal and the Hall currents are prevented by the polarisation of the medium, enhancing the effective conductivity of the ionosphere (see figure for Schematic sketch).

In the present lecture, only a few selected topics related to Sq and its relationship with equatorial electrojet will be highlighted. Broadly they cover : (i) Day-to-day variability (ii) Relation between Sq and electrojet field (iii) Semiannual and annual oscillation of the low latitude

ard equatorial field (iv) Features of Sq focus.

Sq. dynamo is due to winds, generated by solar heating and gravitational tides crossing with the geomagnetic field. Ionisation produced by UV & EUV can change appreciably from day to day leading to the observed changes on the magnetograms. Part of the variability has also been ascribed to shift in the focus of the Sq current system and changes in the electric field.

It has been shown (Schlapp, JATP 35, 827, 1973) that the correlation between deviations from night time base line at local noon and other hours becomes negligible beyond a few hours on either side of local noon. They are basically uncorrelated for time differences of the order of 4 hours. If the Sq curves on different days were altered through the day by only a magnification factor without change in phase the c.c. should have been unity uniformly. The absence of significant correlation indicates the importance of hour-to-hour variability. Yacob and Arora (Ann. Geophys. 30, 473, 1974) showed that the field variance has a diurnal change similar to Sq(H) with a minimum close to dawn (see figure). In problems relating to deriving the external current system of Sq, the correct baseline from which to measure Sq plays a crucial role. Usually local midnight values have been used as reference level because the conductivity in E layer is much lower. However, the day-to variability of the field near midnight hours are greater in magnitude and perhaps pre-dawn hours are more suitable.

In the Equatorial Electrojet region, the day-to-day variability is still more complex. The Sq(H) at low latitudes appear to be unrelated to the jet field (see figure). The correlation of the range of the daily variation between equatorial and low latitude field improves only during significant disturbance. Kane (JATP 33, 379, 1971) suggested that if the daily range is corrected for D_{st} variation and the position of Sq focus relative to the low latitude station, then Sq current system shows improved correlation with electrojet. An example of the day-to-day variability of the latitudinal profile of ΔH is shown in figure.

The day-to-day variability appears to be localised in spatial extent as the Sq range is well correlated only within distance of the order of 2000 km. The coherence length is smaller along the meridian than along cycles of latitude. (Greever and Schlapp, JATP 41, 217, 1979). Hibberd showed that the difference in the diurnal variation of two suitable stations in the same longitude but on either side of the Sq focus is free of contamination by magnetospheric sources and can give a good indication of day-to-day variability in Sq amplitude and phase. The correlation of ΔH_N and ΔH_S (Northern and southern hemisphere) was good on very quiet days which indicated that the two current systems varied similarly. However Greever and Schlapp found that these are not significant correlations.

Onwumechilli (Physics of the Geomagnetic Phenomena) found 3 basic patterns of equatorial H variation (a) A steady rise from midnight to maximum near 10-1100 LT decreasing to a minimum by sunset (b) A symmetric pattern with minima at dusk and dawn with max. near local noon and (c) a dawn minimum leading to a noon maximum declining beyond sunset almost upto midnight. Part of these patterns could be of non-ionospheric origin. Kane (Space Sci. Rev. 18, 413, 1976) proposed that to estimate electrojet strength and to study its day-to-day variability we can adopt a parameter:

$$SdI\ (Equator) = H\ (Equator) - H\ (Low\ Lat.) + Sq\ (Low\ Lat)$$

Similarly to estimate Sq due to ionospheric sources at low latitudes

$$SdI\ (Low\ Lat) = H\ (Low\ Lat) - (H\ focus - Sq\ (focus)\ Sec\ \theta_2\ Cos\ \theta_1$$

where θ_1, θ_2 are dipole latitudes of the low latitude station and focus station respectively.

An important contribution to the variability in Sq can also arise from the intrusion across the equator of one hemispheric current system into another. These intrusion would not only cause amplitude changes but also introduce phase modulations.

Apart from the day-to-day variability of Sq, the mean diurnal variation on quiet days changes from month to month and the mean focus position also shows seasonal variation. During northern summer the two foci tend to shift towards more northerly latitude than during northern winter. The N-hemispheric focus comes to it lower most latitude during September/October before abruptly swinging further north in November. Tarpley (JATP 35, 1063, 1973) found that the movement of the southern hemisphere focus is complementary to that of northern focus. During March (September) equinox the southern (northern) focus moves equatorward which could explain the strong semiannual variation in Sq range seen in the equatorial zone.

The equatorial electrojet strength appears to be related to the strength and focal position of the Sq current system. Larger strengths are associated with an equatorward shift of the Sq focus and with stronger electrojet (Kane, Proc. Indian Acad. Sci. 80, 17, 1974). Though the Sq and electrojet fields are not normally correlated (Rajaram (JATP 45, 573, 1983) found that the movement of Sq focus towards equator is associated with enhanced current concentration in the dip equatorial zone.

Some evidences of the effect of N-S component Interplanetary magnetic field affecting the equatorial geomagnetic field have been presented (Rastogi, Indian J. Radio Space Phys. 1981, 10). Rastogi suggested that the south to north turning of IMF in the presence of strong magnitude of the field can cause reversal of the equatorial electric field leading to counter electrojet. Matsushita (JGR, 80, 4751, 1975) found that the polarity of IMF in the equatorial plane may have detectable influence on the Sq current system. The level of quiet day H field decreases (increases) by about 5 nT when IMF directed toward (away from) the sun. This effect produces about 4° equatorward or poleward shift of the Sq current focus location.

The electrodynamic coupling between polar, auroral and mid-latitude and equatorial electrojet region due to solar wind magnetosphere - auroral ionosphere can be studied using experimental data of electric field change in the ionosphere and the associated surface magnetic disturbance. Doppler

frequency variation of the coherent VHF backscatter radar signals can be monitored. The mean doppler frequency (f_D) of the backscattered signal is proportional to the phase velocity of the 2.7 m scale size irregularities which in turn is proportional to the eastward electric field in case of type II irregularities. (Reddy et al. Nature 1979, 281, 471). It was clearly shown that the ΔH at equatorial minus ΔH at low latitude stations on the same longitude shows excellent correlation with f_D (Rastogi & Asha Patil, Curr. Sci. 1986, 55, 433).

Somayajulu et al (GRL 12, 473) detected excellent coincident decrease and increase of the equatorial electric field in phase with the latitude variations of the polar cusp, clearly indicative of the coupling. Rastogi (Proc. Indian Acad. Sci. 1977, 86, 409) suggested that counter equatorial electrojet current are caused on occasions due to the reversal of electric fields by the spreading of auroral electrojet currents during geomagnetic storms.

Annual components of the low latitude geomagnetic field

One of the most outstanding contributions to low latitude geomagnetic field variation and their seasonal dependence was made by Moos (1910) who extensively analysed the data collected at Bombay India between 1846 and 1905. Moos showed that seasonal changes were more prominent during sunlit hours.

Local-time dependence of the annual line in low latitudes and equatorial electrojet regions was studied extensively by Bhargava and colleagues (P.S.S. 20, 423, 1972; Ann. Geophys. 33, 513, 1977; J.G.G. 26, 467, 1974; Ann. Geophys. 28, 357, 1972). Alibag H data revealed annual component with peak amplitude near 14 LT and a secondary component centred at 2200 LT. This secondary component diminished when data was confined to quiet days, Suggestive of disturbance origin through magnetospheric sources. When data are analysed utilising observatories on all days and quiet days with or without elimination of the contribution of quiet day diurnal variation, it is seen that the annual variation at low latitudes consists of 3 basic components :

(i) Oscillation of the base level of Sq which is independent of local time (ii) Modulation of ionospheric dynamo current whose magnitude varies with local time and (iii) a small but significant part associated with disturbance present preferentially during late evening/night hours (Bhargava and Rangarajan Ann. Geophys. 33, 513, 1977).

Annual variation in declination at low latitudes appear to be consistent with the variation expected from an annual modulation of Sq currents. But in contrast to the H field, there is no associated base level modulation. The local time dependence reveals two peaks around 0800 and 1800 LT with significant forenoon/evening asymmetry in the amplitude (Arora et al 1979).

Closer to the dip equator, the seasonal variation in H during quiet days is dominated by equinoctial maxima so that annual variation cannot be easily identified. Malin and Isikara (Geophys. J. Ras. 47, 445, 1975) have suggested that the dominant semiannual term at equatorial stations can be removed by taking second differences of values separated by 6 months. In contrast to the semi-annual component, there is no equatorial enhancement, close to the electrojet of the amplitude of annual component. During hours where the counter electrojet features are known to be maximum there is a significant enhancement in the amplitude (Rangarajan, Indian J. Radio Space Phys. 11, 152, 1982).

In contrast to the features of annual component at dip equator, differing significantly from that at low latitudes, the local time dependence of the annual variation at a station close to Sq focus is quite similar to the low latitudes, indicative of the strong contribution of the Sq dynamo current modulation and suggesting that electrojet current modulation need not be governed by Sq dynamo.

Semiannual Variation at low latitudes

That the geomagnetic activity exhibits equinoctial maxima is well known. The basic mechanisms are broadly classified into 'Axial' and 'Equinoctial' hypothesis. In 'axial' hypothesis varying heliographic latitude is the crucial parameter with most favourable positions on March 5 and 7. In 'equinoctial' mechanism the enhanced activity is due to near normal inclination of sun-earth line and dipole axis, with dates corresponding March 21 and September 23. Russell and McPherron (JGR 78, 92, 1973) attempted to model the semiannual variation in terms of the magnitude and direction of the southward Bz of IMF. Boller and Stolov (JGR, 75, 6073, 1970) invoke Kelvin-Helmholtz instability on the flanks of the magnetopause for the semiannual modulation.

The fine structure of the semiannual variation at low latitudes and at equatorial zone has been studied extensively. Some of the interesting results are:

i) The SAV amplitude enhances significantly towards dip equator

ii) There is strong local time dependence of the amplitude of SAV with peak centred at 0800 LT and a secondary maximum in late evening hours. The secondary component vanishes for quiet days. The morning peak also diminished in magnitude when data restricted to quiet days are considered.

iii) In the electrojet region peak amplitude was closer to local noon

iv) Near the Sq focus the features were similar to that observed at lower latitudes.

Hibberd (JATP, 1985) that Sq has both annual and semiannual variation.

Recently time variations of amplitude and phase of SAV and AV in indices of activity and at low latitudes has been carried out using the technique of complex demodulation. The phase results reveal that equinoctial hypothesis is perhaps most operative.

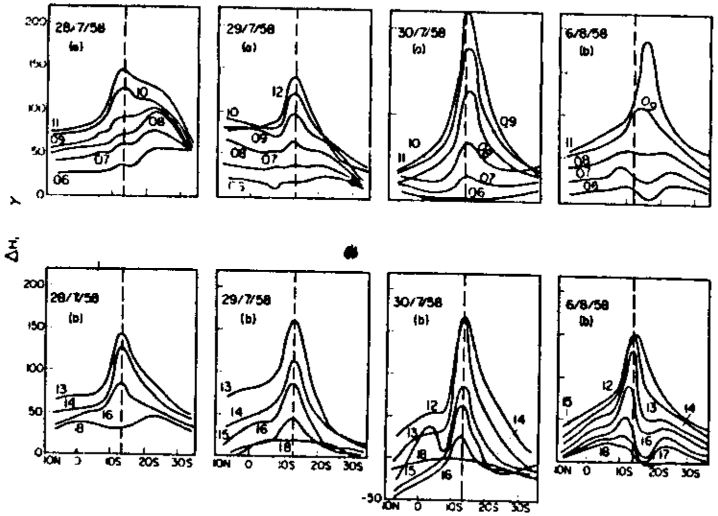


Fig. 3. The latitudinal variations of ΔH for daylight hours for four individual days during the June Solstice in the S. American Zone. Graphs (a)—morning hours until the time of maximum daily value; Graphs (b)—afternoon hours. - - - 0° Dip latitude.

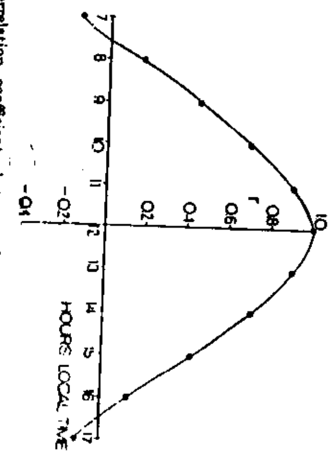


Fig. 2. Correlation coefficients between deviations from night time baseline at local noon and other hours for H at Huancayo for the two years 1923–1924.

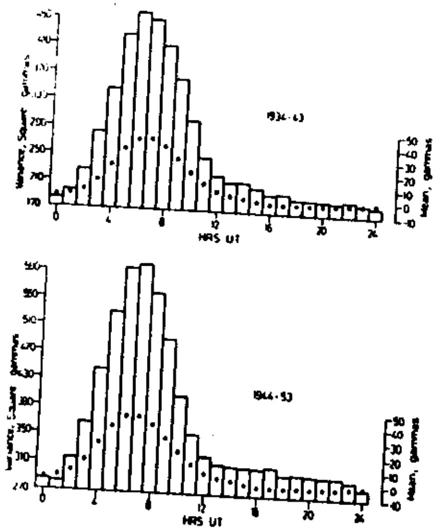


Fig. 1

Hourly means and variances of H at Alibag for 599 IQ days during 1934-43 and 1944-53. To mean field values 37425.6 and 37999.5 gammas have to be added for the respective periods. For Alibag $LT - UT = 4^h51^m$.

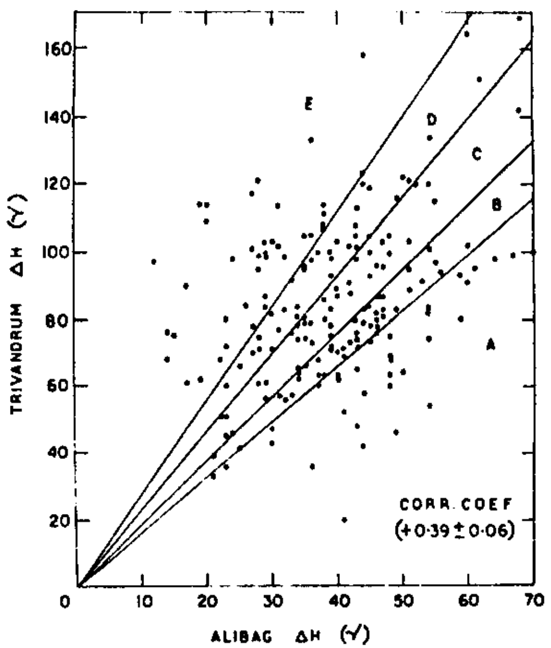
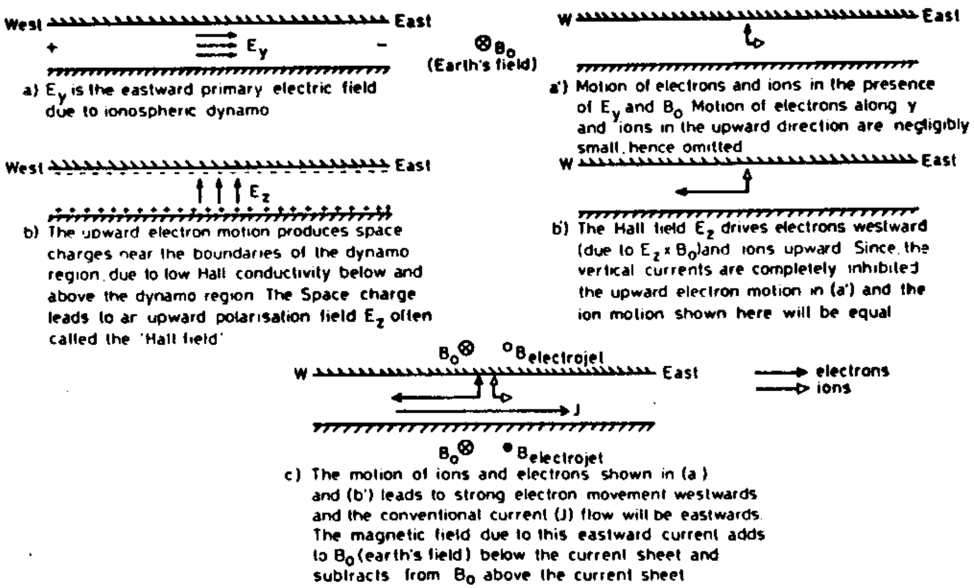
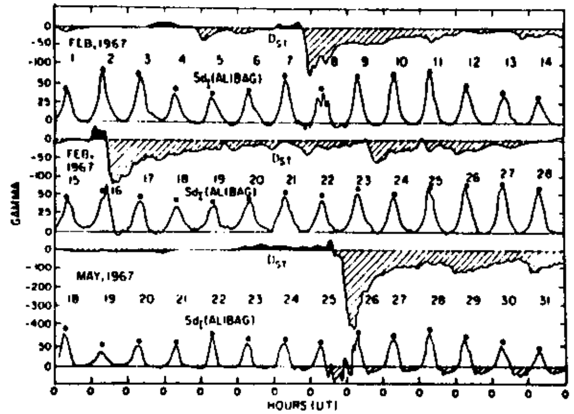


Fig. 23. Daily range of H at Alibag (low latitude outside electrojet influence) versus range at Trivandrum (under the electrojet). Regions A, B, C, D, E correspond to various groups of ratios of the two ranges (Kane, 1971c).



FORMATION OF THE EQUATORIAL ELECTROJET

FIG 1 Schematics, illustrating the formation of the electrojet.



Plots of hourly values of Dst and Sd_f(Alibag) for the whole month of February 1967 (top and middle panels) and for May 18–31, 1967 (bottom panel). Solid circles indicate local noons.

Somayajulu et al. : Cusp movements and equatorial electric fields

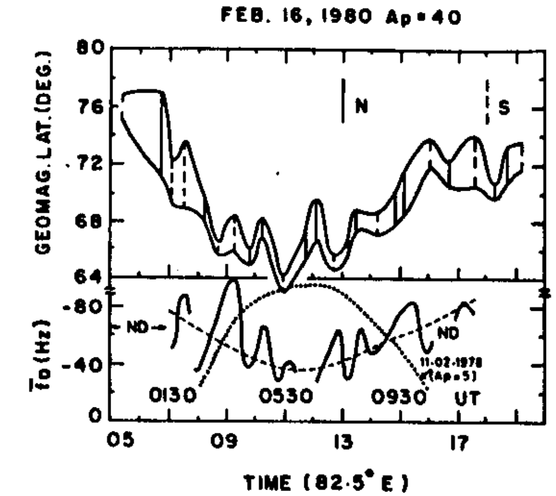
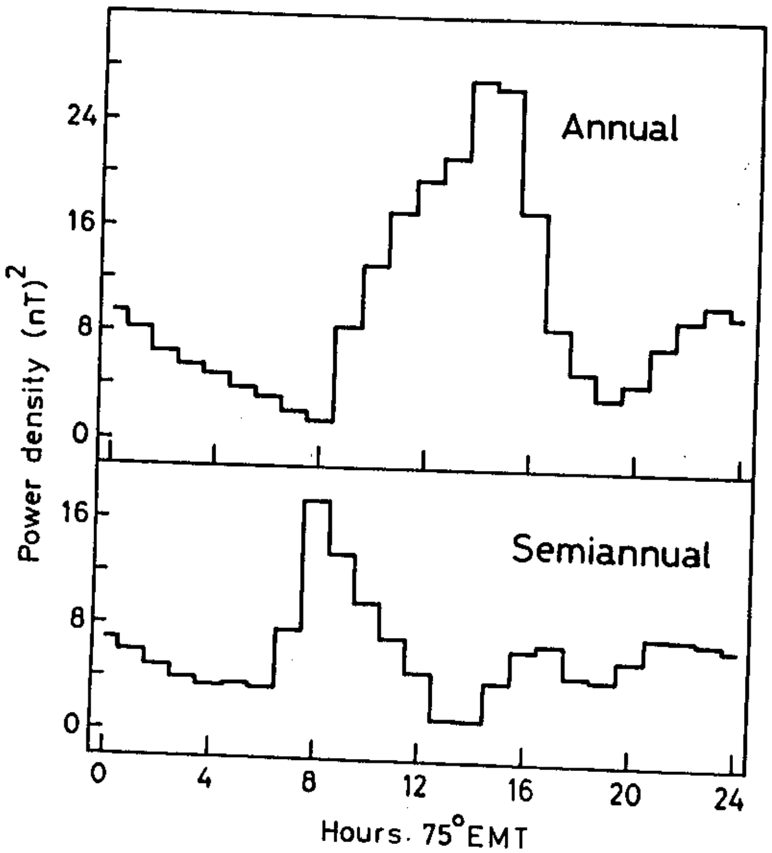
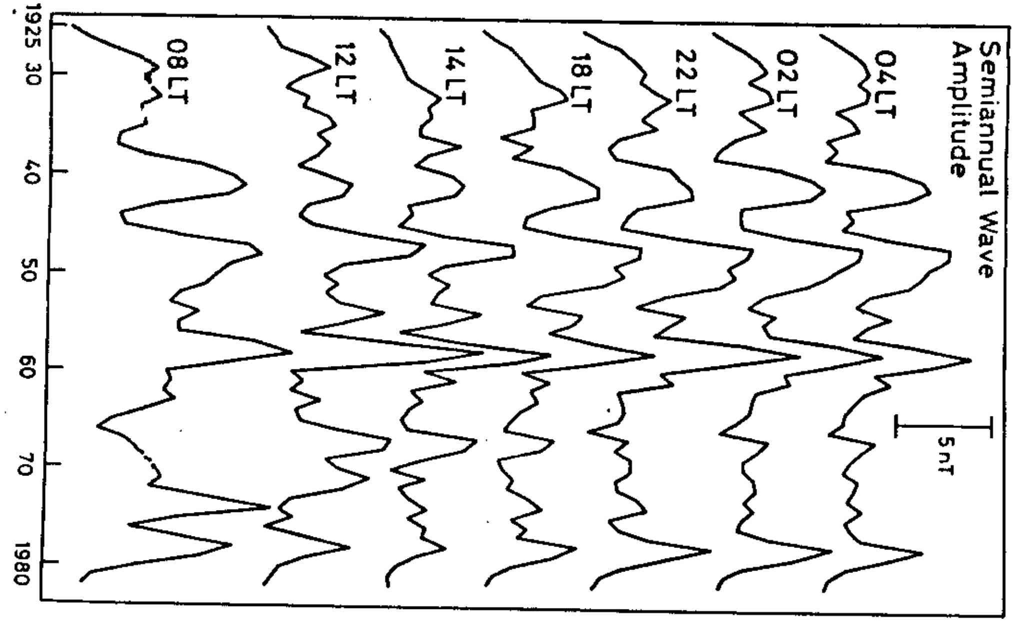
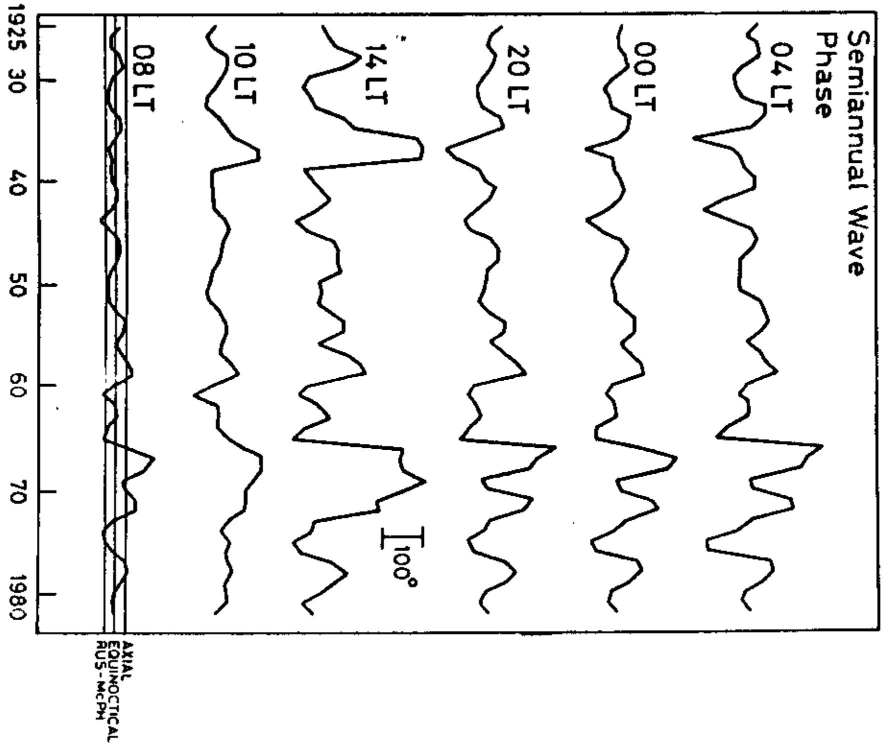


Fig. 1. Time variations of the mean Doppler frequency ($\bar{f}_D$) of the backscatter signals from the 2.7 m scale size irregularities in the equatorial electrojet on February 16, 1980 (A_p = 40). Dotted curve represents the time variations of $\bar{f}_D$ on the quiet day of February 11, 1978 (A_p = 5). The top panel of figure shows the latitude and width of the polar cusp position on the Northern hemisphere (vertical full line) and Southern hemisphere (dashed verticle line).


Annual
Semiannual
Power density (nT)^2
0
8
16
24
Hours. 75°EMT
0
4
8
12
16
20
24


Semiannual Wave
Amplitude
04LT
02LT
22LT
18LT
14LT
12LT
08LT
5nT
1925
30
40
50
60
70
1980


Semiannual Wave
Phase
04LT
00LT
20LT
14LT
10LT
08LT
100°
AXIAL
EQUINOCTICAL
RUS-McPH
1925
30
40
50
60
70
1980