The development of research in E and F regions of the ionosphere in India since about 1950 is briefly described. The various geomagnetic factors controlling the F region at low latitudes during quiet, disturbed days, on different ages of the moon are described. The equatorial electrojet current, its association with general Sq currents, geomagnetic disturbance and solar disturbance are shown due to changes of the electric fields at the equator. The phenomenon of spread-F at low latitudes is shown to be associated with the regeneration of equatorial plasma fountain during the post sunset hours similar to the daytime plasma fountain associated with equatorial ionization anomaly. The narrow belt of ionosphere, the magnetic equator, is shown to be very sensitive to electric fields of local origin or even to electric field generated at the magnetopause due to the interaction of the solar wind on the earth's magnetosphere.

1 Introduction

The existence of electrically conducting region of the earth's atmosphere (now known as ionosphere) was first suggested by Stewart\(^1\) to explain the regular solar daily variations of the components of the earth's magnetic field at different locations on the earth. Schuster\(^2\), representing the magnetic potential at any point on the earth in terms of a series of spherical harmonic functions, examined the geomagnetic field variations on a global scale and concluded that the equivalent current system responsible for geomagnetic variations is mainly external with a small contribution from internal (induced) current. In order to explain the anomalous daily variations of the geomagnetic \(H\) field at Huancayo, McNish\(^3\) presented the first \(S_q\)-current system for western hemisphere of the earth. The \(S_q\)-current system was further developed by Chapman and Bartels\(^4\). The \(S_q\)-current system consists of two loops of electric current, counter clockwise in northern hemisphere and clockwise in southern hemisphere and is confined in the dayside portion of the earth. The focus of the current system is around \(\pm 35-40^\circ\) geomagnetic latitudes. There is a long tradition of the study of geomagnetism in India. The observations of geomagnetic declination at Trivandrum and Augustier Mallay have been discussed by Broun\(^5\), many of these formed a set of original new findings. Magnetic observations, started at Colaba in September 1841 and continued till today at Alibag, form longest unbroken geomagnetic data set in the world. We have today one dozen standard geomagnetic observatories extending from the magnetic equator up to very close to the \(S_q\)-focus latitude. India is the only country other than Brazil incorporating within its political boundary both the dip equator as well as the focus of \(S_q\)-current system.

The experimental evidence of the ionized layers in the earth's atmosphere (ionosphere) was provided by Breit and Tuve\(^6\) and Appleton and Barnett\(^7\) in 1925, about 43 years after its prediction based on geomagnetic field data. In India, ionospheric observations started almost at the same time under the leadership of Prof. S K Mitra. The first experiment consisted of the angle of incidence method of finding height of the ionospheric region. In 1930, experimental evidence of the E layer of the ionosphere was obtained for the first time in India. By the end of 1930s, early observations of the critical frequency and height of the ionospheric layers were started at Calcutta. Regular hourly observations of \(f_oF_2\), \(h'F_2\) and \(f_oE\) were started by All India Radio in September 1945 at Peshawar, Delhi, Bombay and Madras.

With the establishment of a large number of ionospheric sounding stations around the world it became evident that two stations at same geographic latitudes but at different longitudes did not record similar values of \(f_oF_2\). Such longitudinal differences were found among high latitude stations Washington, Rome, Tokyo and Slough, between middle latitude stations Baton Rouge and Delhi, and between low latitude stations Huancayo and Christmas Island. However, Appleton\(^8\) was the first to show that for noon condition a plot of \(f_oF_2\) values as a function of latitude shows a pronounced trough centred on the magnetic equator with crests \(15^\circ-20^\circ\) north and south of it. Thus, for the first time a direct associa-
tion between geomagnetic field and ionosphere at low latitudes was established. Almost immediately after the discovery of this equatorial ionization anomaly (EIA), Prof. S K Mitra suggested possible mechanism for the subtropical peak of \( f_0F2 \) during midday conditions. He suggested that in the regions high above the F2 layer, the collision frequency is very small and the electrons and ions produced by the solar ultraviolet rays have very long free paths. They are thus free to spiral round the magnetic lines of force and are guided along them to north and south away from the equator, and contribute to the ionization density of the F2 region at tropical latitudes. Martyn added the concept of upward electrodynamic drift of the plasma over the magnetic equator followed by the diffusion down the magnetic field lines in the manner as suggested by Prof. S K Mitra. Today so many phenomena in the ionosphere have to be explained on the idea of diffusion along geomagnetic lines of force first suggested by Prof. Mitra.

Although the geomagnetic data at Huancayo showed abnormally large daily variation since 1922, the data from Indian stations Kodaikanal, Madras and Alibag enabled Egedal to discover a narrow belt of enhanced \( S_h(H) \) variation within 5° latitude centred on the dip equator. Soon after, Matsushita showed similar narrow belt of enhanced frequency of Es (\( fE \)) centred over the magnetic equator suggesting intimate relationship between equatorial electrojet current and sporadic E layer.

The main source of \( S_h \)-current system is the electric field produced in the dynamo region (E layer of the ionosphere) due to the tidal winds. The enhancement of the current at equatorial latitudes is attributed to the special configuration of the orthogonality of the horizontal electric and magnetic fields over the magnetic equator. The same field is the cause of the F region uplifting at the equator commonly known as equatorial plasma fountain. It has been shown by Alex et al. that the effect of equatorial electrojet electric fields extends well up to the top side of the ionosphere. The changing electrojet currents affect the plasma distribution up to the latitudes of 30° from the magnetic equator. Thus for this article we define the equatorial ionosphere as the region from about 100 to 2000 km and within latitudes of ± 30° from the magnetic equator.

The Council of Scientific and Industrial Research of India constituted the Radio Research Committee in 1943 under the Chairmanship of Prof. S K Mitra and India joined the International Union of Radio Science in 1950. Next two decades formed the golden years of ionospheric research in India, when Indian scientists contributed fundamentally new findings on equatorial ionosphere. Saha has described remarkably well the development of radio research in India for the first three decades since around 1925. In this article I would briefly describe the development of studies on equatorial ionosphere, first started in India by Prof. SK Mitra, since 1950s.

2 Development of radio research in India since 1950

The decade of 1950 saw the initiation of ionospheric research at All India Radio under the supervision of Prof. S N Mitra. Prof. K R Ramanathan started the ionospheric research group at Ahmedabad around 1950. At Kodaikanal standard magnetic observatory was restarted in 1949 and a C2 model ionospheric sounder started functioning in May 1952 under the guidance of Prof. B N Bhargava. The soundings at Kodaikanal have generated one of the best records of equatorial ionogram available anywhere in the world and provided base equatorial data for ionospheric research in India.

Automatic ionospheric sounder at Ahmedabad started working early in 1953 and the soundings have continued since then. Together with other ionospheric sounding stations in the Asian sector, these provided the network for the study of equatorial anomaly in the F2 layer as shown in Fig. 1 (Ref. 16). It was soon realized that daily variations of \( f_0F2 \) at Kodaikanal were very similar to those at Huancayo, describing features of ionosphere at the trough of EIA. Calcutta and Ahmedabad were found to lie very close to the crest of EIA, and unexpectedly large values of \( f_0F2 \) were observed. It was then understood that it was better to plot \( f_0F2 \) with respect to the smoothed geomagnetic equator rather than the actual magnetic equator. Examining the daily variations of \( f_0F2 \) at pairs of stations (Leopoldville/Madras and Bombay/Ibadan) having same geomagnetic (dipoles) but different magnetic (dip) latitudes, as shown in Fig. 2 (Ref. 19), Ibadan and Bombay have similar geomagnetic latitudes but the daily variation of \( f_0F2 \) at Ibadan is typical of equatorial station whereas the same at Bombay is typical of a station near the anomaly crest. It was concluded that it is actual dip latitude on ground which determines the type of daily variation of \( f_0F2 \) at stations within EIA. Comparing the daily variations of \( f_0F2 \) at the network of equatorial stations in Asian sector, it was found that the double maxima of \( f_0F2 \) at equatorial stations are less separated with increasing latitude and finally converge to a single maximum at a dip of about 25° (Fig. 3). The latitudinal maximum of \( f_0F2 \) was found to develop at low latitudes and shift...
poleward with the progress of the day, the course being reversed in the evening hours. These two anomalies in $f_{0}F2$ were suggested\(^2\) as being due to the vertical drift of ionization together with its motion towards the poles in the morning and towards the equator in the afternoon. This phenomenon was further discussed by Duncan\(^2\) and is popularly referred to as "equatorial plasma fountain". Thus, a close coupling between the electron density distribution at equatorial and tropical latitudes was suggested through the intensity of fountain process. In Fig. 4 (Ref. 22) are shown daily variations of $f_{0}F2$ at anomaly trough station, Kodaikanal, and at anomaly crest station, Ahmedabad, during weak and strong equatorial electrojet days. During a weak electrojet day, indicated by smaller amplitude of daily variation of $H$ field at Kodaikanal, the values of $f_{0}F2$ at Kodaikanal are high without any noon bite out while on strong electrojet day the values of $f_{0}F2$ at Kodaikanal are low with a strong bite out. Contrary to this, at Ahmedabad, the afternoon values of $f_{0}F2$ are higher on strong electrojet day. Thus a strong electrojet corresponded to stronger fountain and a stronger ionization anomaly. The lower panel shows the variation of $H$ which indicates strong and weak jet.

The regular ionogram recordings at Kodaikanal and Ahmedabad led to the understanding of numerous features of the ionosphere not known till then, viz. disappearance of the F layer in the early morning hours (Bhargava\(^2\)), forenoon bite out in $f_{0}F2$ at middle latitudes (Rastogi\(^2\)), recurrence of spread-F echoes (Bhargava\(^2\), Rastogi and Kulkarni\(^2\)), occurrence of E2 layer intermediate between E and F layers (Saha and Ray\(^2\) and Rastogi\(^2\)).

Due to the establishment of an excellent network of ionospheric stations during 1950s, a two-dimensional picture of the distribution of $f_{0}F2$ on local time versus magnetic dip coordinates for the equinoctial month of September for the years 1954-62 was obtained (Fig. 5). It is seen that the anomaly crest started at the equator after sunrise moved to about $35^\circ$ latitude by midday. During low sunspot years 1954-55 the anomaly crest moved towards the equator after sunset. During the maximum sunspot years 1958 and 1959 the anomaly crest remained around $35^\circ$ latitude practically from noon till the next sunrise hours. Very concentrated region of intense ionization was seen after sunset hours.

These post sunset increase of ionization have been studied by Rao\(^2\) and now seem to be associated with post sunset increase of horizontal electric field...
at the equator during post sunset hours of high sunspot years.

Another ionospheric research group developed in the early years of 1950s at the Andhra University, Waltair, under the leadership of Prof. B Ramachandra Rao. His group conducted extensive studies of ionospheric drifts at low latitudes and later expanded their activities to almost all other aspects of ionospheric research. Prof. Rao has the distinction of producing a large number of ionospheric scientists who now hold important positions in India and abroad.

In 1954, Dr A P Mitra joined the National Physical Laboratory, New Delhi, as Secretary of the Radio Research Committee and initiated an ionospheric prediction service which continues till today. Dr Mitra started with a group of ionospheric workers at Delhi. He developed the technique of cosmic radio noise measurement first initiated by him with Shain\textsuperscript{30} at Australia into a sophisticated "riometer" to study the effect of solar flares in the ionosphere. At that time, i.e. before the satellite era, this was the only technique to get any information above the level of peak F2 ionization\textsuperscript{31}. It was also helpful in estimating the electron temperature at F region heights (Kumari and Mahajan\textsuperscript{32}). Riometer experiments were started at PRL Ahmedabad, Kodaikanal and a few other places. At Ahmedabad, the cosmic noise records on 25 MHz showed about 6.5 dB absorption during the solar flare of 23 Feb. 1956 (Ramanathan et al.\textsuperscript{33}). Later, Ramanathan \textit{et al.}\textsuperscript{34} showed that the electron-ion collisions in the F region both below and above the level of maximum electron density contribute in a substantial way to the absorption of cosmic radio noise. They also showed a depletion of electrons above F' maximum during the early days of magnetic storm followed with refilling on later days, suggesting particle fluxes in the F region from Van Allen belts during magnetic storms.

Dr A P Mitra developed a reputed school of scientists, expert on atmospheric chemistry and middle atmospheric research but this subject is outside the purview of this article and not discussed here.

Besides the regular daily solar variations of the geomagnetic field and consequently of the ionospheric parameters, the gravitational tides due to
moon generate corresponding variations in the geomagnetic and ionospheric parameters at low latitudes. Bartels and Johnson demonstrated the existence of abnormally large lunar tidal oscillations in the solar daily range of $H$ at Huancayo. Rastogi showed that the lunar tide in the range of $H$ is enhanced over narrow latitudes around the dip equator in a manner similar to the enhancement of the electrojet current. Lunar tides in $fF2$ at an equatorial station Huancayo was first shown by Martyn with a maximum positive deviation occurring at 03 lunar hour. McNish and Gautier showed that lunar tides in midday value of $fF2$ at equator attains maximum two days after new or full moon while at 20° from equator the phase is shifted by almost 180°. Using the ionospheric data from a large number of stations around the world, Rastogi showed that the phases of lunar tide in midday values are controlled by dip latitude and not by dipole or geographic latitude. The phase of maximum deviation was around 3 lunar hr at stations within ±10° dip latitude and around 10 lunar hr at stations outside this equatorial belt. A pronounced enhancement of the amplitude of the lunar tide within ±30 dip latitudes (similar to the electrojet enhancement) was also demonstrated. To show close anti-relationship between $H$ and $fF2$ at an equatorial station, daily average values of these parameters at Huancayo as a function of lunar age are shown in Fig. 6 (Ref. 40). The variation of $fF2$ is almost opposite to that of $H$.

The launching of Polar Orbiting Ionospheric Satellite Explorer 22 (also known as S-66 or BEB) in October 1964 with onboard linearly polarized radio beacon on 20, 40 and 41 MHz heralded a new technique to monitor total electron content in the ionosphere. Recordings of radio beacons from Explorer 22 and later Explorer 27 were made at Delhi (29°N), Kurukshetra (geog. lat. 28°N), Ahmedabad (23°N), Calcutta (23°N), Hyderabad (17°N), Kodaikanal (10°N) and Thumba (9°N), providing a very

Fig. 4 — Daily variations of $fF2$ at Kodaikanal and Ahmedabad on weak and strong electrojet days (after Rastogi and Rajaram).
good coverage in Indian subcontinent. The diurnal, seasonal and solar cycle variations of the electron content at anomaly crest station were very similar to those of maximum electron density, $N_m F_2$ (Ref. 41). At the anomaly trough station Kodaikanal as shown in Fig. 7, there was no midday bite out in electron content $N_T$ although the height of peak ionization $h_m F_2$ and semi-thickness $Y_m F_2$ showed a maximum around noon and the maximum electron density showed a pronounced bite out around midday hours. Latitudinal variations of TEC were studied by Basu and Das Gupta. Combining the records of Faraday rotation of radio beacon for the same pass at Ahmedabad and Kodaikanal, Iyer et al. were able to compute TEC from 0° to 30° geographic latitude covering entire belt of EIA. It was shown that the latitudinal anomaly in TEC started from the equator around 0900 hrs IST, moved northward with the progress of the day and reached the dip latitude at 15°N by 1300 hrs IST and moved back towards the equator later on. Using same techniques, Rastogi et al. produced the counter maps of TEC on local time versus latitude grid for different seasons and solar activity epochs. A numerical model for TEC in the Indian zone was produced by Klobuchar et al.

During the second phase of the geostationary satellite ATS-6, based at 35°E from August 1975 to July 1976, extensive sets of electron content and scintillation measurements were made at different stations in India, viz. Trivandrum, Ootacamund, Waltair, Bombay, Rajkot, Ahmedabad, Calcutta, Udaipur, Delhi, Gauhati. This formed one of the unique networks of electron content measurements.
within the equatorial ionization anomaly region made anywhere in the world so far. Under the cooperation between Physical Research Laboratory, Ahmedabad, and Environment Research Laboratory, Boulder, USA, a most sophisticated ATS-6 receiving system was operated at Ootacamund providing digital recording of all the beacons from the satellite at an equatorial station; it was again the only experiment of its kind made on low latitudes ionosphere anywhere in the world.

It was found that the diurnal anomaly in TEC at equatorial station was practically absent while the latitudinal anomaly was weaker than the corresponding anomaly in $N_m F2$ (Ref. 48). It was found that the latitudinal anomaly completely disappeared during a geomagnetic storm, suggesting the inhibition of equatorial fountain process during geomagnetic strom. Combining the data from various stations in India, a spatial distribution of electron content ($N_f$) with latitude and local time within Indian subcontinent was possible on day-to-day basis. The anomaly was shown to be absent on very weak electrojet, was around 15° dip latitude during normal electrojet, and beyond even 30° dip latitude during very strong electrojet days. Similarly the lunar tidal amplitude in $N_f$ did not show phase reversal between trough and crest regions nor the enhancement of the amplitude over the magnetic equator unlike the behaviour of $N_m F2$ with lunar phase. These and some other new features of $N_f$ in contrast to that of $N_m F2$ demand remodification of the fountain theory of equatorial ionization anomaly. Attempts are being made to theoretically simulate these findings by adjusting suitably the static and dynamic parameters of the equatorial ionosphere.

Another important result that came out of ATS-6 experiment for equatorial ionosphere was the spatial, temporal and frequency dependence of VHF radio scintillations. VHF radio scintillations were found to be stronger in the American than in the Indian sector during the daytime hours while nighttime scintillations were stronger in the Indian sector. The characteristics of equatorial radio scintillations have been described for Huancayo in the

Fig. 6—Mean lunar monthly variations of the daily mean values of $f F2$ and $H$ at the equatorial station Huancayo (after Rastogi)

Fig. 7—Daily variations of semi-thickness ($Y_m F2$), height of the maximum ionization ($h_m F2$) and the maximum electron density of the F2 layer ($N_m F2$) over Kodaikanal compared with the ionospheric electron content for the years 1964-66.
American sector by Rastogi and at Ootacamund in the Indian sector also by Rastogi. Occurrence of range type of equatorial spread-F on the ionograms was shown to produce fast and saturated scintillations mostly during post sunset hours. Frequency type of spread-F without any range spreading produced very moderate and slow scintillations. During the daytime hours, the occurrence of q type of Es layer produced weak and slow scintillations with amplitudes of 1-2 dB while blanketing type of Es associated with counter electrojet produced strong scintillations even in VHF, exceeding peak-to-peak amplitude of 10-20 dB. Simultaneous recordings of scintillations of HF as well as VHF band enabled the determination of frequency dependence of scintillations at equatorial region. For a particular pair of frequencies, exponent $n$ (with $S_n \propto f^{-n}$, where $S_n$ is the normalized RMS value of the intensity fluctuations and $f$ the signal frequency) was found to decrease monotonously with increasing intensity of scintillations approaching a value of zero for saturated scintillations. The relationship was found to be independent of time of the day and the season in spite of different kinds of irregularities being involved in the scintillation process. Any abnormal reversal of the horizontal electric field in the ionosphere at equatorial region during the nighttime hours from westward to eastward direction was shown to produce VHF scintillations with a delay in time of the order of an hour, suggesting a close relationship between equatorial electric field and scintillation producing irregularities.

Perhaps the most important phase of equatorial ionospheric research started with the installation of Equatorial Rocket Launching Station (TERLS) at Thumba in 1963 by the Department of Atomic Energy, Government of India, then responsible for developing space research in India. Physical Research Laboratory, Ahmedabad, and National Physical Laboratory, New Delhi, were main partners in rocket-borne experiments in collaboration with scientists from USA, France, Japan and West Germany. Prof. Vikram A Sarabhai offered to Prof. R G Rastogi of PRL and Prof. B R Rao of Andhra University facilities to establish ground-based ionospheric experiments in Thumba.

The first experiments with rocket-borne payloads were the release of sodium vapour during the evening hours to measure the neutral winds in the ionosphere by Prof. P D Bhavsar and Prof. J E Blamont, and the measurement of ionospheric electrojet currents by rocket-borne proton precision magnetometers by Prof. T S G Sastry and Prof. L J Cohill. Extensive series of vertical profiles of current density were obtained indicating considerable day-to-day variability in its amplitude, but the peak current altitude was consistently found to be around 106 km (Ref. 59).

Prof. Satya Prakash of PRL was assigned the experiment of measuring electron densities in the ionosphere by rocket-borne payloads. His group developed a very sensitive and high frequency-response Langmuir probe and were able to study for the first time the plasma irregularities in the equatorial electrojet region. These irregularities were detected in the regions of positive gradient during the daytime and in the regions of negative gradient during the nighttime. Recognizing that the Hall polarization field produced by primary east-west electric field would be upward during the day and downward during the night, Prakash et al. concluded that these plasma irregularities in the equatorial electrojet region are caused by the gradient drift instability mechanisms. The characteristics of equatorial plasma irregularities and the mechanisms for their generation have been reviewed by Prakash and Pande.

The ground-based ionospheric experiments established at Thumba by Prof. R G Rastogi and his coworkers developed into equatorial ionospheric research station and consisted of ionospheric drifts riometers, radio beacon satellite studies, vertical ionospheric sounder and other experiments related to equatorial electrojet.

The ionospheric drift measurements at Thumba were found to be very intimately connected with the equatorial electrojet current and thereby to the equatorial ionospheric electric field. The extensive and continuous observations of ionospheric drift velocities ($V_E$, $V_F$) provided for the first time the data of equatorial electric fields unaffected by magnetospheric or induced currents as in the geomagnetic field measurements. The equatorial electric field was shown to decrease with increasing geomagnetic activity suggesting for the first time association between equatorial electric fields with phenomena occurring at high latitudes during periods of increased geomagnetic activity. A slight decrease of electric fields with solar activity was noted; the solar cycle variation of electrojet current was attributed primarily to the change of E layer ionization density.

One of the most important discoveries of Thumba experiments has been the interrelation between the disappearance of equatorial sporadic-E layer, depression of the geomagnetic $H$ field and the reversal of equatorial electric field providing new insights in the electrojet current systems and in the
Kelley et al.\textsuperscript{74} showed that during the geomagnetic storm of 8-9 Aug. 1972, perturbations in the eastward equatorial electric field at Jicamarca followed closely with the fluctuations in the westward auroral electric field at College, Alaska. Rastogi\textsuperscript{5} showed that the fluctuations of westward electric fields at daytime equatorial electrojet in Indian sector varied very distinctly with the nighttime eastward equatorial electric fields at Jicamarca (Fig. 10). Thus it was shown for the first time that the changes in the nighttime auroral electric fields are associated with the changes in the electric fields over the magnetic equator both in the daytime as well as nighttime hemispheres. Later Gonzales\textsuperscript{76} described similar correlations between auroral and equatorial electric fields during a number of geomagnetic substorms. Various aspects of interrelations between equatorial electrojet and IMF have been discussed critically by Rastogi\textsuperscript{77}.

Storm sudden commencements (SSCs) are one of the most important signatures of the solar wind impact on the earth's magnetosphere. SSCs are caused by the compression exerted on the sunward side of the earth's magnetosphere by the plasma cloud ejected from the sun during a solar flare\textsuperscript{78}. The geomagnetic recordings at the network of Indian

![Fig. 8—Relationship between the interplanetary magnetic field component \((B_z)\) and the ionospheric drifts at Thumba during the midday and midnight hours](image)
stations at low latitudes indicated an enhancement of the amplitude of SSCs similar to the enhancement of $H$ itself, suggesting additional electric field on equatorial electric fields during sudden commencements.\textsuperscript{79} Examining original magnetograms at Indian geomagnetic observatories, Rastogi and Sastri\textsuperscript{80} showed that SSC +, i.e. the sudden commencement with preliminary inverse impulse was observed only during the daytime hours and within a very narrow latitude belt around the magnetic equator. These events were shown to be associated with the impact of solar plasma on the magnetosphere incorporating the sudden change of $B_z$ from southern to northern component together with the compression of the magnetosphere\textsuperscript{81,82}. Direct evidence of equatorial electric field changes during SSC were provided by high resolution VHF backscatter radar at Thumba\textsuperscript{83} as shown in Fig. 11.

These facts show extreme importance of equatorial ionosphere close to the magnetic equator in understanding the mechanisms of solar energy absorption in generating not only atmospheric dynamo but also in monitoring the coupling between the solar wind interactions with the earth's magnetosphere and the equatorial electrojet electric fields.

One of the important characteristics of equatorial ionosphere during the nighttime hours is the occurrence of irregularities in the F region producing scattered and diffused echoes on the ionograms, known as spread-F. The occurrence of spread-F at equatorial stations follows the rapid rise of the F layer during the post sunset hours\textsuperscript{84,85}. Geomagnetic control in the occurrence of spread-F was demonstrated when Lyon \textit{et al.}\textsuperscript{86} showed that the latitudinal distribution of spread-F occurrence is most suitably plotted in terms of dip latitudes rather than the dipole or geographic latitudes. Spread-F was shown to occur within a belt 20° wide centred on the dip equator. With the installation of vertical ionospheric sounder at Thumba, Chandra and Rastogi\textsuperscript{87} described the special features of equatorial spread-F. It first starts at the base or below the F layer as an intense scattering layer without any indication of group retardation effects. Association of ionospheric electric fields with the occurrence of equatorial spread-F was first suggested by Rastogi\textsuperscript{88} while comparing the seasonal variations of the times of evening reversal of electric field at Jicamarca and the occurrence of spread-F at Huancayo. Practically an explosion of theoretical studies of equatorial F region plasma irregularities was started with the publication of altitude versus time maps of VHF echo power at Jicamarca by Woodman and LaHoz\textsuperscript{89}. Irregularities were shown to occur even on the topside of the ionosphere not accessible to HF ionosondes. These features of Jicamarca radar maps of spread-F have been successfully synthesized theoretically on the basis of the mechanism of Rayleigh-Taylor Irregularities by Zalesak and Ossakow\textsuperscript{90}.

Comparing the Jicamarca VHF radar F layer drift data with the corresponding ionograms at Huan-
Fig. 11—Changes in the Doppler shift and intensity of VHF backscatter echoes at Thumba associated with sudden commencements of geomagnetic storms.

cayo, Rastogi and Woodman\(^9\) showed that a reversal of the F region electric field to an eastward direction during anytime of the night is followed by the generation of the equatorial spread-F. Rastogi\(^9\) later showed that sudden reversal of electric field in the nighttime followed by the onset of spread-F irregularities was associated with the sudden reversal of interplanetary magnetic field from southward to northward direction. Even the day-to-day variability in the occurrence of spread-F at Huancayo in the evening hours was shown to be related to the temporal variation of electron drift velocities at Jicamarca. It was shown that the continuation of the eastward electric field even after the sunset is a necessary condition for the generations of equatorial spread-F (Ref. 93). Comparing the ionograms at a number of low latitude stations in the Pacific zone established during October 1962, Rastogi\(^9\) showed that the spread-F on the ionograms at equatorial stations is characterized by the scattering of radio waves from very sharp gradients of ionization irregularities, but the non-equatorial spread-F ionograms are characteristic of the overlapping sets of \(V\) traces due to reflections of radio waves from rippled ionospheric iso-ionization surfaces. The development of spread-F within the equatorial belt was suggested as due to the generation of irregularities in the F region close to the dip equator according to gradient drift instability mechanism on the nights where daytime electric field extended beyond the sunset hours. This is followed by the upward lifting of the ionization and the development of irregularities due to Rayleigh-Taylor mechanism and later with the extension of the irregularities to latitudes away from the equator guided by the geomagnetic lines of force. Such a process should involve the regeneration of ionization anomaly simultaneously with the extensions of the equatorial spread-F belt. Regeneration of equatorial ionization anomaly on the nights with equatorial spread-F was demonstrated by Rastogi\(^9\). The unique set of digital recordings of the 140 MHz signals from ATS-6 at Ootacamund on individual cross aerial set has been the only experiment which has enabled the computation of electron content in the equatorial ionosphere even during intense scintillations caused by spread-F (Ref. 96). It has been found by Rastogi et al\(^9\) that during spread-F nights the electron content is reduced at
3 Conclusions
The special configuration of the orthogonality of electric and magnetic fields with the plasma density gradients over the magnetic equator makes the region around 100 km and within ±3° latitudes as a most sensitive region to the electric field changes of local or of distant extra terrestrial source. This region called the “equatorial electrojet” is the seat of host of phenomena. India is ideally suited for research in this field with a dense network of geomagnetic observatories.

The horizontal east-west electric field over the equator interacting with the northward geomagnetic field generates a fountain of plasma and of irregularities the effect of which extends up to 30° latitude from the equator, guided by the geomagnetic field lines as first suggested by Prof. S K Mitra. The effect of Mitra’s phenomenon extends over the entire F2 region above the Indian subcontinent.

The present article is a brief description of various E and F region phenomena associated with the equatorial electric field, and not a critical review of the subject.

References
1 Stewart B, cited in Encyclopedia Britannica, IX Edn, 16 (1882) 181.
6 Mitra S K, Nature (GB), 116 (1925) 357.
12 Matsushita S, J Geomagn & Geoelectr (Japan), 5 (1954) 117.


20 Rastogi R G, J Geophys Res (USA), 64 (1959) 727.


29 Rao B C N, J Geophys Res (USA), 68 (1963) 2551.


35 Barrell J & Johnson H F, Terr Magn & Atmos Elect (USA), 45 (1940) 269.

36 Rastogi R G, J Geophys Res (USA), 68 (1963) 2445.


38 McNish A G & Gautier T N, J Geophys Res (USA), 54 (1949) 303.


49 Rastogi R G & Klobuchar J A, J Geophys Res (USA), in press.


59 Sampath S & Sastry T S G, J Geomagn & Geoelectr (India), 31 (1979) 373.


RASTOGI: EQUATORIAL IONOSPHERE