Evolution of Geomagnetic Studies in India

R G RASTOGI
Indian Institute of Geomagnetism, Colaba, Bombay 400 005

Geomagnetic research is the one branch of science which was initiated in India as early as anywhere else in the world. First, regular geomagnetic measurements in India were made in Madras in 1792. The combined geomagnetic data at Colaba and Alibag since 1841 provide the longest series of magnetic data anywhere in the world. The scientific researches by Broun at Trivandrum, and Chambers and Moos at Colaba, provided the basic and the earliest information of solar, lunar and storm variations of the geomagnetic field. The paper describes the combined evolution of geomagnetic research leading to one of the best geomagnetic observatory network for low latitude in the world. The paper also describes the future plans in India to develop this field of science for the study of upper atmosphere, space physics as well as solid earth geophysics.

1 Introduction
The science of geomagnetism basically deals with the measurement of the magnetic field associated with the earth. Studies of the temporal and spatial changes of geomagnetic field of different wavelengths are associated with various geophysical sciences concerned with the interior of the earth or the space around the earth. The analysis of global data of the geomagnetic field led Stewart in 1882 to suggest the existence of ionized layer of the atmosphere and of the dynamo currents in the upper atmosphere due to heating action of the sun. The existence of the ionosphere was experimentally verified only about 44 years later. The measurements of the geomagnetic field at the ocean bottom led to the idea of the spreading of the ocean floor and to the whole theory of plate tectonics. Geomagnetic methods for prospecting is a very fast growing technique for the search of minerals, oil and other earth resources. Geomagnetism was used for ship navigation since fifteenth century and even today it is the most important means for the guidance of space vehicles.

According to Prof. Pisharoty, Indians knew about magnetic force attracting iron from the earliest time but there is no reference in ancient Indian literature regarding the directive property of a magnet in the earth's magnetic field.

2 Global Geomagnetic Surveys
The component of geomagnetic field which first caught the attention of man around fifteenth century was “declination”. In 1600 William Gilbert wrote the famous tretise De Magnete. The first sea chart of the whole world was prepared in 1701 by Halley and in 1721 William Whiston prepared the chart of inclination. The first mathematical modelling of global geomagnetic field could not be done till 1838, i.e. only after the availability of charts of declination by Barlow (1833), of inclination by Horner (1836) and of total intensity by Sabine (1937). The most notable work remains that of Schmidt who analyzed each component of the magnetic force separately and suggested the three sources of the geomagnetic field (i) internal to the earth, (ii) external to each surface and (iii) non-potential field. These analyses are still being repeated till today only refining the coefficients for spatial and temporal variations of the geomagnetic field.

3 Geomagnetic Observatories
During the late eighteenth and early nineteenth century, permanent geomagnetic observatories started to be established. The first system was again eye-reading observations for diurnal variation of compass using compass needle or bar of magnetized steel suspended horizontally by an assemblage of silk threads and vertical microscopes near the end of the needle. At Greenwich, England, declination was read thrice daily using a Dolland magnet from June 1818 to December 1920. Regular observations of declination were made in Paris from 1820 to 1835. Humboldt constructed an iron-free magnetic observatory at
Berlin in 1828 and organized simultaneous magnetic observatories all over the globe. After the establishment of Gottingen Observatory in 1834, Gauss and Weber organized Gottingen Magnetic Union under which observations of declination were made more frequently than at intervals of 1 hr at a large number of observatories around the world. Out of fifty stations under this organization from 1836-1841, three were in India—at Madras, Simla and Trivandrum.

Count A. Von Humboldt wrote in 1836 to Duke of Sussex, then President of Royal Society of London, urging the institution of geomagnetic observatories in the British colonies. In a circular of the Royal Society dated July 1, 1839, Her Majesty’s government had ordered the establishment of fixed observatories at St Helena, Montreal, Cape of Good Hope, and Van Diemens’s Land. India was not under the British Crown then and the Court of Directors of the East India Company in compliance with the suggestion of the Royal Society resolved to establish similar observatories at Madras, Bombay and Simla. Of these, only the observatory near Bombay (Colaba/Alibag) survives today and forms the proud heritage of the Indian Institute of Geomagnetism.

4 Development of Geomagnetic Observatories in India

4.1 Madras Observatory (1822-1881)

Madras Observatory established in 1792 by the East India Company, was the first to make regular magnetic observations in India. Hourly eye observations were started in 1822 and continued till 1861 when it was decided to record only two observations per day at suitable hours. The work was further reduced in 1875 when the bifilar magnetometer was the only instrument in use. The magnetic observations were finally discontinued there in 1881.

4.2 Simla Observatory (1841-1845)

Magnetic measurements were started at Simla by Lt. Col. Boileau on the grounds of Observatory House not far from the Viceregal Lodge in 1841 as one of the stations under the plan of the Gottingen Magnetic Union. The magnetic observations were recorded at Simla at hourly intervals during the years 1841-1845.

4.3 Trivandrum Observatory

Around 1836, His Highness Rama Verma, Maharajah of Travancore, desirous that his country should partake with European nations in scientific investigations, sanctioned the construction of an observatory in Trivandrum and named Mr. S. Caldecott its director and gave him powers to furnish it with best of instruments to be obtained in Europe. Recognizing the special advantage of Travancore, that the magnetic equator passed across the country, a magnetic observatory was established in 1841. Mr. Caldecott died at Trivandrum in 1849 and the observatory was placed under the direction of Prof. J.A. Broun in 1852. New sets of instruments were ordered by him which were installed in 1853. It was realized that studies should not be limited to a single station but the standard observatory should coordinate the laws of nature depending on differences of height, latitude and even longitude. Another observatory was, therefore, established at Augustia Malley about 22 km ENE of Trivandrum at a height of 6200 ft above sea level. Besides these two permanent observatories, some simultaneous observations were also made at locations 90 miles north, close to the magnetic equator, and 40 miles south of Trivandrum. Trivandrum observatory was established as a scientific research rather than as an operational station; the data were collected to determine every possible action of the sun and moon on the magnetic needle and during his stay up to 1865, Dr. Broun produced remarkable set of original new findings on geomagnetism. Magnetic observations at Trivandrum continued till 1870. Broun retired in 1869 and he published in 1874 a treatise entitled “Observations of magnetic declination made at Trivandrum and Augustia Malley 1852-1869” published by Henry S. King and Co., London.

The most significant results consisted of the isolation of daily, seasonal, solar cycle variations in the magnetic field. He also showed that the daily variations of declination during the period November to February was inverse to that between May to September suggesting the transition in the boundary of northern and southern system of magnetic field near the magnetic equator; this was verified by Prof. Hutton on the basis of IGY data about 90 years later. He showed significant lunar tidal variations in geomagnetic data; the effect was greater during the day than during the night. He extracted the lunar daily variation as a function of lunar phase and lunar declination. Some of the irregular variations were identified by him to be of solar origin since these disturbances occurred more frequently with positive changes. A solar cycle effect in the magnetic disturbances was also noticed. This effect was identified as geomagnetic storms by later scientists. Based on the magnetic survey dates he noted: “The changes of mean horizontal (magnetic) force from day to day are in the same directions over the globe and are proportional to the (absolute) horizontal force at the (respective) places. And the result which I have now obtained from three years’ observations near the magnetic equator, it appears to me, is wholly independent of the moon and is due to the sun’s rotation on its axis”.

The importance of these pioneering investigations
from India can be realized only if we note that the existence of ionosphere or of the dynamo currents was not known at that time.

4.4 Colaba and Alibag Observatories (1826-)

Although the earliest magnetic observations recorded in India were at Madras, the history of geomagnetism could be considered to begin with the birth and development of the Colaba (Bombay) and later Alibag Observatories. The combined geomagnetic data at Colaba and Alibag since 1841 provide the longest series of magnetic data anywhere in the world.

On the advice of Mr. John Curnin, East India Company's Astronomer, the Honourable Governor in Council allotted a piece of land on the Island of Colaba for the observatory in 1823. With a grant of Rs. 3000 for the building for the instruments and for the residence of the Director, it was ready in 1826. In 1840, a magnetic observatory was proposed to be installed at Aden, an important naval station of the British Government. However, on the arrival of the equipments, the installation of the equipments at Aden was not found to be possible. On the advice of the Royal Society, the equipments were transferred to Colaba Observatory. Thus magnetic observations started in Colaba in September 1841 under the supervision of Prof. A.B. Orlebar, Professor of the Astronomy in the Elphinston College, Bombay. In 1864, Bombay Government appointed a Committee under Captain W.C. Barker to give recommendation regarding the improvement of the observatory. Dr. Charles Chambers FRS was appointed first full time superintendent in 1865 and later changed to the post of Director in 1868. He held this post till he died in 1896. The observatory quickly became a first class research institution. The observatory was fully equipped with photographic and mechanical self-recording instruments. A series of original research papers from the observatory were published in standard journals besides the publication of several volumes from the observatory itself.

Chambers studied in detail the lunar variations of \( D \) and \( H \) at Bombay during 1846-1872. He gave the formula that at any lunar phase \( \psi \) the lunar daily variation can be expressed relative to the solar time in the form

\[
f_\psi(t) = f_{\psi,2}(t)\cos 2\tau + f_{\psi,1}(t)\sin 2\tau
\]

where \( f_{\psi,2} \) and \( f_{\psi,1} \) denote the lunar daily variation referred to the solar time \( t \) at new moon and at one eighth phase of the moon, respectively. For the first time, he referred to the phenomenon as "Luni-Solar variation". He also studied the solar cycle effects on the lunar variations of the magnetic field.

On the death of Mr. Chambers in February 1896, Dr. N.A.F. Moos became the first Indian to be the Director of Colaba Observatory. He remained in this position until 1919. Around 1900, Bombay Municipality decided to electrify their horse-drawn street tram service. The geomagnetic work carried uninterruptedly at Colaba for over 60 years was thus threatened and it became necessary to shift the observatory to a location similar in magnetic conditions as that at Colaba but free from disturbing effects of electric lines. Dr. Moos selected a site at Alibag about 35 km south south east of Bombay. A unique architecture was used to construct the observatory building out of non-magnetic Porbandar sandstones. It was equipped with a new set of equipment and started functioning in April 1904. For a period of two years, records were collected at both Alibag and Colaba. It was confirmed from these simultaneous records that the diurnal, seasonal and storm-time variations of all the three components of the geomagnetic field were identical at the two places. The magnetic recordings at Colaba were discontinued on March 31, 1906 and Alibag obtained the status of primary geomagnetic observatory in India, an honour retained by it till today. The proper functioning of the Alibag Observatory is guaranteed by special provisions in the Indian Electricity Act. No AC thermal generator can be located within one mile of the Observatory. DC current is not allowed within three miles of the observatory. No electric traction shall be allowed within eighteen miles of the observatory. The first electric tram was run on the streets of Bombay thereafter on May 7, 1907. It goes to the genius and untiring efforts of Dr. Moos that the continuity of Colaba data is maintained at Alibag.

In 1910, Dr. Moos published two monumental volumes describing the comprehensive analyses of the Colaba data for the period 1846 to 1905. Moos studied the luni-solar variations of the geomagnetic field and gave the formula:

\[
L = C(1 - \cos \tau)\cos(2\tau + \varepsilon)
\]

where \( \tau \) is the solar time and \( \tau \) is the lunar time and \( C \) and \( \varepsilon \) the constants derived from the lunar variation averaged over the whole lunation. This, for the first time, showed clearly that the lunar daily variation is produced by the moon but the amplitude is largely controlled by the sun.

Moos made detailed study of the diurnal, seasonal and solar cycle variations of the three components of the magnetic field at Bombay. He developed the method of preparing the magnetic data bulletins which remains basically unchanged even today.

One of the most important contributions of Moos has been the identification of sudden commencements of geomagnetic storms (he called these X type of storms). He showed that the average storm time
variation consists of (1) a small initial rise (2) a large rapid fall with a minimum of about 10-11 hr after the commencement and (3) a slow and laboured rise back to normal conditions. He also studied the effect of disturbance in modifying the average solar daily variation, thereby obtaining what is now called ‘disturbance daily variation’. These techniques initiated by Moos still remain the standard method of studying disturbances in geomagnetism, ionosphere or in other geophysical parameters.

Referring to the two volumes by Moos, Dr. J.A. Fleming has remarked: “Despite over 1500 selected references in the field of geomagnetism research, listed in Volume III of the Physics of the Earth series of the United States National Research Council, there is none which exhibits so wide and varied and intensive coverage of all the geomagnetic problems in the early twentieth century”.

India can be justifiably proud of its contribution to the science of geomagnetism, particularly during the last decade of the nineteenth century and the first decade of this century.

Colaba and Alibag observatories following their imperialization.

In view of general scheme of imperialization of Indian observatories, the Bombay Observatory which had up to then worked independently under the control of local Government was placed under the administrative control of the Director General of Observatories (DGO) in 1890. The Director was independent to make his own investigations and submit report to DGO, to be forwarded to the Observatory Committee of the Royal Society of London. After the retirement of Dr. Moos there have been 14 appointments to the Director’s post within 29 years and this post became the stepping stone for higher positions in the Meteorological Department. Eminent scientists occupied the chair of the Director like Prof. C.W.B. Normand, S.K. Banerjee, K.R. Ramanathan, S.K. Chakravarty, A.N. Tandon, S.L. Malurkar, P.R. Pisharoty and others (The observatory gradually got transformed to the routine data collection and dissemination centre). Some of the Directors did produce notable contributions in geomagnetism during their tenure at Colaba. Prof. K.R. Ramanathan during his term of office at Colaba undertook many investigations on atmospheric electricity and geomagnetism. His presidential address to the Physics Section of Indian Science Congress in 1939 dealt with the problems of earth magnetism and the upper atmosphere. Prof. S.K. Chakravarty conducted investigations on temporal variations of geomagnetic field and their relations to ionospheric conditions, frequency of micropulsations and their variation at Alibag, and solar streams of corpuscles and their relations to geomagnetic storms. His method of separating observed geomagnetic variations into their internal and external parts is still used extensively by Indian and overseas scientists. Mr. Malurkar investigated the transients in magnetograms, effect of solar flares on geomagnetism and the diurnal variation of atmospheric ozone and geomagnetism. Two new magnetic observatories at Trivandrum and Annamalainagar were established during the tenure of Mr. Malurkar as Director of Colaba and Alibag Observatories.

4.5 Kodaikanal Magnetic Observatory

Magnetic observations were started at Kodaikanal in 1902 as base station for magnetic survey by the Survey of India, Dehra Dun. Until 1916, the observatory functioned under the control of the Survey of India and later placed under the control of Director, Solar Physics Observatory, Kodaikanal. It was closed down in 1923. With growing importance of geomagnetic observations in relation to solar phenomena and because of the proximity of Kodaikanal to the magnetic equator, the observatory was restarted in 1949. The observatory now forms a part of the Indian Institute of Astrophysics, Bangalore.

4.6 Sabhawala (Dehra Dun) Observatory

A magnetic observatory functioned at Dehra Dun under the Survey of India from 1902 to 1943 when it was closed due to the flooding of the underground room in which the instruments were installed. A new observatory at Sabhawala started in 1964 under the Survey of India and continues to function there.

5 Developments of Geomagnetism in India during 1950-1957

One of the outstanding results during this period had been the discovery of the narrow belt of enhanced solar daily variation at the magnetic equator, a result made possible by the geomagnetic data of Kodaikanal, Madras and Alibag. The discovery was made by a Danish scientist Dr. Egedal and Prof. Chapman who christened the same as “Equatorial Electrojet”. On the recommendation of the International Association of Terrestrial Magnetism and Electricity a survey of magnetic daily variation at a number of places in India and Ceylon was made by S.K. Pramanik and his coworkers to study the latitudinal extent of the equatorial electrojet.

In 1947, Prof. Appleton published the well known paper that the critical frequencies of the F2 region of the ionosphere (foF2) at noon hours follow a smooth curve when plotted against the geomagnetic latitude
and rather unexpectedly a minimum over the equator was noticed with two maxima at ±15° geomagnetic latitude. Immediately Prof. S.K. Mitra gave the first explanation of the phenomenon in terms of the diffusion of the ionization from the equatorial altitudes to tropics along the lines of force of the earth's magnetic field. A close association between the geomagnetic field and the ionosphere at low latitudes was envisaged. Besides the manual ionospheric studies of the equatorial electrojet and establish new ionospheric soundings which already existed under the All India Radio, newer automatic ionospheric sounders were installed at Kodaikanal, Ahmedabad and Calcutta.

In 1951 Dr. Matsushita showed that the maximum frequency reflected from the sporadic E layer of the ionosphere showed the latitudinal variation almost identical to that of the equatorial electrojet. A number of ionospheric stations established for the studies of the effect of solar eclipse of 25 February 1952 gave a series of new findings of the equatorial ionosphere and geomagnetism.

Prof. K.R. Ramanathan, then Chairman, Indian National Committee for IGY strongly recommended that the Government should take priorities in the studies of the equatorial electrojet and establish new magnetic and ionospheric observatories in southern India. Thus during the IGY period magnetic observatories were established at Trivandrum and Annamalainagar and ionospheric sounding stations at Trivandrum and Trichinapally.

The immediate effect of these associations between geomagnetism and ionosphere resulted in the discovery of the fact that the lunar variations in the F region were not only associated with the true dip latitude but there was a large enhancement of the amplitude around the magnetic equator similar to the equatorial electrojet. This result further led to the discovery of the fact that the equatorial electrojet current is weaker along Indian longitudes as compared to the same in any other longitude sector. Ionospheric storms, which were thought to be caused by extraterrestrial sources, were shown to be strongly controlled by the actual magnetic fields at low latitude. Thus an inseparable bond between geomagnetism and ionosphere at low latitudes was well established by Indian scientists following the observations taken during IGY/IGC.

6 Developments during 1960-69

Scientists all over the world had realized the usefulness of international cooperation in any branch of geophysics during the previous decade when worldwide studies on sciences related to the earth and its environments were conducted under the umbrella of IGY and IGC. The major results of these experiments started coming only in the 60's. In 1962, the Government of India decided to constitute the Indian National Committee for space research with Prof. Vikram V. Sarabhai as its Chairman and he at the meeting of international COSPAR in 1962 announced the intention of establishing a rocket launching station in India before the end of 1963. The first experiments chosen were the investigation of the electrojet currents and the role of neutral and ionized movements in the electrojet region. The Department of Atomic Energy then under Prof. J.H. Bhabha decided to take the Physical Research Laboratory, Ahmedabad under its umbrella and asked Prof. Sarabhai to organize the space research with the help of scientists at PRL, Ahmedabad; NPL, New Delhi; and other institutes in India.

Prof. Sarabhai asked Prof. R.G. Rastogi of PRL to establish an Ionospheric Research Station at Thumba. Within a year's time, ionospheric drift, ionospheric absorption, riometers, satellite radio beacon monitoring and vertical ionospheric soundings experiments were installed to coordinate the ground-based data with the rocket-borne experimentation data. Taking advantage of the unique facilities at the magnetic equator, these experiments were assigned as Ph.D. work for over half a dozen students and these produced a host of new results associated with the equatorial electrojet.

The ionospheric drift data were shown to be intimately connected with the equatorial electrojet currents, the direction being precisely the direction opposite to the electric field in the dynamo region. Thus, for the first time, data related to equatorial electrojet electric field were monitored on a continuous basis, which were not affected by currents in the magnetosphere or those induced inside the earth. These for the first time extracted the changes in equatorial electric field with the global geomagnetic activity; the electrojet current was shown to decrease with increasing geomagnetic activity.

It was shown that the phenomenon of counter electrojet, decrease of H field during the daytime below the nighttime base value and the disappearance of the equatorial Es layer were concurrent with the reversal of the electric field in the E-region of the ionosphere to westward direction.

The rocket exploration of the electrojet currents by means of proton precession magnetometer, conducted by Prof. T.S.G. Sastry of PRL, Ahmedabad and co-workers, provided extensive data on the profile of the electrojet currents during different geomagnetic activity conditions. It was found that the altitude of maximum current strength was always higher than the theoretically expected region of maximum current.

The vapour release experiments conducted by Prof. P.D. Bhavsar, Prof. R. Raghavarao and their co-
workers at PRL, Ahmedabad gave very important data on the neutral and ionized drifts in the equatorial ionosphere giving finer refinements in our understanding of the equatorial electrojet.

Prof. Satya Prakash and his co-workers at PRL conducted pioneering experiments of the plasma instabilities and irregularities in the ionosphere over the equatorial electrojet region, which have direct bearing on the physics of the electrojet itself.

Under the program of the International Quiet Sun Year, new geomagnetic observatories were established at Sabhawala, Dehra Dun by the Survey of India and at Hyderabad by the National Geophysical Research Institute. In collaboration with USSR and NGRI a geoelectric observatory was established at Choutuppal near Hyderabad.

In February 1966, the directorship of Colaba and Alibag Observatories passed on to Prof. B.N. Bhargava who was earlier head of the Ionospheric and Magnetic Division of the Astrophysical Observatory at Kodaikanal. The group at Colaba extensively studied the long series of geomagnetic data at Colaba/Alibag using modern techniques of power spectrum to extract finer structures of semiannual and annual oscillations. Detailed lunar tidal oscillations of data from Indian observatories were also computed by scientists at Colaba. One of the important results to be noted was obtained by Dr. A Yacob and others while studying the morphological features of the low latitude disturbance field and suggested the possibility of two regions of ring currents associated with magnetic storms. The credit of this discovery, however, goes to scientists from USA due to inordinate delay in the publication of the papers in Indian journals.

The special committee for Solar Terrestrial Physics (SCOSTEP) formed by ICSU selected the Colaba Observatory as one of the World Digital Data Centres for Geomagnetism. With the recommendation of the Indian National Committee for SCOSTEP, Colaba observatory undertook the responsibility of collecting, checking and publishing the magnetic data from Indian observatories under the title *Indian Magnetic Data*. The series started in 1969 and is continuing still today.

During the later part of this decade Prof. Sarabhai questioned the fundamental assumption of scientists regarding the daily variation of the geomagnetic field, namely that the nighttime field represents the internal component and the daily range of the field is a consequence of the electric currents at the dynamo region. He suggested that the daily range of H field at low latitude stations outside the influence of the equatorial electrojet is largely caused by the weakening of the ambient field on the nightside rather than the enhancement on the dayside. The enhancement of H at

7 Developments during 1970-79.

By 1970, it was clearly understood that the magnetospheric processes have definite positive effects on the quiet day variations of the geomagnetic field at ground. The electrical conductivities in the electrojet region being abnormally high, Sarabhai realized the great importance of equatorial electrojet studies in space physics. Prof. Sarabhai organized at PRL, Ahmedabad a meeting of the Directors and scientists from most of the geophysical and geological institutions in India to plan an intensive program on the investigations of the equatorial electrojet. The immediate outcome of the meeting was a plan to delineate the exact position of the magnetic equator in India. The survey was undertaken jointly by NGRI, Hyderabad and IIG, Bombay and the results published immediately. Prof. Sarabhai's sudden demise removed from the Indian scientific scene a towering figure which was a source of enthusiasm for so many younger scientists. PRL scientists pulled out from the ionospheric research station Thumba which was handed over to the Indian Space Research Organisation.

The most notable event in the history of geomagnetism in India during this decade was the formation of an autonomous research organisation, named Indian Institute of Geomagnetism (IIG), out of Colaba and Alibag Observatories on 1st April 1971 and Prof. B.N. Bhargava, who at that time was Director of Colaba and Alibag Observatories became the first Director of IIG. Besides the operation of seven magnetic observatories, the Institute was mandated to develop as a national centre for geomagnetic research in India.

A Committee of scientists from NGRI, IIG and PRL was organized by Prof. Hari Narain to set up a close network of geomagnetic field stations to understand critically the various interactions of the electrojet with the near and far environments of the earth. Accordingly, over twenty portable magnetometers were to be procured from University of Dallas
and deployed in south India jointly by IIG, PRL and NGRI. Due to the revised policies of PRL after Prof. Sarabhai’s death PRL scientists were prevented to take part in geomagnetic researches and the whole scheme was abandoned. It took ten years to pick up the thread and a magnetic array experiment was conducted in India in 1979 by NGRI and IIG jointly with the National Australian University, Canberra. This project provided a number of new findings on the induction inside the earth surface specially at low latitudes. Some conducting subsurface structures were located and this project opened up a new field of research using geomagnetic investigations for the study of solid earth and in exploring natural resources of the country.

In 1974, Rastogi and Chandra showed for the first time the effects of the interplanetary medium on the equatorial electrojet. They showed that the interplanetary drift velocity at Thumba varied systematically with north-south component of the interplanetary magnetic field (IMF). Shortly afterwards Rastogi and Patel showed that a sudden change in the IMF from south to north direction results in the imposition of an eastward field in the ionosphere from the evening to the morning sector of the earth. This opened up a new field of geomagnetism, viz. the coupling of equatorial electrojet with the solar wind. Extensive series of investigations were undertaken at PRL and IIG on the effect of latitude, longitude and scalar value of IMF on the low latitude geomagnetic field, on geomagnetic micropulsation and other characteristics of the equatorial ionosphere including the finer structures of the sudden commencement of geomagnetic storms.

At the XVth General Assembly of IUGG, a new Geomagnetic Meridian Project was approved by IAGA to establish a chain of magnetic observatories from equator to the auroral latitudes along the geomagnetic longitudes 140°-150°. With the cooperation of IZMIRAN, geomagnetic observatories were established at Jaipur and Ujjain in 1975 by IIG and later geoelectric measurements were added at Ettayapuram in 1975 by NGRI. Besides these, IIG installed La Cour magnetometers at the geomagnetic observatories at Shillong in 1975 and at Gulmarg in 1977. With these the network of geomagnetic observatories increased to eleven, one of the densest networks in any country of the world.

The study of counter electrojet still continued to draw the attention of scientists in India. Bhargava and Sastry isolated a strong semidiurnal component on a strong counter electrojet day. Working with French scientists, Rastogi showed that the counter electrojet is not necessarily associated with the decrease of the H at the equator below the nighttime level but due to the reversal of the regular latitudinal profiles of ΔH and ΔZ. Investigating the simultaneous data from VHF backscatter radar and ionosonde data along with the geomagnetic data, Rastogi suggested the existence of two current systems, one the Sq current over the equator flowing at 107 km and another independent current system flowing at 100 km associated with auroral disturbances and due to solar magnetospheric interactions.

Studying the VHF forward scatter data in the American sector taken during IGY with simultaneous magnetometer and ionospheric data, Rastogi showed that the sudden commencement of geomagnetic storms over the equatorial electrojet station is associated with simultaneous change of the ionospheric electric field. It was suggested that although SSC at most of the latitudes may be due to the compression of the magnetosphere, the enhancement of the SSC at the equator is due to the imposition of an additional electric field over the equatorial region due to interaction of the solar wind plasma moving towards the earth and the interplanetary magnetic field. Using the balloon-borne electric field detectors at auroral region and the equatorial electric field by Jicamarca VHF radar, Kelley et al. had shown that during the intense geomagnetic storm of 8-9 August 1972 there were simultaneous reversals of the electric field at the auroral and equatorial regions on the nightside of the earth. Rastogi showed that during the same storm the electric field fluctuations were coherent but opposite in phase at equatorial regions in the dayand night-side of the earth. It was suggested that the equatorial electric field fluctuations during disturbance were partly caused by the spreading of the auroral electrojet current to low latitudes.

The VHF backscatter radar at Thumba earlier started by Prof. Satya Prakash of PRL was greatly upgraded by C.A. Reddy and his co-workers at VSSC and provided direct monitoring of the electric field changes in the equatorial ionosphere. Reddy and co-workers showed that there is excellent coherence in the fluctuations of the magnetic field and the electric field (derived from the doppler shift of VHF backscatter radar) during geomagnetic storms over the equatorial station. They also showed that the equatorial geomagnetic fluctuations are coherent with high latitude geomagnetic fluctuations.

Prof. B.N. Bhargava retired from the post of Director of IIG on 25 December 1979.

8 Progress from 1980 Onwards

Prof. R.G. Rastogi who had been in Physical Research Laboratory, Ahmedabad, assumed the directorship of the IIG in May 1980.

It was realized that IIG should plan to develop facilities using geomagnetic measurement techniques
for the study of upper atmospheric physics as well as the solid earth physics. The measurements of the magnetic field should be measured over all possible range of frequencies, viz. from secular variations to micro-pulsation range. The measurements are planned to be made at different altitudes, from ground, at balloon, rocket and satellite altitudes. The measurements will be made on land as well as on high seas, and in Antarctica.

With the encouragement from the Department of Science and Technology, the Institute became one of the participating institutions in the National Integrated Project on Seismicity and Seismotectonics of the Himalayas. IIG succeeded in the fabrication of the original Gough Reitzal Magnetometers and the model modified at the University of Munster, Germany. These indigenously fabricated instruments are being used in the Himalayan region.

With the launching of three-component magnetic field measuring payload on board MAGSAT satellite by NASA, the Department of Science and Technology of the Government of India constituted a National Working Group for MAGSAT studies in India and identified the various institutes for the analyses of data relevant to Indian region. The institutes were the Indian Institute of Geomagnetism, Survey of India (SOI), National Geophysical Research Institute, and Space Applications Centre. The anomaly map for the Z components was developed by Col. Arur and co-workers of SOI and Prof. Negi and his co-workers at NGRI. Prof. B.P. Singh and his co-workers at IIG developed the anomaly maps for all the three components of the magnetic field. Detailed studies on the coherence of the anomaly map of the scalar field measured by the satellite equipment and the one derived from individual components, were made. Studies are continued to coordinate these maps with the geological and tectonic features of the land.

Shortly after the constitution of the Department of Ocean Development (DOD) by the Government of India, IIG approached for the creation of the facilities of the measurement of the magnetic and electric field at the ocean bottom. A committee was constituted by DOD to study the feasibility of such studies and it was decided to start a division of marine electromagnetism in IIG. The DOD sanctioned the purchase of Ocean Bottom Magnetometers from Japan and it is expected to be deployed by IIG with the cooperation of the National Institute of Oceanography before the end of 1985.

Extensive measurements of total magnetic field on ocean area around India are being made by the National Institute of Oceanography, the Geological Survey of India and by the Oil and Natural Gas Commission.

The IIG was represented in the first, second and fifth Antarctica Expedition. High resolution magnetic field measurements have been made in Antarctica and have proved useful in understanding couplings between the equatorial and auroral regions.

The Seventh Five Year Plan of the Institute consists of the following proposals:

1. Headquarters and research and instrument divisions at Colaba, Bombay
2. The upgrading of the Alibag Observatory as the primary magnetic observatory. A national calibration facility is anticipated. A magnetic free space facility would be established. The World Digital Data Centre with facilities for visiting scientists would be established.
3. The Equatorial Geophysical Observatory at the magnetic equator, near Tirunelveli, is in an advanced stage of development.
4. The northern regional centre specializing in the solid earth studies through geomagnetism.

The institute has been recognized as training centre on geomagnetism for scientists from African and Colombo Plan countries. The contribution of Indian scientists towards international geomagnetism was recognized by the nomination of the Director of IIG, Prof. Rastogi, as a member of the Executive Committee of IAGA and the Chairman of Inter Divisional Commission on Developing Countries of IAGA.

Given a proper support for the infrastructure, the IIG is poised for a quantum jump in the field of geomagnetic research in India in coming years.

It need not be overemphasized that geomagnetism, as other geo-sciences, does not recognize political boundaries and a global cooperation is necessary to unravel the mysteries of earth's geomagnetic field and its variations. Passage of time has revealed that Indian contribution in the international scene in this respect has been in no small measure. Dating back to the Gottingen Magnetic Union of 1836 to the Analyses of MAGS at 1980, Indian scientists have taken part in several international programmes. The magnetic data from Indian geomagnetic observatories are in constant demand by scientists round the world. These data are regularly deposited with the world data centres. The data of Alibag are supplied on immediate basis for the preparation of $D_n$ index which indicates the equatorial ring current intensity.