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# Geomagnetic Repeat Surveys in India

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**ABSTRACT**
The Survey of India, has a long history of geodetic and magnetic measurements, which have contributed to early editions of topographic and geodetic maps. With successive improvements in international collaborative efforts at geodetic mapping, the Survey of India has improved its observational networks. Early magnetic measurements, since 1820, were scattered around the Indian sub-continent. However, after consolidation of available historical magnetic survey data in 1954, regular repeat surveys were carried out all overIndia. Survey of India maintains 183 repeat stations distributed over the country, as well as a magnetic observatory at Sabhawala (SAB) at Dehradun. Isomagnetic maps are produced for vertical, horizontal intensity and declination every 5 years, since 1965. This valuable repeat data set, spanning over a 100 years, has contributed to obtaining smooth models of secular variation in India and compares well with global secular variation models.

**Key words:** Secular Variation, Iso magnetic maps, Magnetic observatory, Co-seismic observations, Magnetic declination.

## INTRODUCTION

Geodetic & Research Branch (G&RB) of Survey of India (SOI), Dehradun, India has its base station at Sabhawala Digital Geomagnetic Observatory. SAB, which has completed 100 years of its existence and is still going strong. G&RB also carries out repeat magnetic measurements at 183 stations established throughout the country. Archived geomagnetic data with SOI has helped in monitoring secular decrease of the geomagnetic field (*Vestine et al, 1947a*). The observations also provide other interesting results, (*Arora et al, 1983*) which can be used for future research in this field.

Magnetic field intensity measurements on the earth's surface is used to model the main field of the earth. Regional features can be removed from closely spaced measurements to reflect local variations that delineate geological anomalies for resource exploration, a significant contribution towards natural resource augmentation. The knowledge of spatial characteristics of the geomagnetic field is of great significance for geological applications, but as the geomagnetic field also undergoes slow temporal variations, called secular variation, it becomes desirable that a complete description of the magnetic field by analytical functions should incorporate time as well as spatial coefficients. (*Vestine, et al, 1947a, b.; Arora et al, 1983; Campbell W.H.,1997*).

The Survey of India (SOI) has been periodically conducting field magnetic surveys for graphical preparation of regional magnetic charts over the Indian region primarily for navigational needs. A magnetic survey was proposed in India in 1896, and Captain H.A.D. Fraser, Survey of India travelled to Europe to consult Prof. Rucker regarding methods and logistics connected with survey and purchase of necessary instruments. The field work of the first magnetic survey was undertaken during 1901 to 1913. The aim of this detailed survey was to determine three magnetic elements Declination, Horizontal force, and Vertical force with unifilar magnetometer. Dip was observed with Dip Circle at 80 permanent repeat stations and 1401 field stations, uniformly distributed at distance 30 to 40 miles apart over undivided India, Myanmar (Burma) and Srilanka (Ceylon).The field observations were corrected for diurnal variation with the help of data supplied by 5 magnetic observatories located at Dehra Dun, Barrackpore, Toungoo (Myanmar), Kodaikanal and Alibag.

The results of these surveys were reduced to epoch 1909.0 and 1920.0 and published in the forms of charts, contoured manually and tables in the Survey of India (Record volume XIX,1925). These charts were published for Declination, Horizontal force, Dip and Total force. The second magnetic survey was carried out in 1930. Observations were carried out at 37 repeat stations under the aegis of Dehra Dun and Alibag observatories as other observatories had been closed down. The results were reduced to epoch 1931.0 and published (*Survey of India Geodetic Report Volume VII, 1931*).The programme of periodic re-observation at repeat stations of the original survey to keep track of secular variations could not be adhered to. All the repeat stations were occupied between 1943 and 1945, but the results were used without observatory corrections.

After delineation of land borders between newly-independent countries in the Indian sub-continent, in 1947, different regions in India were surveyed in detail with Vertical force variometers, unifilar Magnetometers and

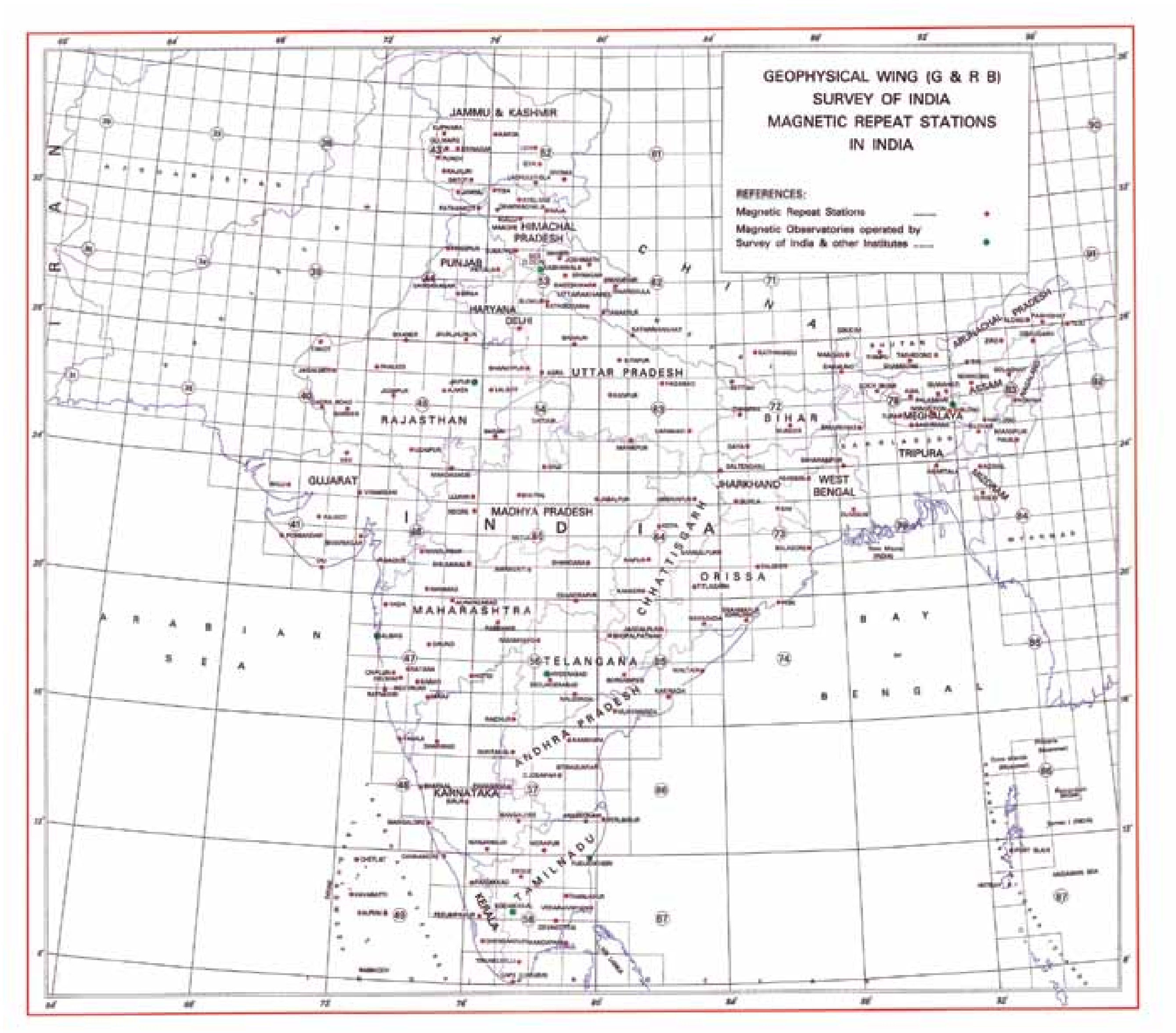


**Figure 1.** Geo-magnetic Repeat Stations

Dip circles in different years and a considerable amount of data was accumulated, some of which were published in different publications and the various annual Geodetic and Technical Reports of the Survey of India. An attempt was made to utilize all the data for reducing the magnetic elements (Declination, Horizontal force and Vertical force) to epoch 1953.0 and the charts were published in Technical paper No. 7. (*Gulatee, 1954*). Following this, all existing repeat stations were re-occupied and six new stations were established during 1957-59.

During World Magnetic Survey (1961-65) (*Heppner, 1964; Zmuda, 1971*) the magnetic survey of the entire country was carried out in detail. The aim was to occupy the old field and repeat stations with Quartz Horizontal Magnetometer (QHM) and Magnetometric Zero Balance (BMZ), at much closer spacing. Since then, repeat observations are conducted approximately every five years and the data are reduced for preparation of geomagnetic charts of the country. Charts of Horizontal and Vertical Intensity, upto epoch 2000.0 and Declination upto epoch 2010.0 are available. At present SOI maintains 183 Repeat Stations and one Magnetic Observatory where measurements are carried out as per specifications and procedures recommended by International Association of Geomagnetism and Aeronomy (IAGA) (*Newitt L.R., 1996*).

## ROLE OF SURVEY OF INDIA

Survey of India is the only organisation in India preparing Isomagnetic charts at different Epochs, at approximately

5 year intervals. Detailed magnetic surveys carried out at the interval of 200 km throughout the country has resulted in establishment of 183 magnetic repeat stations in India (Figure 1). All the geomagnetic observations were made with Q.H.M. and B.M.Z. absolute instruments. This has later been supplemented by PPM and DIFlux magnetometers as well. The three geomagnetic elements i.e. Declination, Horizontal Force and Vertical Force are obtained, on a regular basis.

The geomagnetic data received from the field by SOI is reduced to a particular epoch. The reduced data is used for Publication of Isomagnetic charts by SOI. Details of already published charts are given in Table I.

## SABHAWALA (SAB) GEOMAGNETIC OBSERVATORY

The observatory was put into commission in January, 1964. Prior to this there was an underground Magnetic observatory in the Survey of India (Geodetic Branch) compound at Dehra Dun, which had functioned from 1902 to 1943. In 1943, the Dehra Dun underground observatory went out of action (instruments being damaged due to flooding of its underground chambers).

In view of the circumstances prevailing during World War II, the observatory could not be restarted earlier. However, consequent to a resolution passed by the Geophysical Committee in 1947, it was proposed to restart the observatory – by locating it far from anticipated electrical and industrial disturbances. The land for the new observatory was acquired in 1955, and the construction of the building was completed only by 1960. Some of the observatory instruments were received as late as October 1963. After necessary tests and trials with the various instruments, which were received from time to time, and further training and practice of select SOI personnel,the observatory ultimately started functioning, with effect from 21st January 1964, coinciding with the start (on 1$^{St}$ January 1964) of the programme of the International Quiet Sun Year. The compound area of the observatory is about 2 hectares. At present, the building for magnetic observations comprises one absolute room and one magnetograph room. It has a computer room for digital recording besides residential cum office building. It is situated about 34 km west of Dehradun in Sabhawala village. Besides studying the secular changes in the earth's magnetic field, this observatory being the only one in the northern region will help in controlling the field magnetic survey in the northern parts of India.

In 1986, Sabhawala Magnetic Observatory was awarded a gold medal, during the 100 years celebration of the first polar year to the geomagnetic observations around the world. Prof. Naoshi Fukushima, University of Tokyo, Japan presented the medal, for the observatory`s significant contribution to the global geophysical observations.

## INSTRUMENTS IN USE IN SABHAWALA OBSERVATORY

La-Cour Variometers as well as the portable Askania Variograph are in use in SAB.The Digital flux-gate magnetometer (DFM) was installed at magnetic observatory on 18$^{th}$ January 2007. Presently 1-minute digital data is reported from SAB.

### Field / Observatory Instruments used by SOI:

i) Quartz Horizontal Intensity Magnetometer (QHM): The QHM, a portable instrument is used for measuring the Absolute Horizontal Intensity and Declination of the earth's magnetic field. Accuracy for Horizontal Intensity is ± 5 nT and for Declination ±1′.

ii) Magnetometric Zero Balance (BMZ): The B. M. Z. is a portable instrument used for measuring the Absolute Vertical Intensity of the earth's magnetic field by a zero balance method. Accuracy for Vertical Intensity is ± 5 nT.

iii) ENVI MAG: ENVI system is an easy to use, lightweight, battery powered, portable magnetometer. The magnetometer is a total field instrument using proton-precession techniques to measure the local field / the total intensity.

iv) Theodolite Wild T2:The well-known Wild T2 Theodolite is ideally suited for almost every type of survey task. Being simple tohandle, it has a well-illuminated optical and reading system andcan be used with a large variety of accessories and attachments. The optics are sufficiently good to allow proper observations of normal targets present at distances up to 20 kms. Circle readings are made through one eyepiece, an inverter knob ringing the required circle image into the field of view. Coincidence setting provides a direct measuring of the two diametrically-opposite circle positions. Theodolite is widely used for triangulations up to 3rd and even 2nd order limits, for precise traversing, sub tense measurements, astronomical observations, tacheometry, engineering works of all types, cadastral lay-outs, staking-outstraights and curves and mining surveys. It has least count of 1.0 second.

v) Declination Inclination Magnetometer (DIM): The system permits very precise angular measurements of the terrestrial magnetic field F. The angular components measured are declination D (Variation) and Inclination I (dip). The value of F, together with the components X( horizontal),Y and Z (vertical ) may also be measured to an accuracy of 0.25%.

### Magnetic Surveys and Charts

The magnetic measurements were made at established repeat stations, using QHM, BMZ and T2 theodolites. At present, the SOI deploys DI flux and proton precession

Table – 1 . List of published magnetic charts of various epochs

| Sl. No. | | Epoch chart |
|---|---|---|
| 1 | Line of equal magnetic declination | 2010.0, 2005.0, 2000.0, 1995.0, 1990.0, 1985.0, 1980.0, 1975.0, 1970.0, 1965.0 |
| 2 | Horizontal force | 2000.0, 1995.0, 1990.0, 1985.0, 1980.0, 1975.0, 1970.0, 1965.0 |
| 3 | Vertical force | 2000.0, 1995.0, 1990.0, 1985.0, 1980.0, 1975.0, 1970.0, 1965.0 |

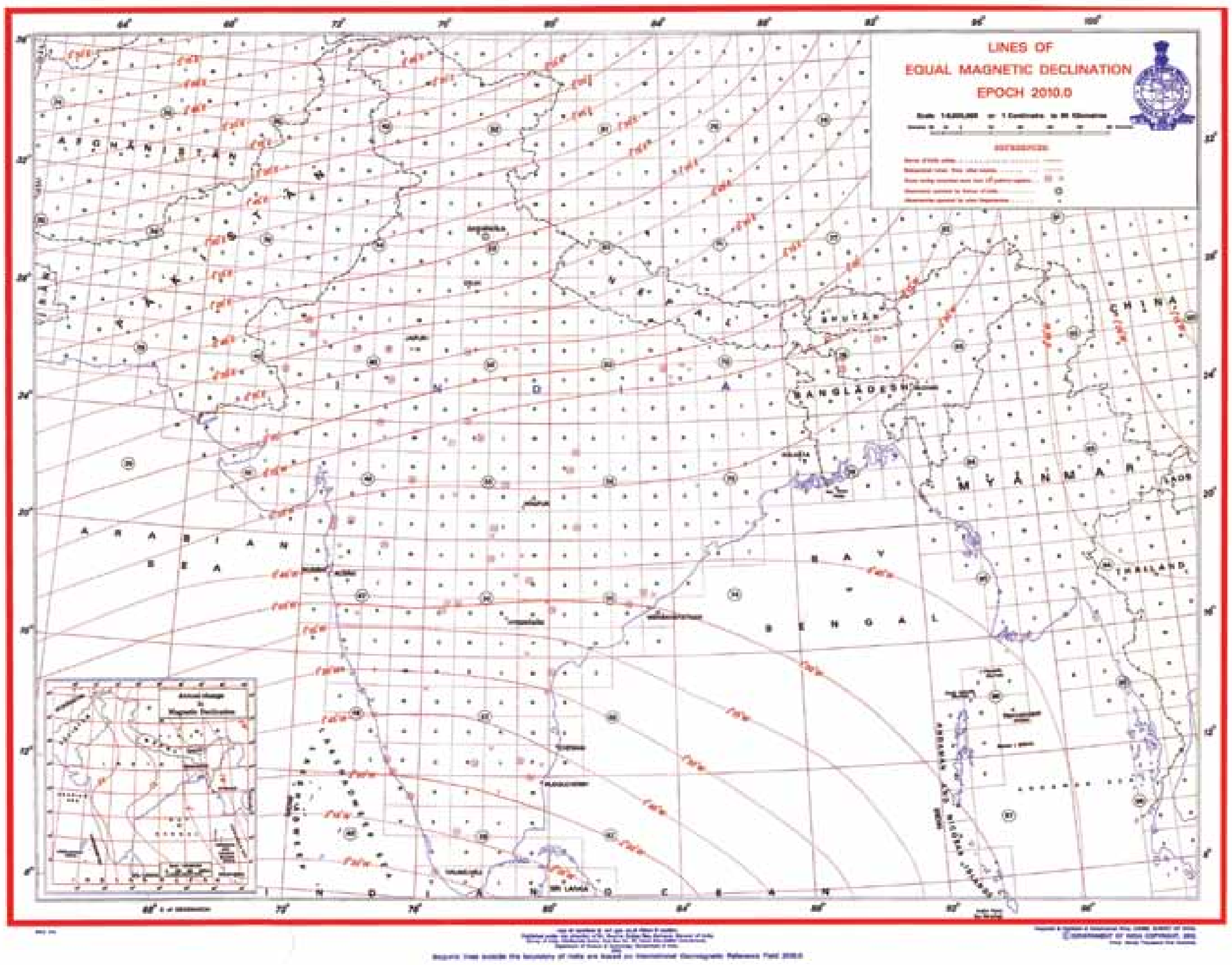


**Figure 2.** Magnetic Declination Chart

magnetometers, for these measurements. These observations are used to compute horizontal (H), and vertical intensity (Z) & declination (D) at repeat and field stations. The field instruments used in the survey were calibrated against the prime geomagnetic observatory standards, at Alibag (ABG) and other permanent observatories located in different regions of the country. Effects on the data due to instrumental differences are corrected. In addition, the quiet-day daily variation and magnetic disturbance effects are eliminated from the data, by comparing with data from the permanent magnetic observatories. During the magnetic survey of 1962-66, 989 field and repeat stations were covered.

The world magnetic survey Board had recommended a scale of 1:50,000,000 for world magnetic charts and 1:5,000,000 to 1:10,000,000 for regional magnetic charts. In Survey of India a scale of 1:6,000,000 is followed. Following geomagnetic charts are published by Survey of India at an interval of 5 years, since epoch 1965.0.

i ) Isomagnetic charts for Horizontal intensity.
ii) Isomagnetic Charts for Vertical Intensity
iii) Isomagnetic Charts for Declination (Figure 2 )

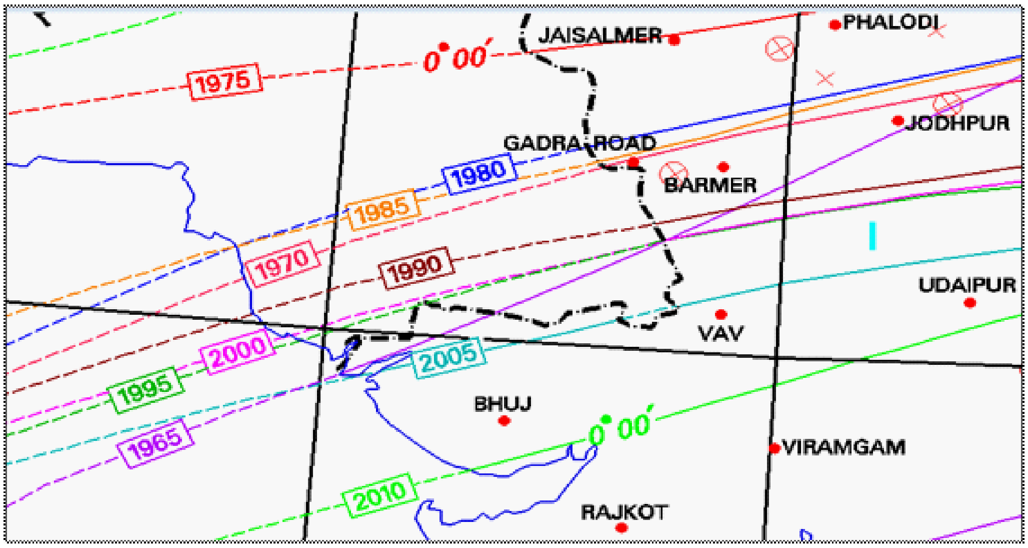


**Figure 3.** Temporal change of magnetic declination lines over Kutch, Gujarat, 1976-2000

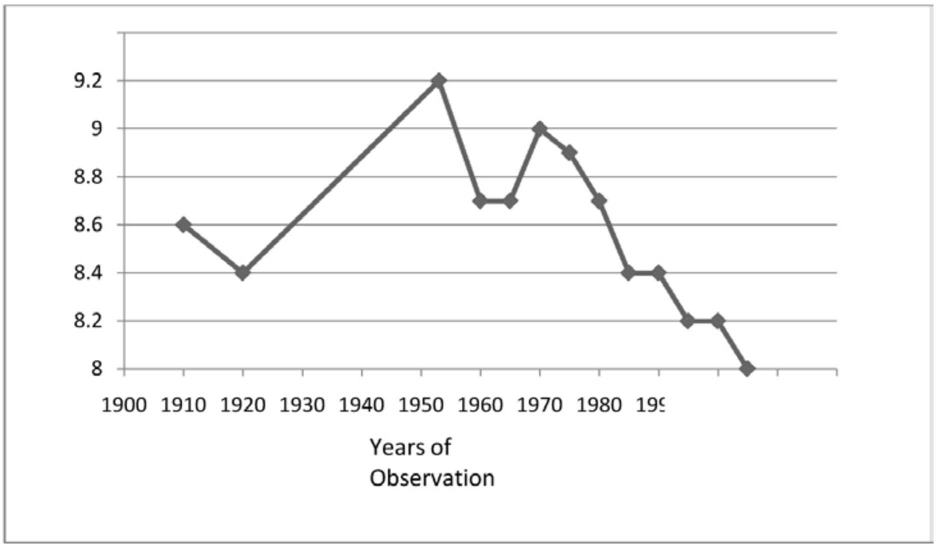


**Figure 4.** Geographic location / migration of the Dip Equator during last hundred years of Indian Peninsula based on Iso-magnetic Chart published by Survey of India epoch 1909 to 2005 for Z (1953 onwards) and for I (1909 - 1920)

The Survey of India specialises in determining true North at required locations, in addition to determination of declination change, with respect to fixed azimuth markers, to user agencies in India with accuracy of 1″.

## STUDIES WITH MAGNETIC DATA

**a) Secular variation in India:** Repeat stations were established, in addition to those already existing. This survey was carried out over 5 years (1962-1966). The separation between the new field stations ranged from 30-80 km, in contrast to repeat stations,which are about 200-300 km apart. Isomagnetic charts were prepared for epoch 1965.0. Thereafter, repeat surveys were carried out at about 5-year intervals leading to preparation of isomagnetic charts every 5 years.

The reduced data from this survey was used to compute the first analytical isomagnetic chart for Indian region, using 6$^{th}$ degree polynomial. The fit of this model is comparable with that of the IGRF 1965.0. Due to the closely spaced data set, the model could reflect more features of wavelength ~ 1000km. Comparison with IGRF showed agreement in major features. Further models for 1970.0 and 1975.0 were computed with fewer repeat stations. The coefficients of the model obtained for secular change were also found to be similar to the IGRF and also in agreement with secular variation trends observed at the permanent magnetic observatories (*Srivastava and Abbas, 1977*).

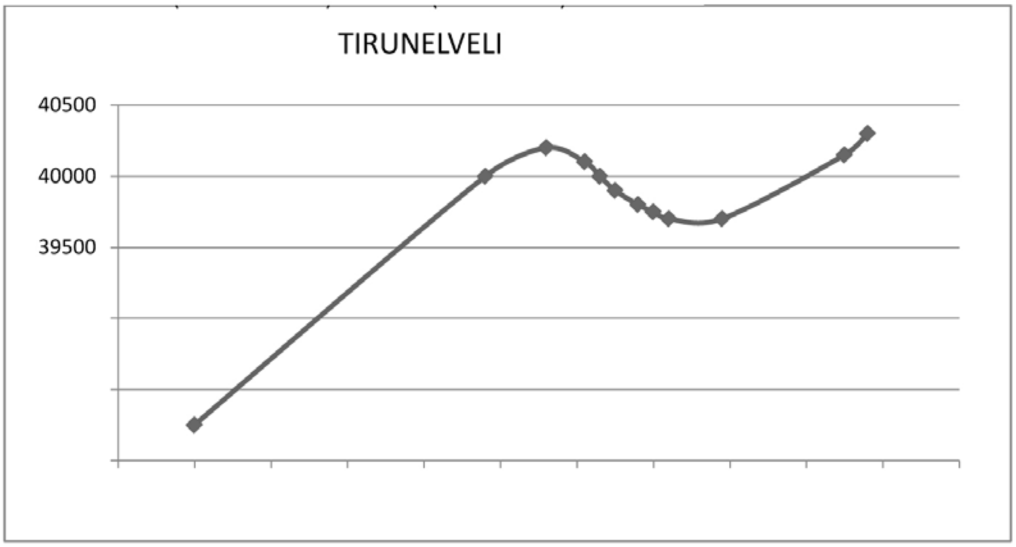


**Figure 5.** Temporal variation of total magnetic force at Tirunelveli during 1920-2005

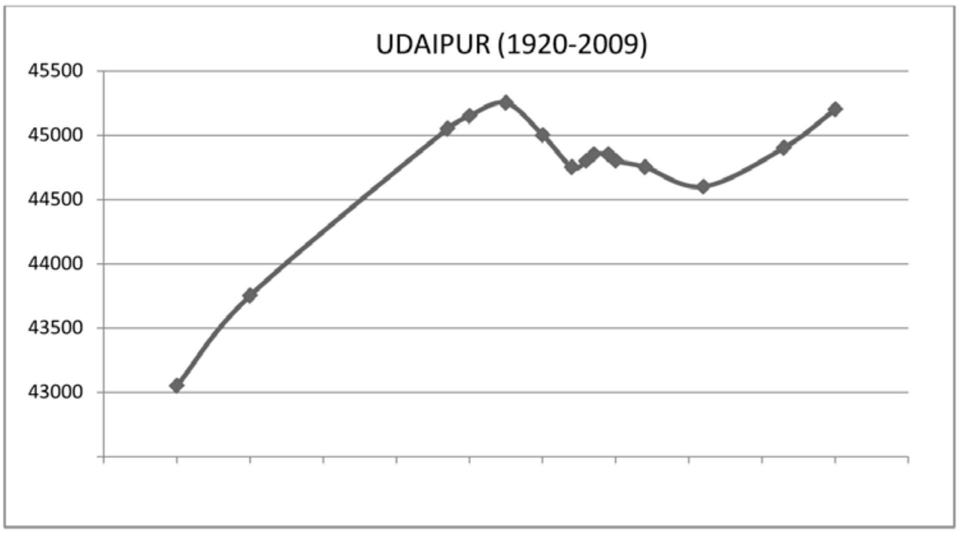


**Figure 6.** Temporal variation of total magnetic force at Udaipur during (1920 – 2009)

Using the repeat station network data of 1965.0 epoch, Arora et al, (*1983*) made as moothed polynomial fit to the data, including the annual mean of observatory data for 1965.0. The isolines thus obtained, were compared with the IGRF model and found in agreement. Secular variation rates were also estimated, and compared with IGRF. However, detailed observations for secular change in Declination (1965-2000) over Western India (shown in Figure 6), indicate more rapid and complex behaviour. It was also shown that coefficients for secular variation derived, by using 1970.0 and 1975.0 epoch surveys, compare well with IGRF models, as well as secular variation features noted at 6 Indian magnetic observatories (*Srivastava and Abbas, 1977*).

b) **Declination trends in Peninsular India** : The agonic line passes through the Indian region. Long series of measurements, over the region have shown finer details of secular variation in D (*Chatterjee, 1971; Gulatee, 1954*). An example of such variations of the agonic line, in the Western Indian province of Kutch, is shown in the Figure 3. Agonic line variations could be obtained using measurements upto 2005. Migration of Dip equator is shown in Figure 4 and variation of total magnetic forces at Tiruneveli and Udaipur in Figure 5 and Figure 6, respectively.

**(c) Co-seismic observations:** Geomagnetic studies based on experimental techniques basically determine the electrical conductivity and magnetic susceptibility of the

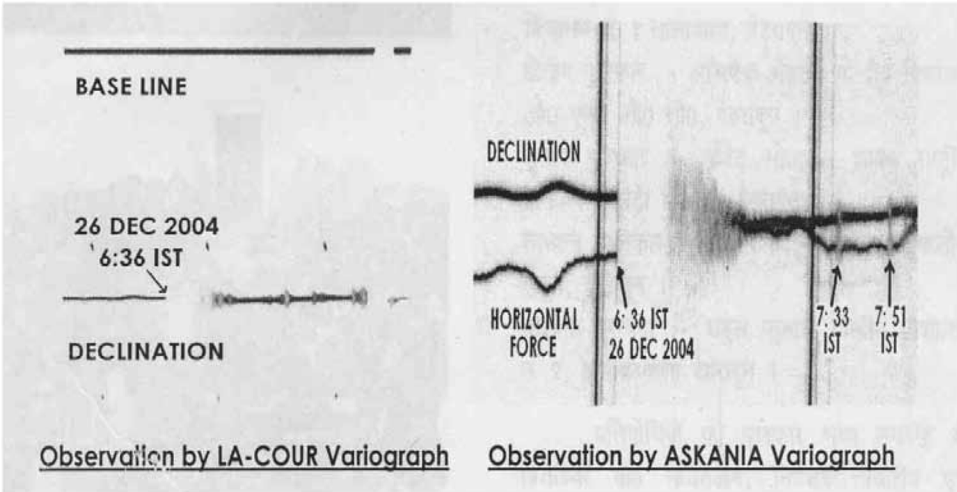


**Figure 7.** An example of co-seismic effects on magnetic variation is shown for the instant of tsunami 26 Dec., 2004

Earth crust, which in turn are dependent on the chemical composition of the sub-surface material. The magnetic susceptibility is effected by rock – stress; this aspect is known as tectono-magnetism, and efforts have been made to study its efficacy in the prediction of earthquakes (*Arora 1991; Johnston 1997; Johnston 2002*). Signatures of recent earthquakes have been recorded at Sabhawala Geomagnetic observatory in Figure 7 for the 26th December, 2004 tsunami genic earthquake. Signatures of Japan tsunami of 11th March, 2011 and Sikkim earthquake of 18th September, 2011 have also been recorded. Numerous other magnetic field variations have been recorded just prior to local earthquakes such as Uttarkashi and Chamoli earthquakes in Uttarakhand state.

## CONCLUSION

A systematic approach to obtain magnetic repeat station data has been initiated by the Survey of India, Geodetic & Research Branch, in last six decades. The data is mainly used for navigation purposes, correction of maps and compasses used in aviation. But,as stated in the foregoing paragraphs, this valuable data can be used for many scientific studies. A collaborative and more systematic study among Indian agencies working in this field and global agencies can derive fruitful results for the benefit of the society.

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