J. Ind. Geophys. Union (January 2005)
Vol.9, No.1, pp.41-46

Location of the Dip Equator over Peninsular India

R.C.Deka, L.A.D'Cruz, V.J.Jacob, A.Iype and P.Elango
Indian Institute of Geomagnetism, New Panvel, Navi Mumbai – 410 218

ABSTRACT

The dip equator runs over only the landmass of South America, Central Africa and peninsular India apart from a small section further east of India. A ground magnetic survey was conducted to determine the absolute values of both (I) and (Z) in the southern most part of peninsular India, to know the location and migratory nature of the dip equator for the epoch 2003.7. Though no trace of dip equator was found on the said landmass even after the last possible site at Kanyakumari, based on the data of ground magnetic survey, attempts are made here to trace it statistically. A well-defined southward migration over a period of last three and a half decades is still evident.The location of the dip equator between 76°E and 78°E (Indian sector) and its migratory nature in this sector are highlighted by the ground survey data comparing with the IGRF model data along with the nature of secular trends of the vertical field from stations in the equatorial region of India.

INTRODUCTION

Dip equator is the imaginary line on the Earth's surface along which the geomagnetic vertical component (Z) and inclination angle (I) are zero. The equatorial electrojet phenomenon is linked closely with the dip equator. The electrodynamics of the daytime equatorial ionosphere and consequent enhanced geomagnetic signature on the horizontal component due to Equatorial Electrojet currents are intimately tied to the location of the dip equator. (Rastogi 1989). At the dip equator, the field lines are totally horizontal, parallel to the surface of the Earth .

The causative mechanism of the equatorial electrojet current is this unique horizontal magnetic field configuration over the dip equator which causes almost 20~30 times more east west Cowling conductivity than the original east west Pedersen conductivity (Onwumechilli 1967).

The geographic location of the dip equator in the Indian sector has been determined at different epochs earlier, by Chatterjee(1970), Sankernarayan & Ramanujachary(1971), IIG, NGRI & SOI (1972) Srivastava & Habiba abbas (1977), Murty, Subrahmanyam & Jacob (1975) and Murty, Ahmed & Rao (1984) , Rangarajan & Deka (1991), Srivastava (1992), Paramasivam, Vijayakumar & Elango (1999). In West Africa, the movement of the dip equator was northward by about 10° between 1913 and 1986 but near 15°E longitude there was practically no movement during last 75 years (Vassal 1990). Vassal also found that the drift was faster after 1970 as compared to 1950 –1960. Between 1904 and 1960 the movement of the dip equator over Brazil was found to be nearly 8° northward and by only 4° between 1960 and 1985 (Barreto 1987). In the Indian peninsular region, the movement was found southward since 1945, more rapid after 1970 compared to the interval 1945-1970 (Rangarajan & Deka 1991). Confining attention to the longitudes where the dip equator passes through the landmass of the South American (between 80°W and 35°W), African (30°W to 45°E) and Indian sectors (50°E to 95°E) Rangarajan & Barreto (2000), found that the line delineating the dip equator is nearly parabolic in the American sector, all the curves tend to converge over 30°E in the African sector and in the Indian sector the shape of the curves tends to be sinusoidal. They also showed that in the American sector, the minimum of the curves deflects farthest away from the geographical equator in the southern hemisphere, close to 75°W longitude, whereas centered at 30°E longitude the dip equator remained stationary for over 100 years between 1900 and 2000 AD at 10° N geographic latitude.

It is now well established that the dip equator has a meandering path. It is migrating in different directions at different times in different regions with different speeds. It, therefore, becomes necessary to monitor the migration of the dip equator in different longitude sectors with special emphasis to fully understand the mechanism responsible for the contrasting migratory trends. The Indian Institute of Geomagnetism undertook the responsibility of demarcation of the dip equator in the peninsular India again in 2003.7. For this, a ground magnetic survey was conducted on the landmass in the southernmost part of Indian peninsula between 8°N to 9° N latitudes. The results of the present survey to locate the dip equator, its comparison with that derived from International Geomagnetic Reference Field model (IGRF) for the corresponding epoch, the movement of the dip equator in the past decades based on IGRF models and the secular trends in the vertical component (Z) of the magnetic field in the Indian region are presented and discussed.

DATA ANALYSIS

The instruments used in the survey are Declination Inclination Magnetometer (DIM) for the measurement of absolute Z and absolute I, Proton Precession Magnetometer (PPM) for the measurement of absolute F and Fluxgate based magnetometer to measure absolute Z. Apart from these, two Fluxgate magnetometers were installed to monitor the diurnal variation of (H), (D) and (Z) at two temporary locations, one at Pushpavanam(8.33° N , 77.60°E) and the other at Kanyakumari (8.09°N ,77.56°E) for a period of 9 days between September 13 and September 22, 2003 . Magnetic disturbances were observed on 17 September (Ap=70) and 18 September (Ap=50), and no survey was carried out on 19th September2003. Before commencing the survey, all the instruments were calibrated first at magnetic observatory Alibag (18.62°N, 72.87°E) and then at the Magnetic observatory Tirunelveli (8.67°N, 77.82°E). After the completion of the survey, the results of the observations of different instruments were again verified at Magnetic Observatory Tirunelveli.

The PPM was first used to make a quick survey in the vicinity of the site selected for final observations to ensure that the selected site was free from any type of strong local anomalies. This was followed by spot absolute observations of I, Z and F. We are aware that the Declination Inclination Magnetometer (DIM) is used to detect zero field normal to the magnetic north in the horizontal position and normal to the total field and thereby determine absolute D and I. However we found that when the sensor is kept precisely vertical, the same unit can also be successfully used to get absolute values of vertical component in the range of 0 to 1600nT (when no bias field for compensation is generated). So an attempt was made to record absolute Z directly from DIM taking the average in four orientations of observation North, East, South and West. It was then followed by the observations of the inclination angle (I) and vertical component (Z). Area of about 5000 sq. km. touching 93 points in different locations were covered between September 13 and September 22, 2003. The survey team carried out spot observations of Z and I every 5 km apart initially starting from Tirunelveli towards south, reduced the spacing to 3 km and finally to 2 km apart near Kanyakumari area.

It will be worthwhile to mention here that the survey team used for the first time a mobile Global Positioning System (GPS) to record the geographical latitude and longitude of each point of observations along with the real time of observations. Fig.1, gives the location of the observation sites occupied during the survey. Maximum precaution was also taken to minimize the duration of the time between two successive observations by two different instruments and avoided observations between 1100hrs to 1430hrs.

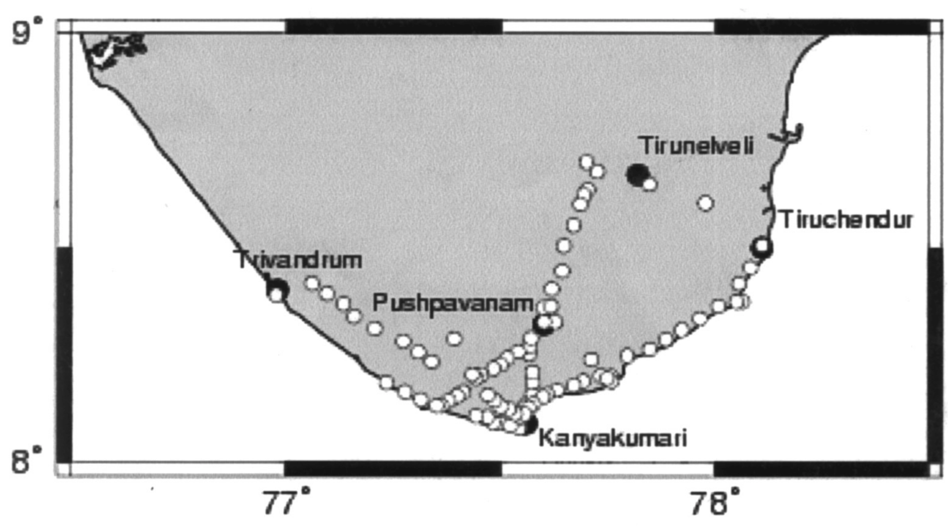

Figure 1. The exact Geographic location of the sites of the field observation.

The survey data were reduced to get absolute Z from the observed I and F on the spot itself and observations were repeated if any doubt was there on quality of the data. Absolute values of F observed by PPM and absolute values of I observed by DIM were used to calculate Z. Z observed directly from the DIM and Z determined from I and F are found to match except for one or two observations. In contrast, Z observed by Fluxgate based magnetometer was not very satisfactory. This may be due to high temperature effect on the fluxgate sensor, which is not compensated for variable temperature. From F and Z, horizontal component H is computed. After carefully checking the variations observed at Pushpavanam (a temporary station) with Tirunelveli, (a permanent station of the Institute), H and Z data are then corrected for the diurnal variation using the digital data recorded at Puspavanam, which is almost at the center of the all the observational points. The observations are reduced to midnight reference level by allowing for the difference in diurnal variations in H and Z components, as observed at Pushpavanam.

RESULTS AND DISCUSSION

i) Location of the Dip equator during 2003.7 epoch.

Even up to the last available land site in the peninsular India we could not arrive at an area to record zero values of Z and I, though a linear decrease of both the values were observed as we moved from north to south. This indicates clearly that the geographic latitude corresponding to the dip equator should be further south of Kanyakumari and we have to take recourse to some statistical method to evaluate the same. Using the observed data by three different instruments and carefully correcting them for diurnal variation etc. with respect to Puspavanam records, we analyzed the data in four different ways to get the latitude corresponding to zero Z, and zero I. By fitting a least squares regression line between Station Latitudes and (i) absolute Z directly observed from DIM (Fig. 2a), (ii) Z calculated from I and F (Fig. 2b), (iii) observed I from DIM (Fig. 2c), and finally (iv) observed Z from Fluxgate- magnetometer (Fig. 2d), we find that the geographical position of the dip equator at 77.5° E longitude corresponds to 7.954 N, 7.957°N, 7.971 °N and 7.885° N geographic latitudes respectively. The first three independent sets of observations yield values of the geographic latitude for zero dip in close proximity to each other .We can therefore state that in the epoch 2003.7, over 77.5°E the dip equator was located at the average latitude of 7.961°N. The geographical location of the dip equator derived from fluxgate-based Z magnetometer (Fig.2d) differs slightly. In terms of distances, the first three differ by a maximum of less than 2 km whereas the last one differs by about 9.5 km.

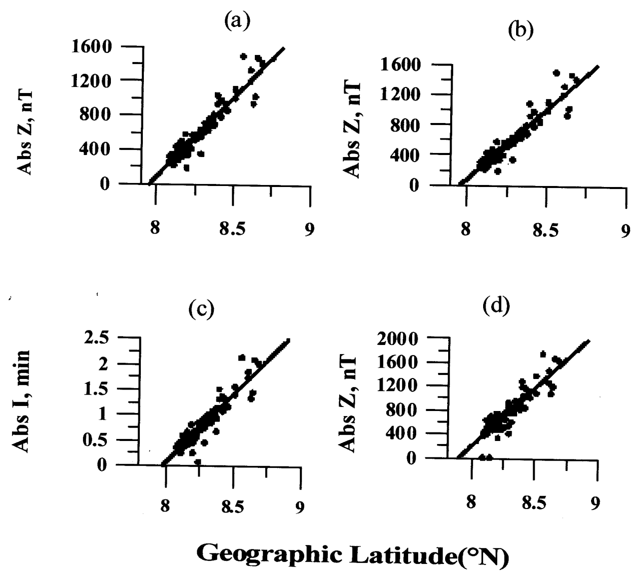

Figure 2. Graphical representation of least square regression line of the vertical component of the Earth's magnetic field observed with different instruments (PPM, DIM and Fluxgate based magnetometer) during the survey for the determination of the dip Equator on 77.5° E Geographic longitude. Station Latitude vs (a) Z observed directly from DIM (b) Z determined from observed F and I. (c) I observed from DIM. and (d) Z observed from Fluxgate based magnetometer.

ii) Migration of the dip equator during last 100 years along 77° E longitude sector.

World Data Center has made available Definitive Geomagnetic Reference Field Models for the year 1900,1905…2000 covering the entire 20th century. Using the spherical harmonic coefficients defining the IGRF models, attempts are made to know the position of the dip equator at 77.5° E longitude zone in the Indian sector. Fig 3 shows the geographic latitude of the dip equator during last one hundred years along with the dip equators determined in various ground campaigns between 1971 and 2003. The observational lines of zero dip in Indian peninsula between 1971 and 2003 and IGRF–based dip equator for 1970 to 2000 have similar behavior and comparable locations.

The dip equator migrated southwards up to 1925 and then reversed to a northward direction smoothly. After 1970, a southward migration is again noticed. Between 1945 and 1980, it is seen that the dip equator was totally confined to a narrow latitude belt between 8.5° and 9°N. Around 1950 there is a peculiar break in the smooth time profile. Rangarajan & Barreto (2000) showed that the break is seen in almost all the longitude sectors between 50 and 95 deg E. They further showed that this could not be attributed to any artifact of the models because such a feature was not seen in the other two regions (American and African sectors), nor was it seen uniformly everywhere in the Indian sector.

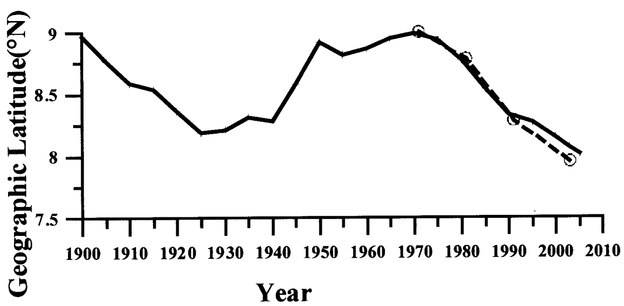

Figure 3. Geographic location of the dip equator during last hundred years (solid line) along with the dip equator determined in various ground campaigns between 1971 and 2003 (dashed line)

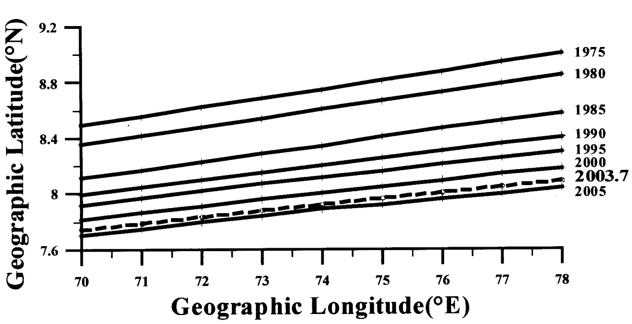

Figure 4. Geographic location of the dip equator (corresponding to the vertical Component Z=0) in Indian sector determined from IGRF model for 7 epochs 1975,1980 ......2005 along with 2003.7 epoch (dashed line)

iii).Migration of the dip equator in the recent past.

IGRF models up to 2000.0 and extrapolated to 2005.0 are used in Indian sector to estimate the rate of change of position of the dip equator in every 5 years period from 1975 to 2005 in every longitude from 70°E to 78°E (Fig.4). In a joint survey carried out by IIG, NGRI and SOI in 1971, the dip equator was identified to be located just north of Tirunelveli. Using the ground magnetic data on Z component, Murty, Ahmed & Rao (1984) identified the dip equator about 24 km south of 9° N which was nearly the position of the dip equator even in 1971 along 77.5°E. longitude. Rangarajan & Deka (1991) located the dip equator at 8.28°N on 77.5°E. The average rate of southward migration was ~4km /year during 1971~91 but it was faster ~5 km in the later decade.

From the Fig.4, it is clear that the maximum speed of migration of the dip equator (as derived from IGRF models) was between 1980 to1990 about ~5 km per year. From our ground survey data, it is now determined that the present position of the dip equator is about 13 km south from the tip of Kanyakumari and about 35 km south as compared to 1991 survey on 77.5°E longitude. During the last decade the rate of southward migration is ~2.92 km per year.

A quasi periodicity of about 80 years in the migration of the dip equator was pointed out by Srivastava & Abbas (1977). In fig 3 we can also identify a quasi periodicity. However both the minimum and the maximum are rather ill-defined but the periodicity is apparently much less than the 80 years attributable to the Gleissberg cycle.

Using IGRF model 2000.0 extrapolated to 2003.7 corresponding to the present survey period, we have determined the dip equator at 77.5°E and this corresponds to 8.0512°N Geographic latitude which is only about 10 km further north from the location determined by the ground survey (Fig.4 dashed line). After carefully observing the data from different angles it is now clear that the Dip Equator in 2003.7 epoch is within 7.95° to 7.96° N latitude on 77.5° E longitude which is about 12 to 13 km south of Kanyakumari and about 10 km south as determined from the IGRF model data.

Just south of the southern tip of peninsular India, is known to have anomalous magnetic variation brought about by process of electromagnetic induction through possible electrical conductivity in the Palk Strait region (Rajaram et al. 1979), (Thakur et al. 1986). Arora (2000) suggested that the displacement of electrojet axis with respect to the dip equator would be the result of the contribution of internal channeled currents along the Palk Strait. This anomaly however would affect mostly the amplitude of quasi-periodic variations in the magnetic field recorded at or near the site of conductivity anomalies. We have confined our data only to spot observations on magnetically quite days reduced to a mid- night level. We therefore expect that the contribution, if any, due to Palk Strait conductor will be minimal.

(iv) Secular trend in Z at low latitude stations in India and its relation to the Dip Equator.

Based on the secular change of Z from three equatorial stations, Srivastava(1992) had estimated that the southward drift of the dip equator would reverse around 2005. From the annual mean values of Z from several low latitude observatories of the world for 1945 to1995, Rangarajan (1994) showed that at most of the observatories the secular trend in Z is consistent with the direction of the meandering dip equator.

To reconfirm this, we plotted the annual mean of absolute Z from the Observatories Annamalainagar / Pondicherry (ANN/PON), Trivandrum / Tirunelveli (TRD / TIR) and Kodaikanal (KOD) along with Alibag (ABG) observatories (Fig.5). (Annamalainagar/ Pondicherry (ANN / PON) (TRD/TIR) are combined here because of the closing of Annamalainagar and Trivandrum observatories in the years 1994 and 1998 respectively).

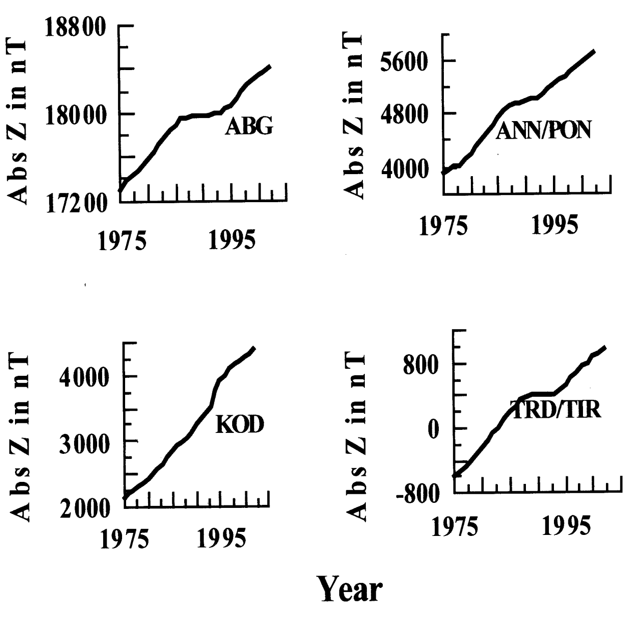

Figure 5. Secular variation of the vertical field of Indian equatorial stations along with Alibag from 1975 to 2002.

When the dip equator moves southward or northward the vertical component of the earth magnetic field should reflect this with increase or decrease in absolute Z respectively at northern geomagnetic latitudes. From the plots of the annual mean absolute values of Z in Indian equatorial stations, it is observed that the rate of increase of Z values between the periods of 1988 to 1993 is very slow with a sharp rise from 1993 to 2000. A peculiar rise of Z was observed in 1990 almost at all the equatorial stations in India including Alibag situated away from the dip equator. Again the rate of increase is more at equatorial stations than the stations outside of it. Thus this southward migratory nature of the dip equator is a direct consequence of the secular variation of the Z component of the Earth's magnetic field and it is believed to be related to the core dynamics. Though it is clear that the migratory nature of dip equator can be verified from the change of annual absolute Z from the equatorial stations it may not yield as precise a result as that can be obtained by a carefully planned ground magnetic survey. Such exercise should be repeated periodically.

ACKNOWLEDGEMENTS

The authors express their grateful thanks to the Director of their institute for his enthusiasm and keen interest towards this survey. They are also thankful to Mr. B. Paramashivam and his colleagues from EGRL who assisted the survey team in the preparation. Thanks are also due to Dr. B.M.Pathan for critical comments.

This work is dedicated to Late Prof D.R.K.Rao, who over the years, continued to blaze the trail of Indian Geomagnetism and survey practices and under whose valuable guidance the survey team could complete the survey in time.

REFERENCES

Arora,B.R.,2000. Effects of anomalous electromagnetic induction in the source-characterization of equatorial geomagnetic fluctuations. The J. Ind. Geophys. Uni., Sp issue 4 (2 a), 29-39.

Barreto, L.M., 1987. Consideracoes sobre a variacao secular e o modelamento de campo geomagnetico no Brasil, Publ. Observatorio Nacional do Brasil, No 5/87

Chatterjee, J., 1970. Geomagnetic anomalies in south India, Proc. *Seminar on problems of Equatorial Electrojet Ahmedabad, paper No8*

IIG,NGRI & SOI ,1972. Ground geomagnetic Survey in the Equatorial Electrojet region in India – a report. Geophy.Res.Bull., 10,167-180.

Murty, A.V.S., Ahmed, K. & Rao, D.R.K., 1984. Migration of the dip equator in the Indian region, Proc. Indian Acad.Sci. (Earth & Planet Sci), 93, 129~133.

Murty, A.V.S.,Subramanian, Y.H. & Yacob, A., 1975.A comparative study of the geomagnetic phenomena at the experimental station Kanyakumari, Proc. Symp. Equatorial Electrojet Phenomena, Bombay (Indian Institute of Geomagnetism, Bombay), pp126-131.

Onwumechilli,A., 1967. Geomagnetic variations in the equatorial zone , in Physics of geomagnetic Phenomena, vol.1 ed. Matsuhita S. and Campbel W.H. Acad. Press, N.Y.,London,p 425

Paramasivam,B., Vijaykumar,K. & Elango,P., 1999. Migration of dip equator-Ground geomagnetic Survey, The J. Ind. Geophys. Uni., 6 (1), 19-23.

Rajaram ,M., Singh, B.P,Nityananda,N.& Agarwal,A.K., 1979. Effect of the presence of a conducting channel between India and Sri Lanka island on the feature of equatorial electrojet . Geophys.J.R. Astron.Soc..56,127-138.

Rangarajan, G. K. & Deka, R. C., 1991.The dip equator over peninsular India and its secular movement. Proc. Indian Aca. Sci. (Earth & Planet Sci), 100, 361~368.

Rangarajan, G. K., 1994. Secular variation in the geographic location of the dip equator. PAGEOPH, 143, 697~711

Rangarajan, G. K. & Barreto, L.M., 2000. Secular change in the location of the magnetic dip equator in the twentieth century. Geofisica Inter.,39, 323-336.

Rastogi, R. G., 1989, The equatorial electro jet: magnetic and ionospheric effects in Geomagnetism, 3 (ed. J.A Jacobs) Academic Press, London , 461-525.

Sanker Narayan, P. V. & Ramanujachary, K.R., 1971, Nature (London), 231-37.

Srivastava, B. J., 1992. New results on the dip equator and the equatorial electrojet in India, J.Atmos.Terr.Phys., 54,871-880.

Srivastava, B. J. & Abbas, H., 1977, Geomagnetic secular variation in India: Regional and local features, J.Geomag.Geoelectr., 29, 51-64.

Thakur , N.K., Mahashabde, M.V., Arora, B.R.,Singh, B.P., Srivastava,B.J. & Prasad, S.N., 1986. Geomagnetic variations anomalies in peninsular India. Geophys.J.R.astr.soc., 86, 839-854

Vassal, J., 1990, The drift of geomagnetic equator in West Africa from 1913 to 1986, J. Geomag. Geoelectr., 42, 951-958.

(Accepted 2004 August 11. Received 2004 June 10; in original form 2004 March 5)