J. Ind. Geophys. Union (January 2016)
Special Volume-2/ 2016 pp: 80-85

Calibration Experiments conducted at ETT observatory, 1980-2000

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ABSTRACT

Data standards at Hyderabad (HYB) and Ettaiyapuram (ETT) magnetic observatories in the era of suspension variometers and secondary calibrated absolute magnetometers could be maintained only bycontinuous evaluation and self-consistent data reduction. Experiments were devised at these observatories using minimal equipment, without calibration facilities,to compare and calibrate absolute and variation magnetometers in situ. Of these experiments three are described here:

i) Determination of the thermal coefficients of the La Cour suspended magnets and assessment of the impact of diurnal temperature variation, within the wooden, thermally insulated variometer room at ETT.

ii) Evaluation of the effect of H-variation (diurnal range ~100nT) on the La Cour D-variometer at ETT, that was dynamically balanced in the'astable' position, with torque equal to the force exerted by ambient H-component. The H-field, around the D-variometer was increased in steps, using the Helmholtz coils of the assembly, to estimate the coefficient of change in D for every 10nT increase in H. This was used to re-calibrate declination values at ETT.

iii) Improved constant current source, bias coil assembly and in-house proton precession magnetometer(PPM) were deployed in the experiment. Baselines obtained from two different methods of vectorised measurement, Nelson's method and Serson's method, were compared for equatorial latitudes, against those obtained from DIFlux. Serson's method of vectorised measurements was found to be optimal for low values of vertical component.

Keywords: Calibration of observatory magnetometers, Equatorial vertical field measurements, Experiments on magnetometers.

INTRODUCTION

Hyderabad Magnetic Observatory (HYB, 17.4ºN,78.5ºE) and the Equatorial Observatory, Ettaiyapuram (ETT, 09.2ºN, 78.0ºE) were established in 1964 and 1978 respectively (*Sanker Narayan, 1964; Sanker Narayan et al, 1978*).The two observatories operated similar quartz suspension La Cour variometers and used calibrated secondary absolute standards, Quartz Horizontal Magnetometer (QHM) for H and D, and Zero Balance Magnetometer(BMZ) for Z, and yielded consistent continuous magnetic variation data. In the processing of data, checks were made to verify consistency and identify causes for baseline drift. One of the primary causes for drifting baselines and variation data was temperature change. The variometers at HYB were placed in a semi-underground double-walled vault with variation of temperature ~1° C. At ETT, where the variometers were installed above ground in a wooden insulated building, temperature variation was greater. This was a primary concern. Therefore thermal coefficients of the La Cour suspended magnetic were initially experimentally determined at HYB (*Sanker Narayan et al, 1966*) and later at ETT in 1980, and some results are presented below.

The D diurnal variations are of low amplitudes at low latitudes. It had been suggested that sensitivity of the La Cour D variometer improves considerably in the astable position i.e. the D Variometer magnet north pole pointing towards magnetic south, with sufficient torsion given to the suspending thick quartz fibre. In this orientation sensitivity is high due to magnetic repulsion and high torsion exerted by the thick suspension quartz fibre (*MacComb,1952*). This was the 'astatic' equilibrium position of the D variometer suspension installed at ETT. Later it was noticed that D-variation at ETT showed anomalous diurnal signature, the probable cause being the large diurnal range of H (~100nT) at an equatorial observatory. In order to investigate this and quantify the effect of H variation on D variation, an experiment to estimate the effects of calibrated increase of H-component, with simultaneous absolute measurements was performed. The ETT hourly variation data was revisited to correct this effect and an artifact of apparent EEJ effects in D-variation was eliminated (*Saratchandra et al, 2002*).

Careful checks of baselines also showed effects of ambient temperature and humidity on the secondary calibrated standards; QHM and BMZ. This had a seasonal effect on baseline determination. By means of careful measurement and recording of ambient conditions, these effects were minimized. It was recommended by the Danish Meteorological Institute (DMI), that absolute magnetometers be re-calibrated against a standard every 2 years. However it was not possible to complete these checks against external standards as regularly as advised. The inter-comparison of Balance Zero Magnetometers, posed a challenge. Usual practice was to compare these instruments against the baselines at Alibag Magnetic

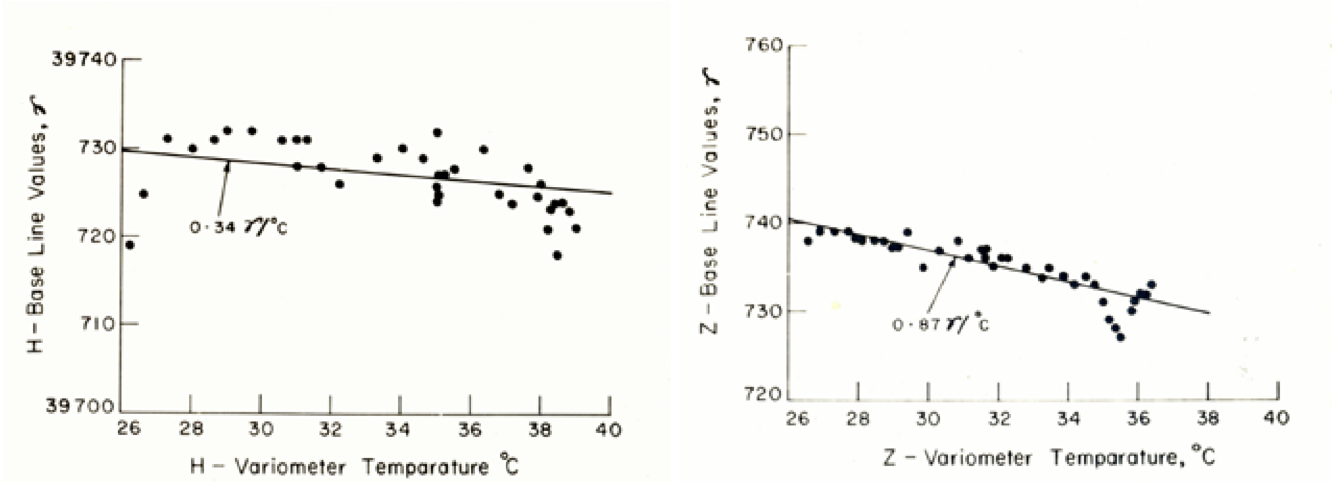


Figure 1a,b. Thermal coefficients of H and Z variometers (ETT) determined by heating and cooling of the variometer room, over a few hours, while continuously makingabsolute measurements at a nearby location.

Observatory (ABG). The settings of the collar magnet of the BMZ were different for HYB and ABG, giving an offset to values. Further, at ETT, near the equator, no collar magnet was used, therefore intercomparison at higher latitudes, was not feasible. Thus it was not possible to calibrate these instruments against ABG baselines. Efforts were made at NGRI to develop an absolute standard that could be used to monitor the QHM and BMZ. A proton precession magnetometer with a set of vectorising coils was developed (*Sarma et al, 1975*). After several improvements to the vectorising coil assembly and the constant current source, testing of the vector proton precession magnetometer (VPM) assembly and a novel method of vectorising at low latitudes were also carried out at ETT, comparing it with absolute measurements of the DI Flux magnetometer (*Saratchandra et al, 1999*). The efficacy of the method is reported below.

The three experiments are presented below along with their results.

DETERMINATION OF THERMAL COEFFICIENTS OF LA COUR VARIOMETERS

An experiment was conducted to obtain the thermal coefficients of La Cour variometers, at HYB (*Sanker Narayan et al, 1966*). Based on this, and an observed change of 1ºC/day in the double walled variometer vault, it was established that HYB variation data was free from thermal effects. A similar exercise was carried out at ETT in 1980 where the variometers were installed above ground, in a wooden walled housing. There was a concern that temperature effects might be large at ETT. In January 1980, the variometer room was heated from 25ºC to 40ºC, and cooled gradually and the temperature of the variometers was recorded every 5 min. At the same time, absolute experiments were carried out to determine baselines of H,D and Z, throughout the day. The absolute measurements were made using QHM and BMZ, and the values were reduced to a base temperature, from the values recorded. This satisfied the condition of stable absolute values. Plots of the change in baseline values (Figure 1a,b) reduced from the variometer records, during heating and cooling clearly demonstrates the thermal effects on magnetic variations. Heating was done using four charcoal braziers, one in each corner of the variometer room, in order to provide uniform heating. Temperature gradients for both heating and cooling cycles were kept approximately the same. The absolute experiments were carried out at 10-minute intervals during the cycles and temperature was recorded every 5 minutes. The thermal coefficients of the La Cour variometers were derived from the plots and found to be -0.34 nT/ºC, for H-variometer and -0.87nT/ºC for Z-variometer. In the plots reproduced here, magnetic field units are γ and not nT, as this experiment was conducted in January 1980!

ESTIMATING EFFECT OF H-VARIATION ON D VARIOMETER IN ASTABLE POSITION

As described above, D-variometer magnet was in astable equilibrium At ETT, the field values are: H ~ 40000n T,D ~ 3° and ∂D ~ 3′. It was desired that the La Cour D Variometer set up, should have sensitivity, such that a deflection of about 2.6 to 3.3 mm on the photographic chart would correspond to a change of 1' arc, in order that the diurnal variation is measurable from the magnetogram. Various quartz fibres were used in the Dvariometer suspension to try and obtain the desired deflection that was tested by giving measured currents in the Helmholtz coils. However, even with the thinnest quartz fibre, in the normal position, the deflection observed on the chart was only 1 mm for every 1′arc. This is constrained by the geometry

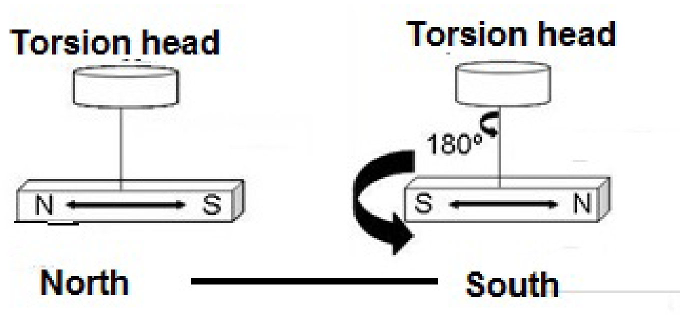


Figure 2a. Schematic illustration of Normal andAstable positions of La Cour D-variometer magnet.

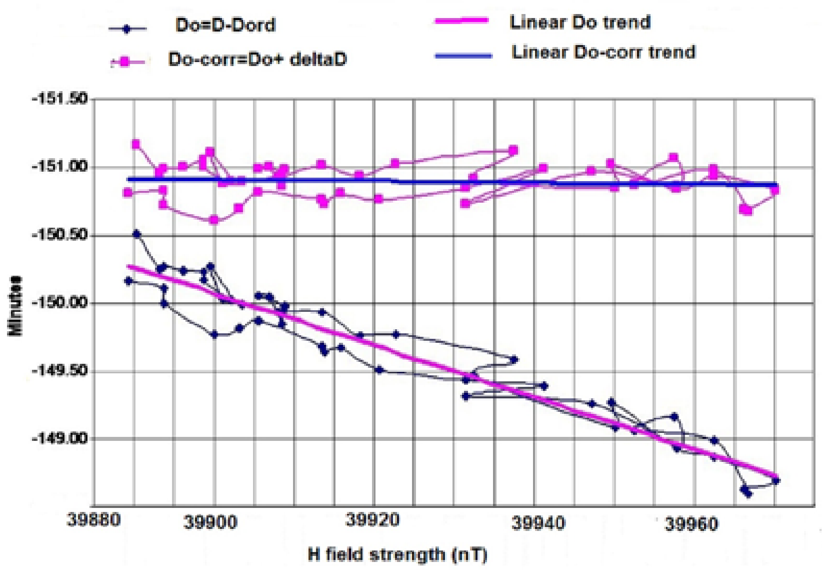


Figure 2b. Comparison of D-baselines reduced without and with corrections for astable position, showing the depeendence of uncorrected Do on values H field, from measurements of 22nd December 1992.

of the photo-registration arrangement and the thickness of the trace on the paper. The diurnal variation would then have a deflection in the record of about 3 mm, which is not at all useful for monitoring diurnal variation of D, from a trace of 1mm thickness. Both normal and astable positions and subsequent sensitivity have been outlined in manuals of observatory practice (*McComb, 1952, Weinert, 1970*).

Normal Orientation: In this orientation, the suspended magnet is oriented in the magnetic meridian with its north pole towards magnetic north with zero torsion in the suspension thin quartz fibre (torsion coefficient is very low) i.e., the magnet orients itself parallel to the direction of H because of zero torsion as shown in Figure 2a. Since the suspended magnet is in the magnetic meridian, it responds ∂Y and is not free to respond to the variations in H.

Astable Orientation: In the astable position of D Variometer, the suspended magnet is oriented with its north pole pointing south with required torsion in the suspension fibre, for which a very high torsion coefficient thick quartz fibre is used (Figure 2a). Therefore it was decided to suspend the magnet of the D variometer, in the astable position. The desired sensitivity was obtained for D variations. However, the effects of diurnal variation in H on D-variation were noticed, during periods of activity and also in the drift of D-baseline values, despite repeated observations with 3 QHM tubes. The magnet orients itself anti-parallel to the direction of H due to high torsion. Since the magnet is suspended in dynamic equilibrium with the ambient strength of H, in the magnetic meridian, it responds to ∂Y and also to ∂H due change in the equilibrium, with H variation ~100nT. Then from the equations:

$$Y = H \sin D \qquad (1), \text{ differentiating,}$$

$$\partial Y = H \cos D . \partial D + H . \partial H \sin D (2) ,$$

$$\partial Y = X . \partial D + Y . \partial H,$$

where Y=0 in the meridian position (normal), then

$$\partial Y = X . \partial D$$

And in the astable position, $\partial Y corr. = \partial Y + Y . \partial H$, is

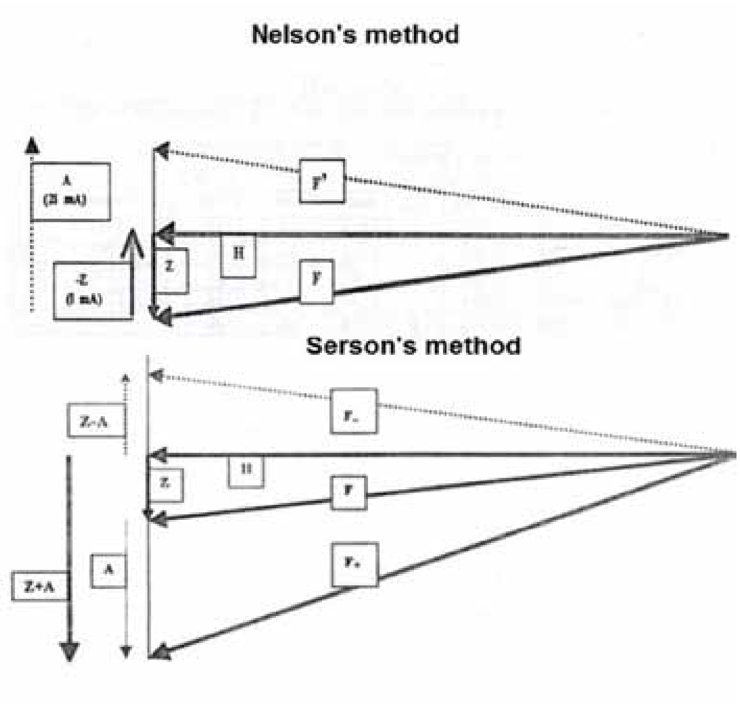


Figure 3a. Schematic to show measurements of F, F′ in Nelsons method, and F, F+ and F- in Serson's method, where the vertical component Z is augmented by a field A, estimated from the constant current source.

dependent on both ∂D and ∂H.

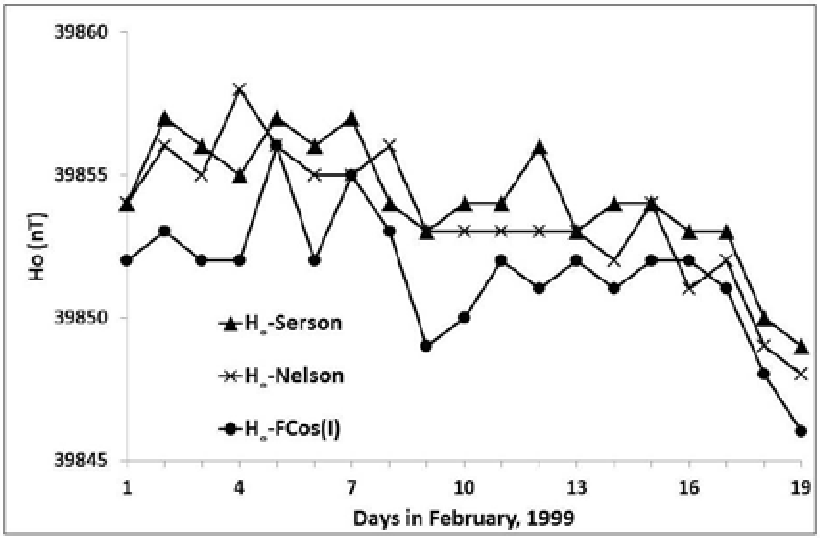
In order to accurately report D variation, the baselines had to be stabilised and diurnal variation corrected for the effects of ∂H, on ∂D. An experiment was carried out in 1992, to determine a linear relationship between ∂H and ∂D. Using the Helmholtz coils of the D variometer, an additional H field was added in measured increments. At each step, DIflux measurements of H and D were also carried out. Figure 2(b) show the effect of H variation on the baseline values obtained for D, from the magnetogram, using absolute values conducted throughout the experiment. It is established that the effect of increasing H, is a linear increase in D variation. An effect of 1′ of D variation was observed for a change of 50-60 nT of H. The value of 54 nT/′ as the effect of H variation on D from the continuous observations of DIM-100 for D and the respective baseline plots was accepted and a correction of 0.019′/nT of ∂H variation was applied to hourly means of D Variation.

This procedure was followed in the finalization stage of Do Baseline values and at D data processing stage considering the available H Magnetic data, to output D Magnetic Data independent of H Variations. However, this relationship was not estimated for very large changes in H, viz., likely values of storm ranges. It is also known that torsion suspended variometers can have varying scale values (sensitivity) for large fluctuations. Therefore though this formula to correct D variations was used for the entire series of hourly variations the storm ranges, or short period D ranges were not reported for ETT.

Estimation of Z value by Vector proton magnetometer

The low magnitude of absolute values of Z at low latitudes posed a challenge to accurate measurement. The relatively higher rate of annual variation in Z, in the Indian region, required close monitoring and accurate determination of absolute values at these observatories. Estimation of Z at low and equatorial latitudes has inherent imprecision. The performance of BMZ over time could not be evaluated by inter-comparison, at ETT for reasons given above. Limitations regarding calibration of BMZ also made it desirable to have an independent means of making absolute measurements (*Weinert, 1970*).

A proton precession magnetometer, vectorised with bias coils, to determine absolute 'H' and 'Z' was developed. PPM only measures the magnitude of the total scalar magnetic field (F). However, PPM can be vectorised using suitable bias coils to measure the larger of signal strength (either H or Z) using bias coils. Design and construction of bias coils and a reliable constant current source are critical inputs to obtain vector magnetic measurements using a PPM (*Auster et al, 2007, De Vuyst 1972*). There are intrinsic errors in this instrument set up i) errors in machining the coils, ii) proper orientation and centring, iii) maintaining constant current during vectorisation.



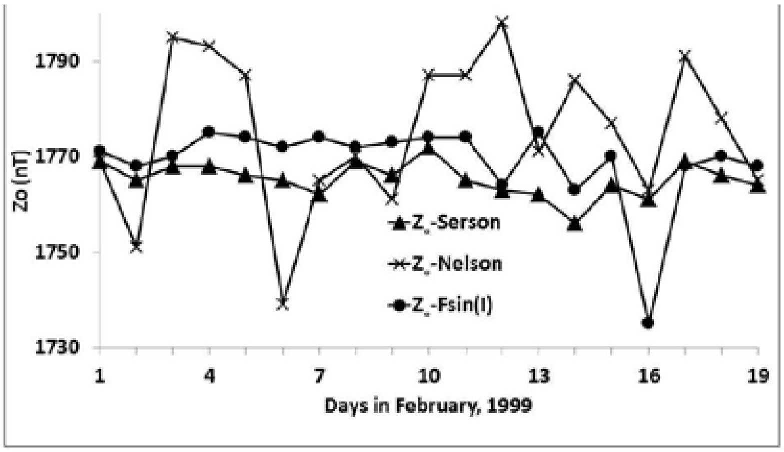


Figure 3b,c. Baselines of H and Z obtained from all VPM measurements: Nelson's method, and Serson's method, compared against F.sin(I) obtained from DI flux measurements, on 19 days in February, 1999.

The bias coil unit and turntable were fabricated at NGRI, replicating one used at HYB observatory (*Sarma et al, 1975*). The coil configuration that was found to produce a volume of uniform magnetic field with most compact coil configuration was the Faneslau-Braunbeck coils. The constant current source was designed specifically for this experiment, the emphasis was on keeping the bias current constant within +/- 10.0 μA, being about 0.65nT. The bias coil constant determined in the laboratory was 65nT/mA (*Sarma et al, 1975, Saratchandra et al, 1999*). The vector PPM (VPM) was used at HYB initially. With improved constant current source, it was felt that the system was sufficiently accurate to obtain reliable vector absolute values even at equatorial station like ETT. The low absolute values of Z at ETT, and inherent errors in determination of absolute values, using BMZ, or VPM, provided suitable conditions to test the vector assembly. Further the relative accuracy of two methods of vector measurements i) Nelson's method and ii) Serson's method were also evaluated. The measurements were compared against absolute values obtained using a DIFlux. A schematic illustrating the two methods is given in Figure 3a.

Nelson's method

Schematic of the magnetic vectors of Nelson's method is given in Figure 3a. F is the total field readout, with zero current in the bias coil. A bias vertical field A, is created in the coil unit by sending a current 2i, which can produce a total field F' as read on the PPM output, F'=F. Then half that current i produces a total field readout F=H. With readouts of F and H, Z is determined. Five sets of these readings are taken under quiet field conditions and averaged to obtain absolute values of H an Z. In this method F and H are measured and Z is calculated.

However, at low latitudes, this measurement has a high intrinsic estimated error. When F and H are measured using Nelsons method, $Z = \sqrt{(F^2-H^2)}$. Differentiating, the error in Z, $\partial Z=(F+H)/Z$. This error can be large at equatorial stations where F~H and Z <20% of Fafter differentiation error dZ = (F+H)/Z * dF(dH). In∂Z~(40,000+40,000)/1900=42nT*dF(dH) nT.

Sersons method

A schematic of the field measurements is given in Figure 3a. A bias current'i' is used to create a bias vertical field A~3Z. The bias current is kept constant during the measurement cycle, only the polarity is switched. The estimates of F (no bias current), F+ (increased Z and F- (opposing Z) are noted. Five sets of these readings are taken, without altering the current. From the averaged values, Z and H are calculated (*Serson, 1962*).

During these experiments, DI flux measurements of inclination (I) and declination (D) were also made. This was repeated on18 days of February 1999. All the absolute measurements were reduced to baseline values H_o and Z_o. In Figure 3b and c, values of Z_o and $H_o$the baselines obtained from Serson's method, Nelson's method and DIM are plotted for successive days of the experiment in February 1999. Both the VPM methods give similar values for H, with very little scatter (Figure 3b). The values are comparable with the DI Flux measurements, which themselves show some scatter. The stability and similarity of Z baselines obtained by Sersons' method and DIM experiments is clearly seen in Figure 3c.It is seen that Serson's method showed less scatter in Z values. Nelson's method provides more erratic estimates of baselines, due to the inherent errors in determining Z at low-latitudes. It is an acknowledged observation that errors of ~42nT, in Z values, are unacceptable in the measurements at low and equatorial latitudes. The changes in measurement made in Serson's method adequately address this issue and it was demonstrated that stable baselines are obtained at an equatorial station. Further, this experiment, evaluated the performance of the in-house developed PPM, bias coils and constant current source.

CONCLUSION

Due to the isolation of magnetic observatories it was necessary, to periodically test the magnetometers for self consistency, using experiments applying basic concepts of magnetism. Over the past 50 years, when magnetometers were calibrated against secondary standards, extreme care was taken to check and re-check their consistency, as it was not possible to compare and evaluate the performance of variometers and absolute instruments regularly. Further, with the development of modern magnetometers, and the absolute measurements made with proton precession magnetometers, it was once again necessary to compare and calibrate these magnetometers against the older classical instruments. Such experiments help to maintain the validity of a long series of measurements, as in the case of reducingthe effect of ∂H variations on D variometer. Geometry of fields at the magnetic equator, small absolute values and large diurnal variations all provided challenges. These were opportunities to calibrate magnetometers and test methods of measurement using fundamental principles, all the while without disruption of the continuous record of variations.

ACKNOWLEDGMENTS

We thank the LOC of the 16^{th} IAGA Observatory Workshop, 2014, for support to attend the Workshop and the invitation to contribute to this volume. We are grateful for all the assistance and expertise provided by all the staff of ETT observatory, over the years during these experiments and for the fundamental understanding and conceptualisation provided by late Mr Y.S. Sarma.We thank two reviewers for their helpful comments. Support of the Ministry of Earth Sciences (MoES/P.O. (Seismo)/1(124)/ 2010) is acknowledged (NN).

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