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On the anomalous features of the geomagnetic quiet-day field variations at Nagpur, India

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SUMMARY

The quiet-day geomagnetic field variation data from the recently commissioned Nagpur geomagnetic observatory, which has augmented the currently active latitudinal chain of Indian magnetic observatories, are analysed for the year 1993. The variations for diurnal frequencies (Sq) recorded at Nagpur do not follow the expected trend with latitude. This is most conspicuous in the northward horizontal (X) component. The anomalous behaviour at Nagpur is also seen in the diurnal harmonic amplitudes when compared with those of the neighbouring stations Alibag (south of Nagpur) and Ujjain (north of Nagpur). This behaviour is attributed to the presence of electrically conducting anomalous sources in the vicinity of Nagpur. The anomalous internal source is inferred to be located at relatively shallower depths and is highly localized.

Key words: India, Nagpur magnetic anomaly, *Sq* variations.

INTRODUCTION

The time-varying geomagnetic field of natural origin observed at the Earth's surface is the vector sum of its external and internal parts. The external part has its origin in the current systems generated in the ionosphere and distant magnetosphere by the interaction of solar plasma with the Earth's permanent magnetic field. The internal part arises from the currents induced in the Earth by the external time-varying current systems and provides information on the electrical conductivity distribution within the Earth. The depths at which the induced currents flow within the Earth depend on the frequency of the inducing source field and the conductivity of the medium. Thus, it is possible to interpret the geomagnetic field variations recorded at an observatory in terms of changes in the electrical conductivity distribution within the Earth. In addition to their application in determining the internal electrical conductivity distribution, the field variations also act as unique tools for a better understanding of the external current systems associated with them (Schmucker 1970; Campbell 1987).

A geomagnetic observatory at Nagpur was recently commissioned to enhance the network of observatories within the Indian longitudinal sector. The observatory is located on the main peninsular land mass and is sufficiently far from the sea coasts that the coastal effects on the recorded magnetic field variations are expected to be small. Also, the observatory is far from the influences of the equatorial electrojet and the northern Sq focus. In the present study, the average diurnal variations of the geomagnetic field components recorded at Nagpur are analysed for the year 1993 and are compared with those recorded at the neighbouring stations Alibag (south of Nagpur) and Ujjain (to the north).

DATA

Quiet-day geomagnetic field data for the year 1993 from six geomagnetic observatories in India extending from Pondicherry (PON) to Sabhawala (SAB) were considered. The geographical locations of the stations and their corresponding dip latitudes are shown in Fig. 1. Hourly mean values of the five international quiet days of each month for the three components X (northwards), Y (eastwards) and Z (vertical) at all the stations were used for the analysis. The data were subjected to non-cyclic correction prior to further analysis.

RESULTS AND DISCUSSION

Fig. 2 shows the average quiet-day field variations of X, Z and Y for the stations Alibag (ABG), Nagpur (NAG) and Ujjain (UJJ), obtained after combining the months into Lloyd's seasons. Since these three stations are in increasing order of latitude (see Fig. 1), the expected contribution of the external current system at these stations should give a decrease in amplitude in the X variations and an increase in amplitude in the Z variations.

However, it is observed that the amplitudes of the X component are enhanced at NAG, compared with those of the neighbouring stations for all seasons, deviating greatly

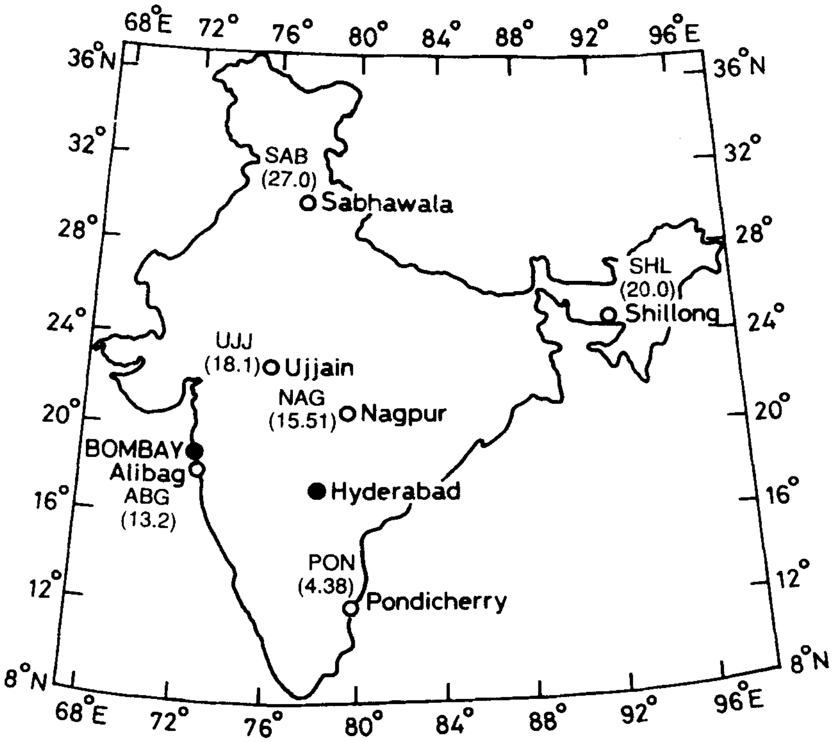

Figure 1. Map showing the geographical locations and codes of the magnetic observatories used in this study. Corresponding dip-latitudes of the stations (in degrees) are given in parantheses.

from the expected latitudinal trend. Also, for all the d- (Nov, Dec, Jan and Feb), e- (Mar, Apr, Sept and Oct) and j- (May, Jun, Jul and Aug) seasons, the amplitudes of the Z variations are smaller at NAG than at ABG and UJJ. For the Y variations, however, the deviations at NAG from those at ABG and UJJ are not significant. The large amplitudes of the X variations and the smaller amplitudes of the Z variations at NAG, compared with those of ABG and UJJ, suggest the presence of a subsurface conductive anomaly in the vicinity of Nagpur. However, the enhanced amplitudes of the Z variations at ABG may, to a large extent, be attributed to the conventional coast effect (Parkinson & Jones 1979). From Fig. 2, it is also seen that the large variations in the X amplitudes for all the seasons at NAG are conspicuous during both day and night times, although the night-time amplitudes are small.

To test the consistency of the anomalous behaviour of the variations at NAG, the seasonal variation patterns at all the stations were examined. Fig. 3 shows the variation of X amplitudes with dip latitude for four selected hours (1000 LT, 1200 LT, 1400 LT and 2000 LT) for three selected months (February, September and July), representative of the d-, e- and j-seasons, respectively. Enhanced X amplitudes at NAG, for all the selected hours and seasons, are evident in Fig. 3.

To quantify the departures of the amplitudes at each station from the best-fit curve of the data, a second-order polynomial was fitted to the observed latitudinal profiles of X amplitudes at the selected hours. The goodness of the fit was found to be better for second-order than for third- and other higher-order polynomials. Figs 4(a) to (d) show the plots of variations of the X amplitudes and their second-order polynomial fits at the selected hours at each of the three seasons. Using the coefficients of the second-order polynomial, the field values that are expected at each station were estimated. The difference between the observed and the estimated values for the selected hours and seasons shows that, at NAG, the magnitude of the difference is almost twice that of the standard deviation. At all other stations, the deviations are well within the magnitude of the standard error. This result suggests that the anomalous characteristics of the variations observed at NAG at all seasons and for all the selected hours are significant.

The observed anomalous features at NAG are probably due to the variations in the electrical conductivity distribution within the Earth. Arora *et al.* (1993), while analysing their magnetovariational (MV) data for central India, proposed a localized high conductivity anomaly to explain the Satpura anomaly in the northeastern part of their array (see Fig. 2 of Arora *et al.* 1993). The presence of a subsurface high-conductivity anomaly, associated with the large-scale basic intrusions in the NW–SE-trending Godavari Graben in the vicinity of Nagpur, is supported by the high heat flow observed (Rao & Rao 1983; Ravi Shanker 1991) and by other geophysical studies such as those of gravity and magnetics (Quereshy 1982; Mishra *et al.* 1987) and deep seismic sounding (Kaila 1986).

The effect of anomalous behaviour at NAG does not influence the electromagnetic (EM) response function determined in estimating the depth of the conductosphere or perfect substitute conductor (Schmucker 1970) beneath the Indian subcontinent, using long-period variations such as the 27-day variation and its harmonics (Chandrasekhar & Arora

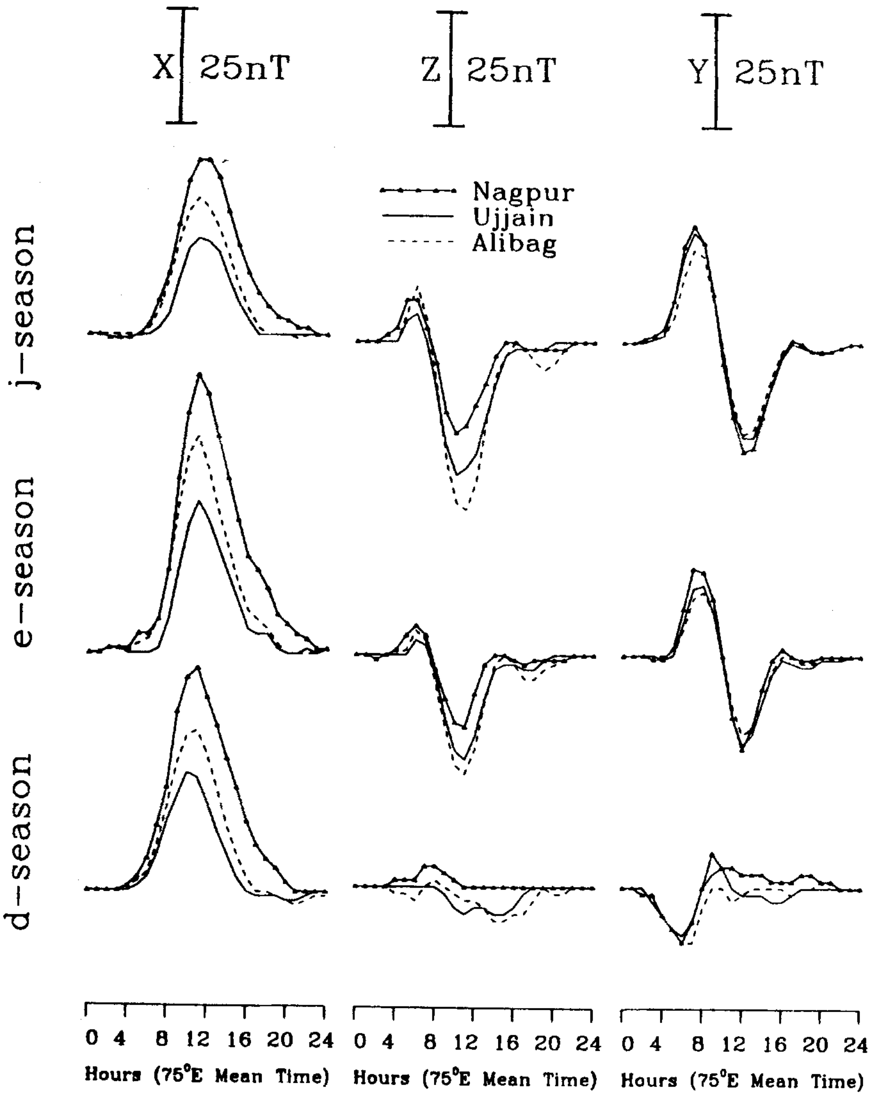

Figure 2. Stacked plots of the average quiet-day geomagnetic field variations for northward (X), vertically downward (Z) and eastward (Y) components, obtained after combining the months into Lloyd's seasons.

1996), recorded at 75°E longitude along the Indo–Russian chain of observatories. Hence, the possibility of an anomalous internal conductive source at large depths at Nagpur can be ruled out.

Since the depths to which the induced currents flow inside the Earth depend upon the frequency of the inducing source, the data were subjected to harmonic analysis to obtain various harmonics (or periods). From these it may therefore be possible to estimate the approximate depth of the anomalous internal source.

Fig. 5 shows the variation of amplitudes of each of the harmonics with dip latitude for all three seasons. From Fig. 5 it is evident that the amplitude of the first harmonic (Fig. 5a) at NAG is large, compared with those of the neighbouring stations. The enhancement in the amplitudes of the second (12 hr period), third (8 hr period) and fourth (6 hr period) harmonics (Figs 5b–d) is also quite significant at NAG. The amplitudes of the second, third and fourth harmonics during the e- and j-seasons at PON are slightly higher than at NAG. The reason for this might be the close proximity of PON to the equatorial electrojet region. This feature is not seen during the d-season. Also, since the anomalous behaviour of the variations, as observed at NAG, is not seen at its adjacent stations, ABG and UJJ, it can be concluded that the anomalous internal causative source is highly localized and concentrated in the vicinity of Nagpur. The presence of anomalous behaviour at Nagpur is conspicuous even in the amplitudes of the fourth harmonic (Fig. 5d). Therefore, it is suggested that the source of the anomalous behaviour of the variations observed at NAG is located at shallow depth. A detailed analysis of shorter-period fluctuations, of the order of a few minutes to a few hours, in order to understand in a more quantitative manner the anomalous characteristics of magnetic field variations at these three stations (ABG, NAG and UJJ), is currently in progress.

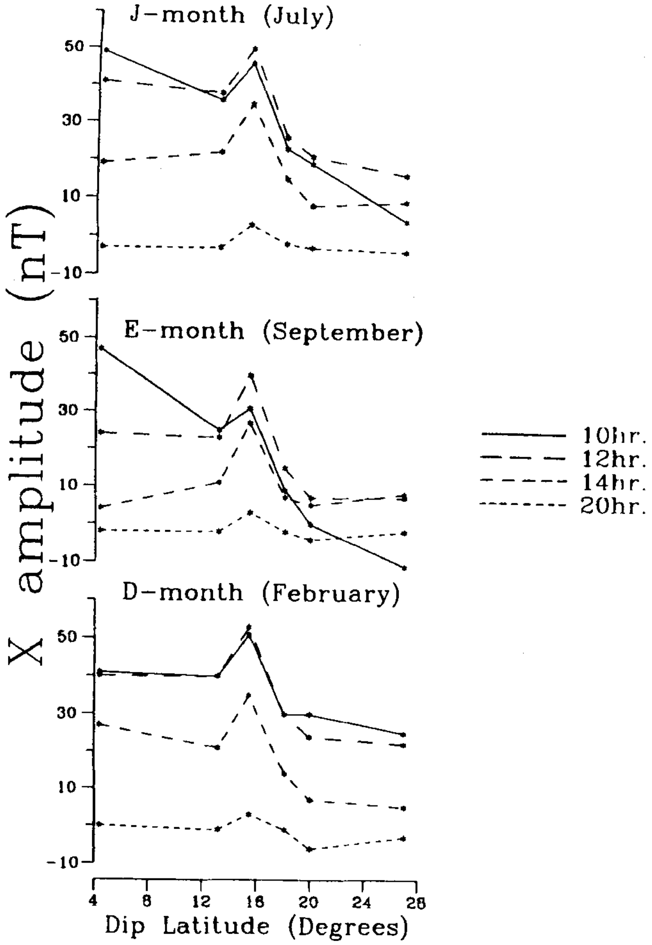

Figure 3. Variations of X amplitude with dip-latitude for four selected hours (1000 LT, 1200 LT, 1400 LT and 2000 LT), representative of morning, afternoon and night, for three selected months (February, September and July), representative of the d-, e- and j-seasons respectively.

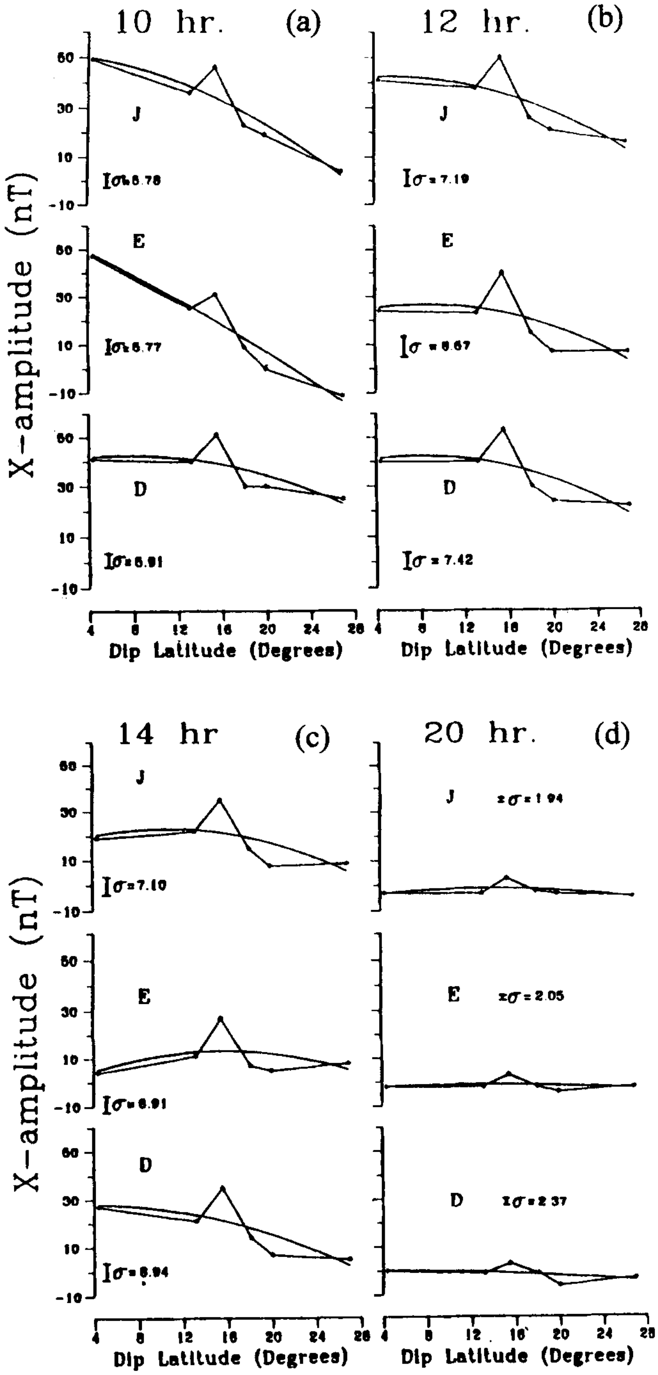

Figure 4. Variations of X amplitudes and their second-order polynomial fit obtained with dip-latitude for (a) 1000 LT, (b) 1200 LT, (c) 1400 LT and (d) 2000 LT. The vertical bars in each of the figures depict the magnitude of the standard deviation (σ). Note that the deviation of the amplitudes from the best-fit curve at the latitude of NAG is almost twice that of the standard error at all the selected hours.

CONCLUSIONS

It is concluded that the diurnal variations at Nagpur are anomalous even at the period of 6 hr (fourth harmonic). The anomalous behaviour is also observed to be independent of the strong seasonal variability of Sq prevailing over the Indian region. Also, since such behaviour is not observed at ABG and UJJ, which are situated close to NAG, the suspected anomalous internal source is believed to be highly localized and located near the surface, in the vicinity of Nagpur.

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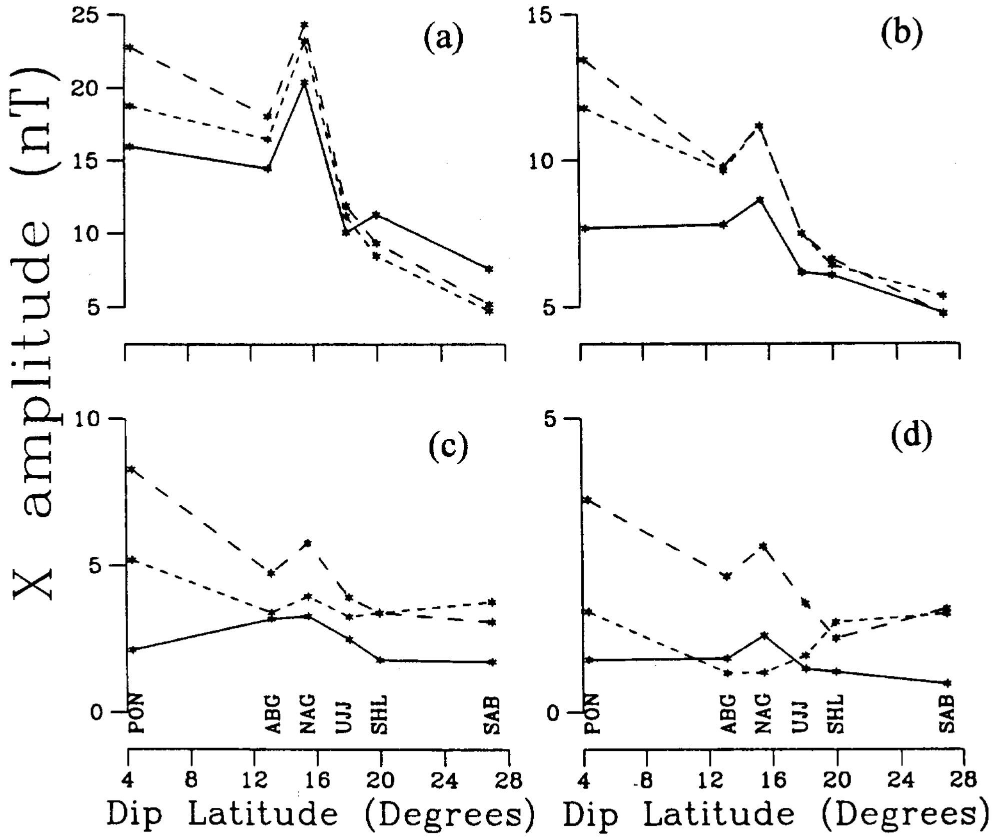

Figure 5. Variations of (a) first, (b) second, (c) third and (d) fourth harmonic amplitudes of X with dip-latitude for d- (solid line), e- (long-dashed line) and j- (short-dashed line) seasons.

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