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Rapid decrease in total magnetic field intensity at Indian Antarctic Station Maitri

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ABSTRACT
Studies of total magnetic field intensity (F) at the location of the Indian Antarctic Station Maitri reveal a rapid decline over the past eight decades, the rate of decline amounting to more than 100 nT/year. Since this far exceeds the decrease in the Gauss coefficient g^o_1, which is proportional to the axial dipole moment and is only about 19 nT/year for this century (Gubbins 1987), this study is significant for understanding the global secular variation pattern. In this paper, we discuss the significance of this rapid decline in F at Maitri and nearby Antarctic stations and emphasize the importance of geomagnetic measurements at Antarctica.

INTRODUCTION

Secular variation refers to the variation of the Earth's magnetic field over a long period (typically ranging from few years through decades to centuries). There exists a variation in all the components, X, Y, Z, H, F, I and D and this variation is attributed amongst several other causes to changes occurring in the liquid core of the Earth. Secular variation is believed possibly be due to one of the following causes :

Slippage between the rotation of the core and mantle. This may lead to the westward movement of the secular variation features. This theory also requires an electromagnetic coupling between core and mantle to be taken into consideration (Bullard et al., 1950).

Topography of the core-mantle boundary (CMB), viz., presence of 'bumps' at the CMB may affect mantle convection and thus contribute to secular variation (Hide 1966).

Free hydromagnetic oscillations of the core may be the cause of observed secular variation features (Hide 1966).

Temperature anomalies in the mantle which drive geomagnetic secular variation (Bloxham & Gubbins 1987). Development of hotspots in the mantle could lead to changes in surface observations since they result in flux expulsion through increased upwelling of fluid flow beneath them.

Chapman (1951) studied global secular variation in total field intensity and found a rapid decrease in F at regions beyond 30° S latitude for the period 1940-1945. Nagata (1961) studied the secular variation in the Z-component at Antarctica and found it to be remarkably large with the field showing a decrease amounting to 180nT/yr at Syowa station. Also, Nagata (1982) found the geomagnetic dipole shifting northwards at about 2km/yr from 1960 to 1980 and suggested this could be a cause of the decrease in F in the Antarctic region.

In this paper we study the behaviour of the total field intensity F at the Indian Antarctic station Maitri. The measurements of F at the Indian Antarctic station Maitri in 1996 and earlier at Dakshin Gangotri (DG), the first Indian Antarctic station, in 1982 and 1986 was what initially made us take notice of the large decrease in F at these locations. The two stations are separated by a distance of about 75 km.

OBSERVATIONS

Fig.1 shows the contours of rate of change of Z-component of the field in the southern hemisphere for the period 1955-1960 (Nagata 1962). The rate of variation is seen to reach 200 nT/yr around the pole. Since the Z-component in this region is negative and also since Z is the main contributor to F at the poles, an increase in Z would correspond to a decrease in F.

The drop in secular variation at the location of the Indian Antarctic station Maitri as shown in figure 2 is quite steep, particularly after 1950. The sources of the values used for the plot is given in the figure with three of them being actual observations at Maitri and DG. As mentioned earlier, this was the starting point of our study. A few words about how the curve in Fig.2 was obtained may not be out of place. When our 1996 observations of F at Maitri by proton precession magnetometer showed a value much less than those obtained in 1982 and 1986, we decided to check it against the IGRF (1995) chart for F. We found the two to tally well. We then decided to use this method to go back in time and read off values of F at the location of Maitri from world magnetic charts for 1922, 1945 and 1955. The result showing a drop of ~ 9000 nT in F over 75 years was a startling one, and this is what made us aware of a possible large annual decline of ~ 120 nT/yr in the Antarctic region. Our doubts assumed reality when we found a report by

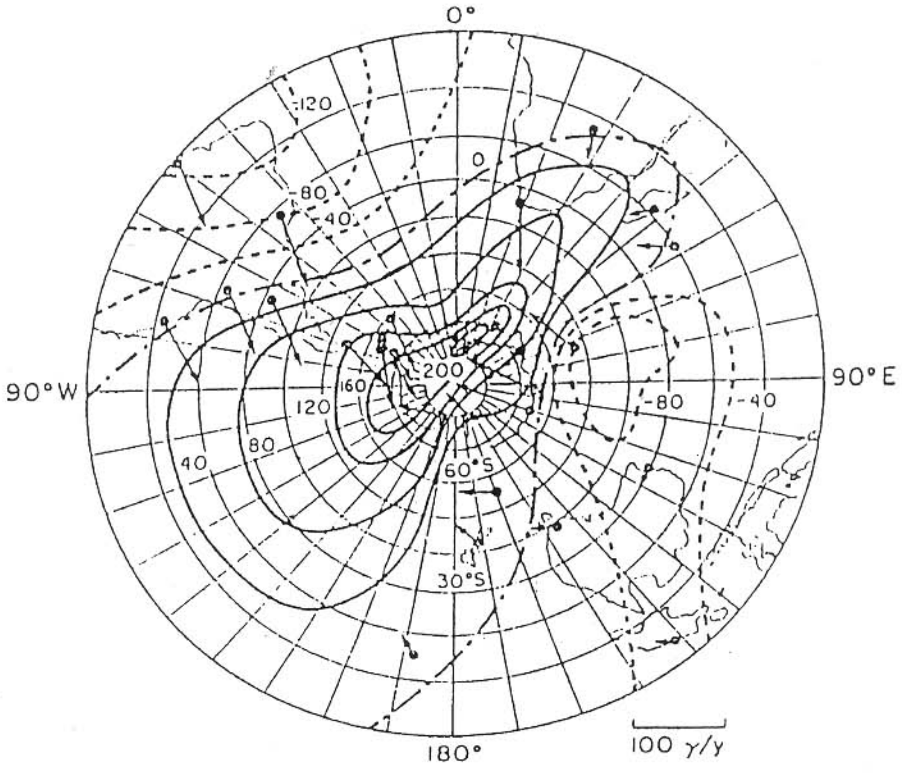

Figure 1. Contours of annual rate of variation for the Z-component of the geomagnetic field in the southern hemisphere for the period (1955-1960) in geographic coordinates. Full contours denote positive values and dashed conours represent negative values. Parallels of latitude 0° to 90° are shown. The observation points are shown by full circles and arrows represent the rate of H-component variation (From Nagata 1962).

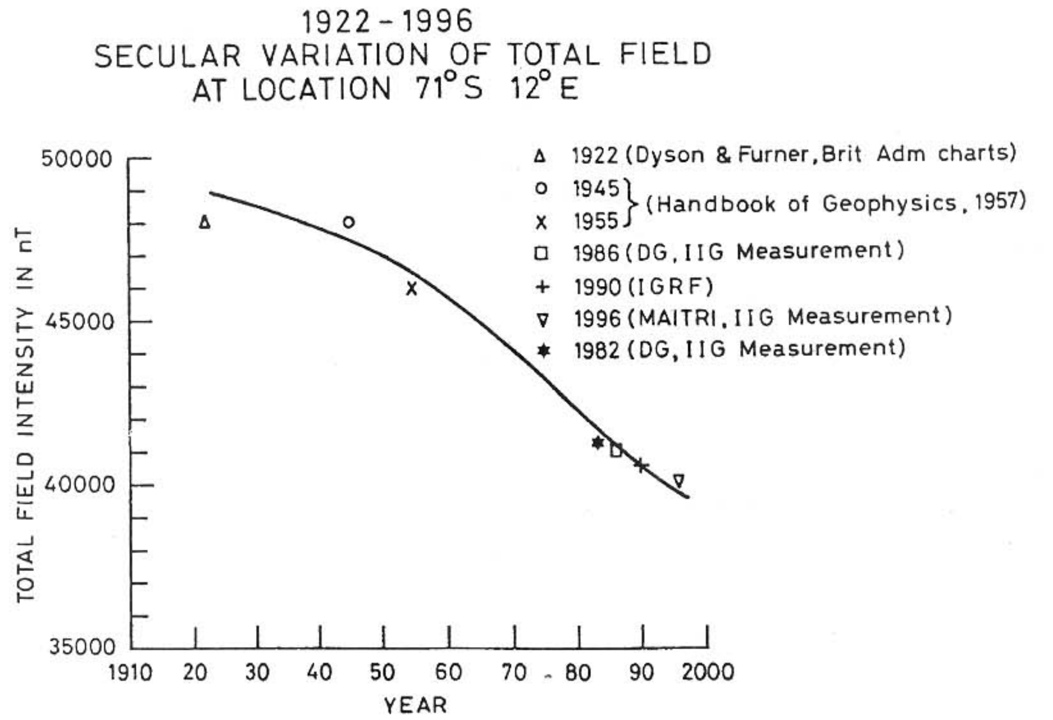

Figure 2. Variation of total field intensity F at the location of 71° S, 12° E. Maitri, the present Indian Antarctic station is at 70° 45'S, 11° 45'E and the older station Dakshin Gangotri is at 70° 05'S, 12° 00'E. Since the stations were set up recently, the earlier values of F at the location were obtained from different sources as indicated.

Bormann et al., (1995), stating that the Russian station Novolazarevskaya (located ~ 10 km away from Maitri) had over 1960-1990 observed a decline of ~116 nT/yr. The same report stated that the German station Georg Forster (also located some 10 km away from Maitri) showed a drop of about 100 nT per year over 1982-1989. The secular variation in F at these two stations are shown in Fig.3(a) and Fig.3(b) (from Bormann et al., 1995). The F values in the Fig.3(a) from 1983 to 1989 are derived from measurements made at Georg Forster station. The steep decline in F is evident in the plots. The secular variation in F at selected stations worldwide is shown in Fig.4. For Maitri, the data used is the same as for Fig.2 and for the other stations the observed annual means have been used. We find that southern hemisphere stations tend to show a drop whereas the northern hemisphere stations seem to show an increasing or a stable trend. In order to check whether the northern hemisphere area conjugate to Maitri show any rapid decline in F, it was decided to examine data at the near-conjugate locations, Leirvogur and Narsarsuaq. These are shown in Fig.5 but they do not show any rapid drop in F akin to Maitri.

It is interesting to note that when polar views of the total intensity contours of F for the northern and southern hemispheres are compared they show markedly outstanding differences. This is shown in Fig.6 from WDC Data Catalogue No. 23, Japan (1993). The northern hemisphere shows two foci as against only one in the southern hemisphere. Thus the behaviour of F in the high-latitudes of the two hemispheres seems different in these plots. Also the gradient in the southern hemisphere high latitudes is much sharper than in the northern hemisphere as evidenced by the closeness of the contour lines.

The Gauss coefficient g^{o}_{1}, which gives the axial dipole moment, shows a decrease throughout the current century (Fig.7, from Gubbins 1987). The annual rate of decrease of this Gauss coefficient for the second half of this century amounts to about 20 nT. This axial dipole moment is the major contributor to the total dipole moment and is far less than the annual rate of decline of ~ 100 nT seen at Maitri and neighbouring Antarctic stations over the last few decades.

The rate of change of magnetic field with time at the core-mantle boundary in the northern and southern hemispheres are shown in Figs 8(a) and 8(b) respectively (Gubbins 1987). The component plotted is the time variation of ZcosT, where Z is the downward vertical component and T is the colatitude. The negative variation features (dashed contours) are concentrated at regions where the reverse flux regions are located in the southern hemisphere and the northern hemisphere is bereft of any such feature. Regions where the radial magnetic field direction is opposite to that expected for the current dipole are known as reverse magnetic flux (RMF) features. These reverse flux features have been observed to be concentrated over much of the Antarctic continent and adjoining areas.

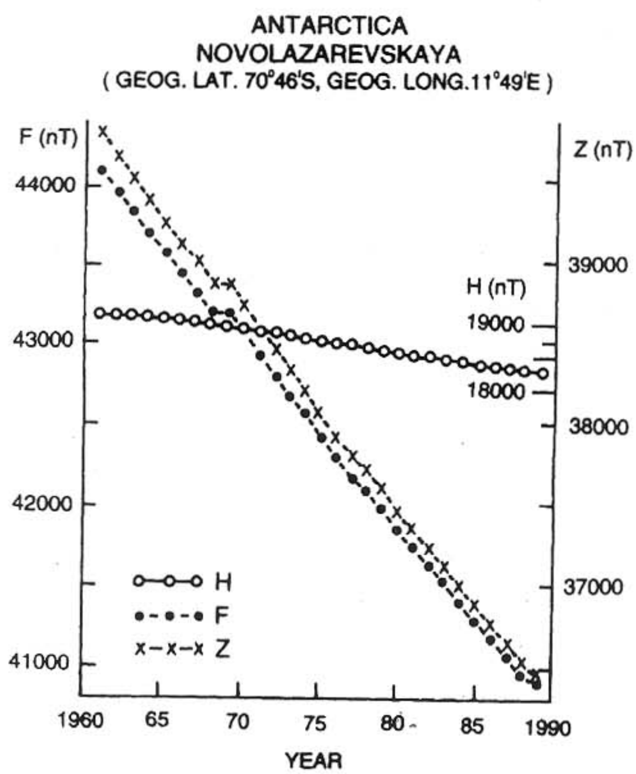

Figure 3(a). Variation of F at Novolazarevskaya which is about 10 km from Maitri. The observations for the years 1983-1989 were derived from observations at Georg Forster station (from Bormann et al., 1995).

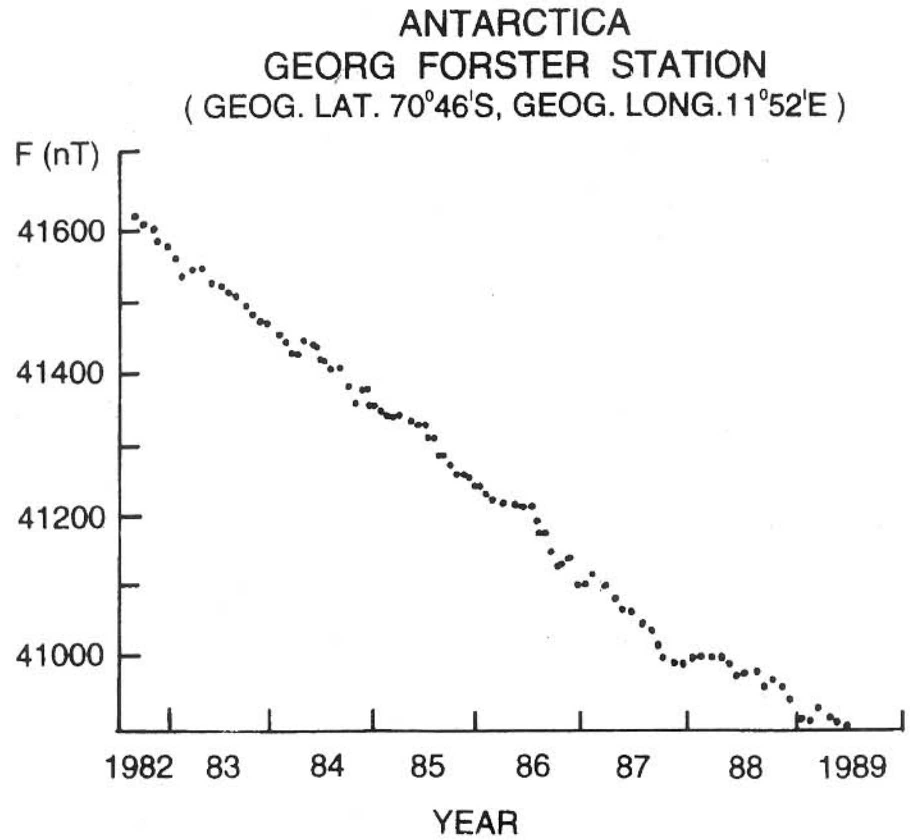

Figure 3(b). Monthly mean values of total field F at Georg Forster station (after Bormann et al. 1995).

DISCUSSION

It is indeed significant that observations of decrease in F at Maitri support the modelling studies of Gubbins (1987) postulating the presence of reverse magnetic flux (RMF) region's near the location of Maitri. Gubbins studied the formation of these regions at the core-mantle boundary and suggested that these formed near Indonesia and drifted westwards to intensify at the location of South America by the process of toroidal flux expulsion. His results for epoch 1945 showed the presence of two reverse flux regions in the southern hemisphere and from core-field maps for different epochs he noted the merging of the two regions in 1980. The time variation of these features for epoch 1945 are shown in Fig.8. In 1987 one of these features was located beneath South Africa and the other beneath South America. The growth in intensity of these reverse flux regions mirror the decay of the dipole moment since the component ZcosT and the Gauss coefficient g^{o}_{1} are mathematically related.

There have been other explanations offered for this large decline in F. Nagata (1965), for example, suggested that the decrease in F at Antarctica was the combined effect of the two factors, the decrease in the dipole moment of the Earth and the northward motion of the geomagnetic dipole. He found the effect of the northward shift to be dominant. He also found an increasing F trend in the northern hemisphere polar regions and suggested that this was due to the effect of the dipole intensity decrease being amply compensated by the northward motion of the dipole.

The difference in the behaviour of F at the high latitudes in the two hemispheres was also brought out by Smith's (1967) results from a study of the intensity of the geomagnetic field for epoch 1945. He calculated the mean F at different latitudes in the two hemispheres by averaging the fields at intervals of 10° longitude for epoch 1945. Smith's table indicated different patterns in the northern and southern hemispheres. The mean F at latitudes above 70° S were greater than those at corresponding northern hemisphere latitudes whereas for lower latitudes the opposite was the case. Thus the field behaviour at the high latitudes seems markedly different from that at the low latitudes in each of the hemispheres. Also, the standard deviation of F at southern hemisphere stations were about twice the values at the corresponding latitudes in the northern hemisphere, implying that the southern hemisphere has a larger gradient. McElhinny & Senanayake (1982) interpret Smith's results as reflecting the hemispheric asymmetry of the non-dipole field.

A look (Fig.6) at the contours of geomagnetic elements for the year 1990.0 based on the IGRF 90 (WDC Data catalogue No. 23, 1993) model confirms the difference in the field behaviour in the two hemispheres and also supports

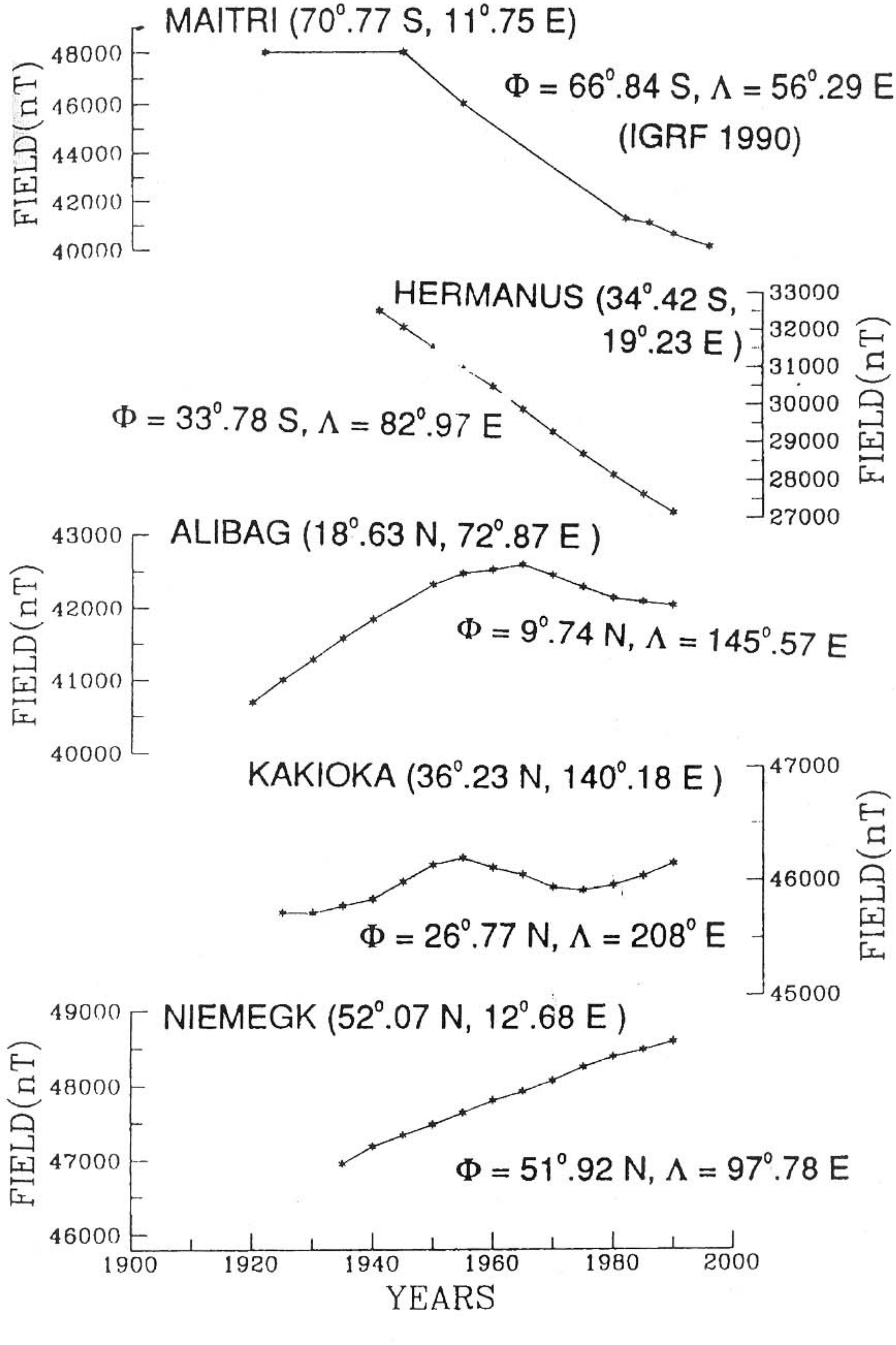

Figure 4. Variations in F at selected locations in northern and southern hemispheres. Note the fairly steep decrease at southern hemispheric stations (Maitri and Hermanus) compared to those in the northern hemisphere (Alibag, Kakioka and Niemegk).

the above-mentioned point about the southern hemisphere having a steeper gradient. As mentioned in the previous section the F contours, in particular, suggest the presence of a single focus in the southern hemisphere corresponding to a single pole whereas the northern hemisphere has two foci resembling the patterns due to two poles.

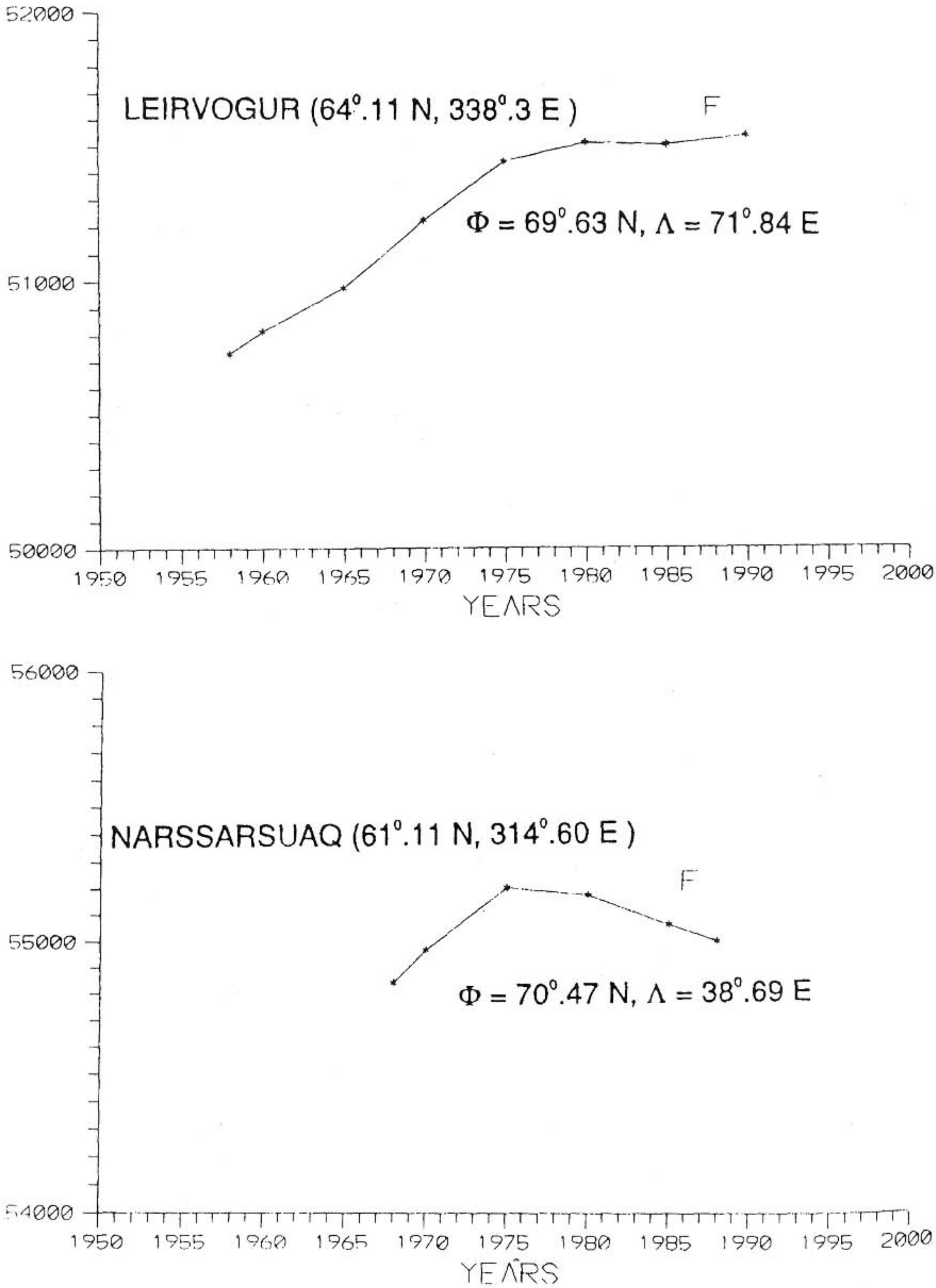

Figure 5. Variations in F (in nT) at northern hemisphere high latitude stations, Leirvogur and Narssarsuaq. These two stations are near conjugate to the Indian Antarctic station Maitri. The trend shown by these stations is a gradually varying one of little change in F compared to the steep variation at Maitri.

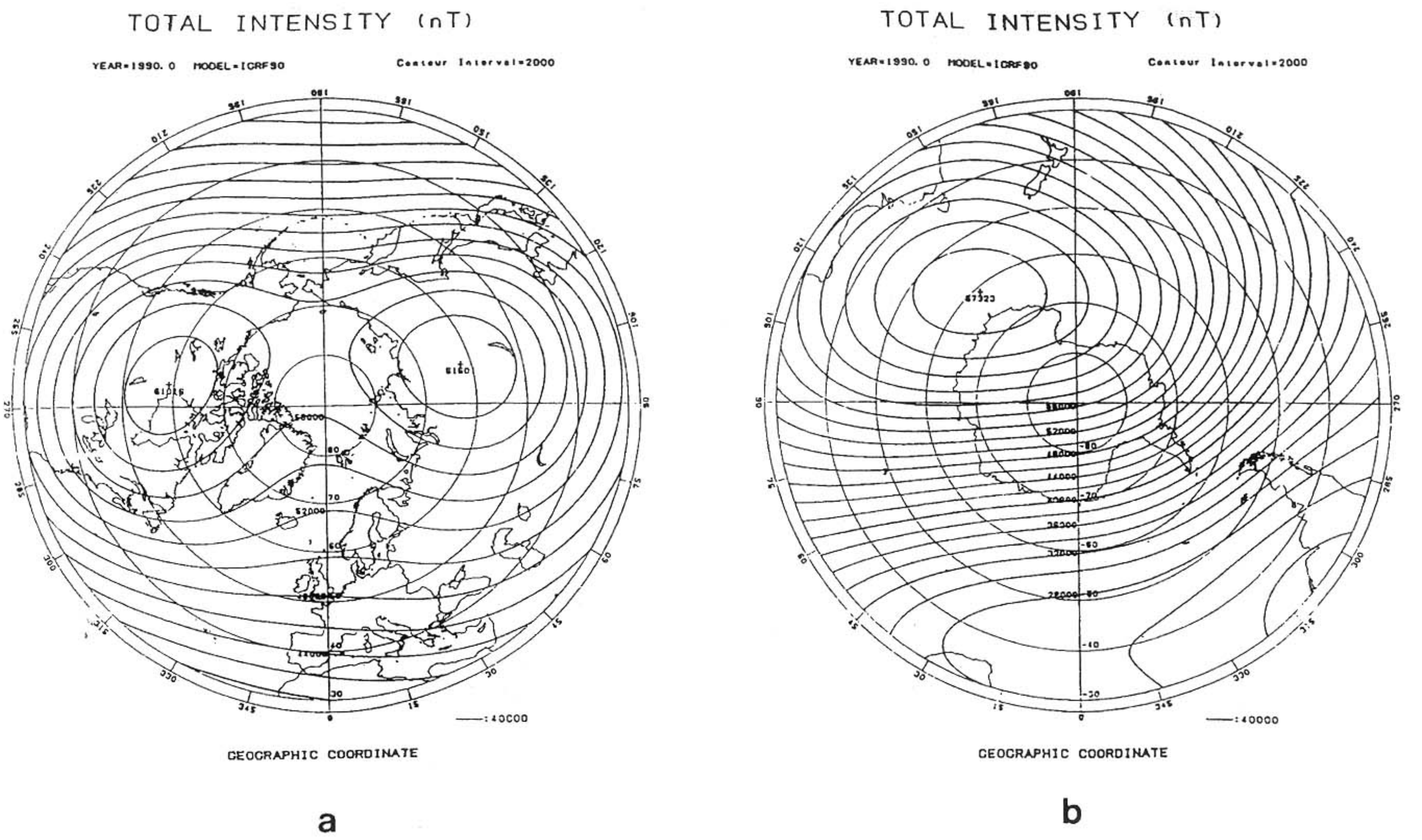

Figure 6. Contour plots of F in the northern (a) and southern (b) hemispheres using IGRF90 model. The two hemispheres seem entirely different (from WDC Data Catalogue No. 23, 1993).

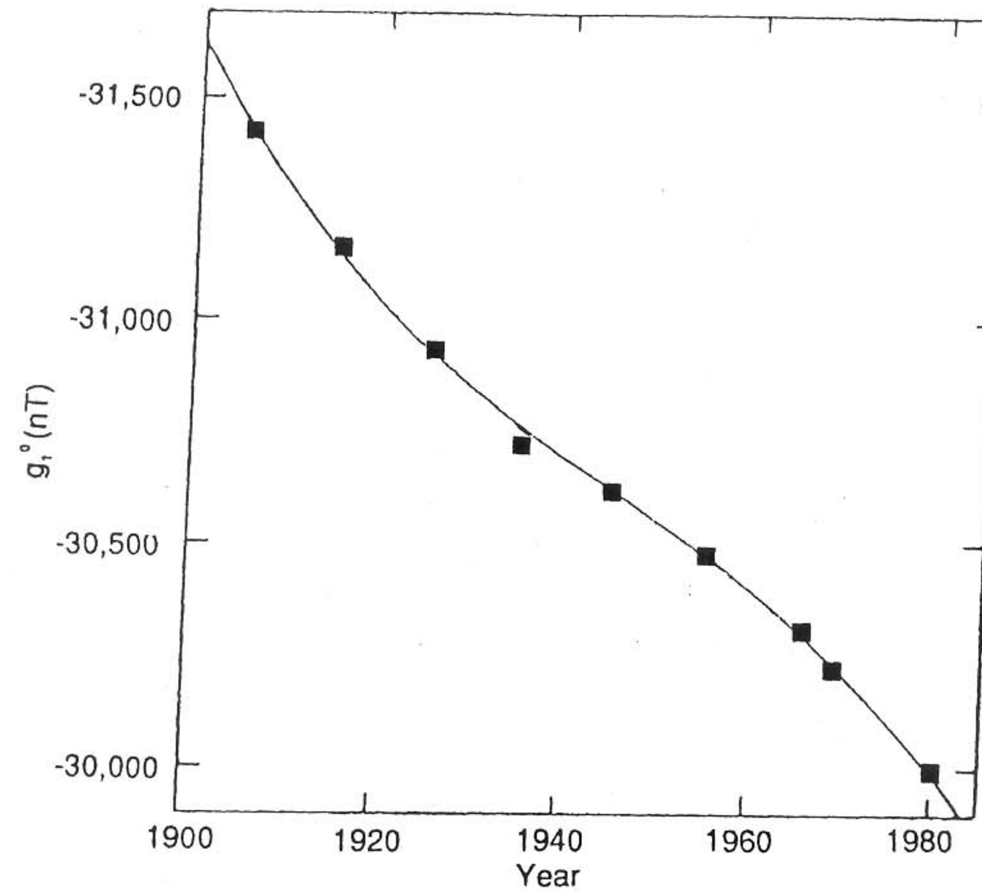

Figure 7. Decreasing trend shown by the Gauss coefficient for the current century. This being proportional to the axial dipole moment, it also reflects the decrease in the dipole moment of the Earth averaging to about 19nT/yr (From Gubbins 1987).

CONCLUSIONS

Understanding the behaviour of the dipole field is important for understanding the polarity reversals of the Earth. In fact, the present decrease in the dipole field which started about 2000 years ago (McElhinny & Senanayake 1982) might well be part of an excursion which might subsequently lead to a change in polarity of the Earth's magnetic field. Gubbins (1987) states that the increase in intensity of the two regions of reverse flux, one over South America and the other near South Africa, is directly related to the frequency of reversals in geomagnetic polarity in the recent past. Hence monitoring of the field at Antarctic regions is particularly important to understand both the dipole field as well as the non-dipole field, the latter of which is responsible for drifting features (e.g. the reverse flux features).

The decrease at Maitri does indeed seem to originate in the toroidal field. If the poloidal field were to be involved, then the decrease should be observed in the northern hemisphere stations also. But, clearly from figure 5 which shows F at northern hemisphere stations near conjugate to Maitri, this is not the case.

Since obtaining the results reported in this paper, we have made a study of the annual rate of decline in F at a large number of Antarctic and sub-Antarctic stations located between 30° S and 90° S. The results suggest that the majority of them suffer a very large decline in F in keeping with the results of Gubbins (1987) as shown in Fig.8. We shall be presenting this work of ours in a forthcoming paper.

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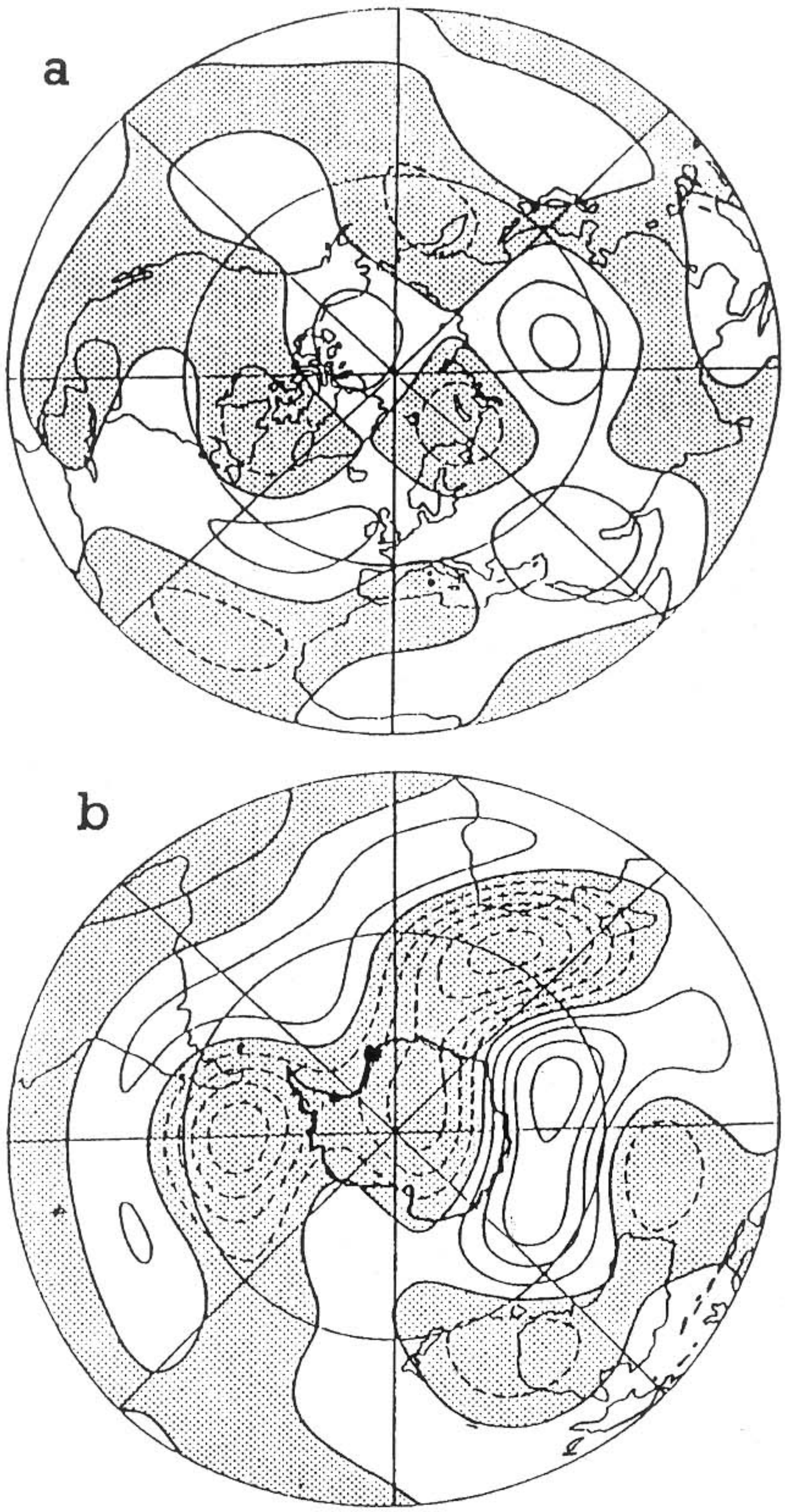

Figure 8. Contours showing the rate of change of magnetic field with time at the core-mantle boundary (CMB) for epoch 1945 for the northern (a) and southern (b) hemispheres. Component plotted is the time rate of change of ZcosT at the CMB where Z is the downward vertical component of the magnetic field and T is colatitude. Contour interval is 1μT/yr. Dotted contours represent negative variation which contribute to the decrease in dipole moment of the Earth since the quantity ZcosT is directly related to the gauss coefficient (From Gubbins 1987).

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