Indian Journal of Geosciences, Volume 63, No. 2
April - June, 2009; pp. 187-194

Declining magnetic field at Maitri, Antarctica

B. M. Pathan, Ajay Dhar*, R. L. Asinker, R. Selvamurugan and Arun N. Hanchinal

Indian Institute of Geomagnetism, New Panvel, Navi Mumbai - 410 218, India.
** Corresponding author. E-mail: ajaydhar56@gmail.com*

Abstract: The Earth's magnetic field is due to huge electric current circulating in the core of the Earth. Geomagnetic field is mostly dipolar in nature although multi poles also have some contribution. However, the main complication lies in the fact that there are a multitude of extraneous sources, which produce distortions in the magnetic field. As a consequence, the Earth's magnetic field is very complex which protects the Earth's surface and its inhabitants from hazardous cosmic radiation (energetic protons) received from the Sun. It is known that the Earth's magnetic field is decaying faster than any other worldwide geophysical phenomenon. This reported decrease is a major concern for the human kind. Will this continuous decrease lead to zero magnetic field sometimes in future? If so, how life on this planet will be affected? It is seen that the decline is mostly in the dipolar contribution. The decrease in magnetic field is not uniform all over the globe. It is reported that the geomagnetic field is declining in the Southern Hemisphere while in the Northern Hemisphere it is more or less steady or at a small increase. In the Southern Hemisphere too, the decrease is higher at certain locations. Indian Antarctic station, Maitri (Geog. 70.75° S, 11.75° E), is one such location recording a sharp decrease. Indian Institute of Geomagnetism is taking part in the annual Indian expeditions to Antarctica since its inception in 1981-82. A Proton Precession Magnetometer (PPM) is used to monitor the total magnetic field (F). It is seen that the magnetic field at Maitri has decreased by more than 2000 nT in the last 20 years. Geomagnetic field model reveals that the rate of decrease in the magnetic field at Maitri during the last century is about 105 nT/year. Maximum rate of decrease of about 120 nT/year is seen further north of this station. This result is discussed in terms of change of magnetic pole position, magnetic dipole moment and magnetic energy. It is seen that the decrease of energy in the dipole part has been, almost completely balanced by a corresponding increase in the energy of the non-dipole field. As a net result the energy of the total observed field measured all over the globe has remained almost constant. However, the magnetic moment has been found to change more rapidly at locations close to magnetic poles. Hence, the importance of continuous monitoring of total magnetic field at Maitri is emphasised.

Keywords: Geomagnetic field, Dakshin Gangotri, Maitri, Antarctica, Southern Hemisphere, Northern Hemisphere

Introduction

The geomagnetic field is an ever-changing phenomenon, influencing human activity and natural world in numerous ways. This field changes from place to place, on time scales ranging from seconds to decades, to hundreds of years. The geomagnetic field and its associated phenomena can both assist and degrade navigation and surveying techniques, impede geophysical exploration, disrupt electric power supply utilities and pipeline operations and influence modern communications systems, spacecrafts etc. It also protects the Earth from cosmic rays (the high-energy particles coming from outer galaxy) and also acts like a barrier to the solar wind, the ionised gas or plasma flowing out of the Sun.

The Earth acts like a huge spherical magnet, surrounded by its magnetic field. This magnetic field resembles in general to the field generated by a dipole magnet, located at the centre of the Earth. At any point, the Earth's magnetic field is characterised by a direction and intensity, which can be measured. However, this magnetic field is different in different places. The magnetic field changes with both location and time. The changes are so irregular that they need to be measured at many places to obtain a satisfactory picture of its distribution.

The geomagnetic field measured at the Earth's surface is generated by various sources, both internal and external to the Earth, superimposed on and interacting with each other. More than 90% of the field is generated internally in the Earth's outer core. This portion referred to as Main Field varies slowly in time and can be described by various mathematical models. The Main Field creates a cavity in interplanetary space called the magnetosphere, where the Earth's magnetic field dominates. The magnetosphere deflects the flow of most of the solar wind particles around the Earth while the geomagnetic field lines guide charged particle motion within the magnetosphere. The differential flow of ions and electrons inside the magnetosphere and in the ionosphere form current systems, which cause variations in the intensity of the Earth's magnetic field. These external currents in the ionised upper atmosphere and magnetosphere vary on a much shorter time scale than the internal Main Field and may create magnetic changes as large as 10% of the Main Field.

The Earth's magnetic field is changing slowly over centuries. It is possible to reconstruct the history of the Earth's magnetic field over the last 160 million years or so by rock sampling and using radiometric dating techniques. The picture emerging from the paleomagnetic records shows the Earth's magnetic field strengthening, weakening and often changing polarity in a periodic manner. The global secular variation in total field intensity studies showed rapid decrease in F at regions beyond 30° S latitude for the period 1940-45 (Chapman, 1951). The studies have shown that secular variations in Z component at Antarctica were remarkably large with the field showing a decrease amounting to 180 nT/yr at Syowa Station (Nagata, 1961). He also found the geomagnetic dipole shifting northwards at about 2 km/yr from 1960 to 1980 and suggested this to be a cause of the decrease in F in the Antarctic region (Nagata, 1982). Arun et al. (2000) suggested the decrease to originate in the toroidal field as the decrease is observed in southern hemisphere only. It should be observed in northern hemisphere stations also if the poloidal fields were also involved. Yoshida and Hamano (1993) investigating westward drift suggested the cause to be due to forced magnetohydrodynamic waves. Humphreys (1990) explained the physical mechanism for reversal of the Earth's magnetic field by employing the principles of magnetohydrodynamics, to the electrically conductive fluid in the molten core of the Earth, in connection with heat and convection there.

The location of Indian Antarctic Station, Maitri (70.75° S, 11.75° E) has shown a drop of nearly 9000 nT in total magnetic field intensity in the last 75 years, and is still dropping at 110-120 nT/yr. The purpose of this work is to plot the IGRF values of total F intensity around Maitri, and try to locate the area where the decrease is maximum. The observations from the nearby stations of Georg Foster (~100 nT/yr) and Novolazarevskaya (~116 nT/yr) over the last few decades are comparable with that of Maitri (Bormann et al., 1995).

Instrumentation

A Proton Precession Magnetometer (PPM) was specially designed and fabricated at Indian Institute of Geomagnetism for operation in low-temperature environment round the clock, for measurement of total intensity of the Earth's magnetic field (F) at Maitri, Antarctica. The PPM works on magnetic resonance-related property of protons. A low-freezing point liquid Hexane is used as fluid in the sensor. The PPM works on the principle that the frequency of the precession of protons is directly proportional to the Earth's magnetic field. When a current is passed through the sensor, the precessing protons are forced to align their spin momenta along the direction of the field. When the current is withdrawn, the protons experience a torque and start precessing about the direction of Earth's ambient magnetic field. As they precess, an induced EMF is generated in the coil, which is amplified to give an output signal of a few volts. This PPM has an operating range of 25,000 to 60,000 nT and sensitivity of 0.1 nT for the entire range. The sampling rate can be adjusted from 10 sec to 150 sec and the instrument works on a DC supply of 12 V/1.5 Amp.

Observations

The observations of Total Field F were started during the very first Indian Antarctic Expedition in 1981. The observations were carried out for a short duration of 3 weeks at Dakshin Gangotri. The observations were repeated at Dakshin Gangotri during 1982, 1986 and 1987. With the shifting of Indian Antarctic Station to Maitri, nearly 70 km away, south of Dakshin Gangotri, the observations were repeated at that location from 1996 onwards. The observations are taken on a continuous basis at 10 sec sampling interval. However, the annual mean values are considered from the observations taken during low or quiet magnetic activity days, typically with Kp (3-hourly magnetic activity index) of 1_- to 1_+.

Figure 1 shows the variations in Earth's magnetic field intensity at various locations in the Northern and Southern Hemisphere. The top left bracket (I) shows the variations at two northern stations Leirvogur and Narsarsuaq. The field at Leirvogur has increased by nearly 900 nT in the last 65 years and is more or less constant now, while the Narsarsuaq station is showing a variation of nearly 500 nT in the last 35 years. The field strength increased at this station in the first 10 years (1967-1977) and is showing a decreasing trend now (roughly 20 nT/yr). The right bracket (II) shows the variation at some of the Southern Hemisphere stations. The total field at Novolazarevskaya (II) is decreasing by ~116 nT /yr and at Georg Foster (III) by ~100 nT/yr (Bormann et al., 1995). The Novolazarevskaya station and Georg Foster station (now closed) are roughly 6 km away from Maitri Station. The drop in total magnetic field intensity (F) shown by other stations is as follows : Hermanus- 105 nT/yr, Argentine Island - 103nT/yr, Syowa – 94 nT/yr, Mawson – 72 nT/yr and Dumont d'Urville – 33 nT/yr.

Figure 2 shows the declining magnetic field intensity (F) at the location of Maitri (70.75° S, 11.75° E) for the last 100 years obtained from IGRF and superimposed with the actual observations taken from time to time in the lower bracket. The upper bracket shows the plot of F values at the location of Alibag (India), a low latitude station, obtained from IGRF model, which is showing a slight increase. The drop in F values at the location of Maitri is quite steep, particularly after 1950. The observations show a drop of ~9000 nT in the last 80 years i.e. ~120 nT/yr. The observations from the Northern Hemisphere stations do not show any rapid drop in F values as shown by Maitri, over the past five decades, suggesting that this decline is confined to Southern Hemisphere only. While examining the F values over most of the stations operating in Southern Hemisphere

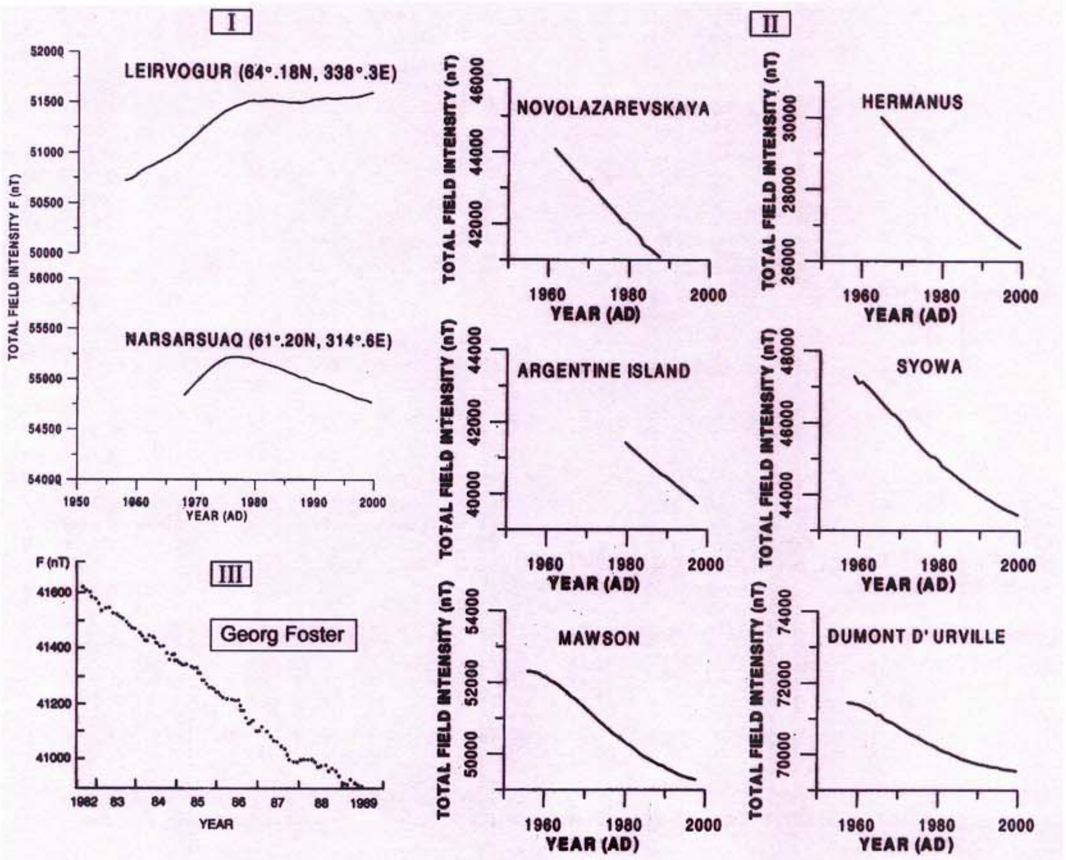

Fig. 1. Plots of F at various northern and southern stations. The bracket-I shows the F plots at two northern station Leirvogur and Narsarsuaq. Bracket-II show the plots at Novolazarevskaya, Hermanus, Argentine Island, Syowa, Mawson and Dumont d'Urville. Bracket-III shows the F plots at Georg Foster station (station closed) (from Rajaram et al., 2002).

over the past five decades or so show varying degree of decline. The F data for these stations was received from the website (www.nmh.ac.uk/gifs/annual_means) of the British Geological Survey. The geographic and geomagnetic coordinates, along with other relevant data is listed in Table 1.

Figure 3 shows the contours of rate of average decrease in F in nT/yr, over the past five decades for Antarctic and sub-Antarctic stations between 30° and 90° S in geographic and geomagnetic coordinates. The locations of the stations considered are shown using star symbols. The stations and their details are listed in Table 1. The contours are better distributed in geomagnetic coordinates, covering a wider area compared to their depiction in geographic coordinates (Rajaram et al., 2002).

Figure 4 shows the variation in different components Z (vertical), Y (easterly) and H (northerly) at the location of Maitri. The Z component is showing a drop of ~12000 nT in the last century, while a very little variation is observed in Y and H components. In higher latitudes, Z component being the dominant component, maximum decline in F will be reflected

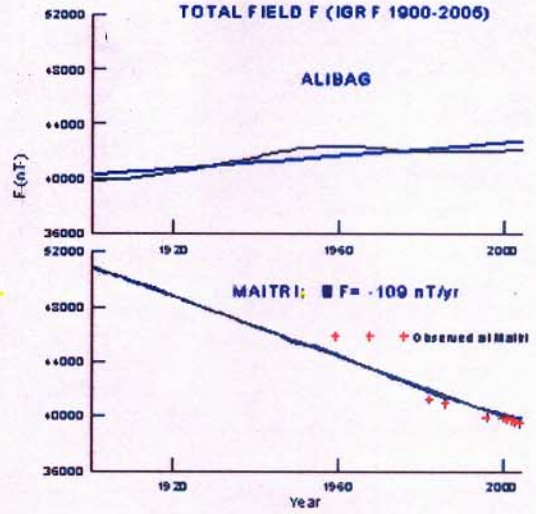

Fig. 2. Plots of F values for the location of Alibag (India) and Maitri (Antarctica) obtained from IGRF model, superimposed with actual observations. While the total field F is increasing at Alibag it is decreasing at a very fast rate at Maitri.

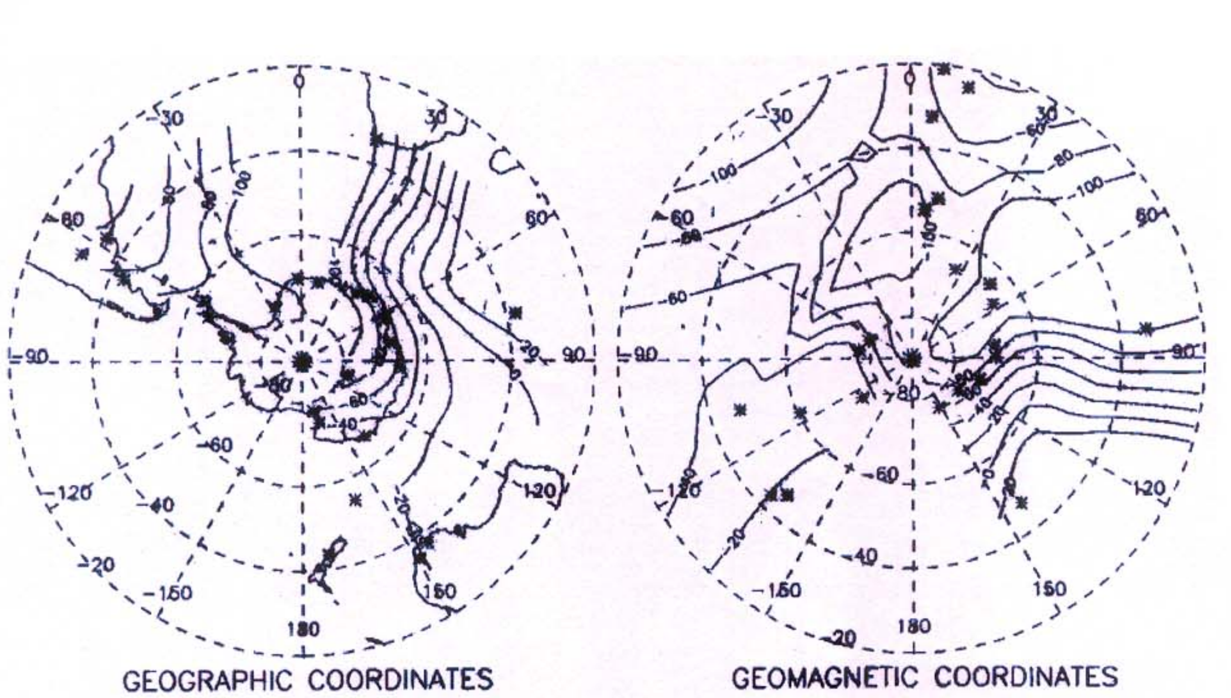

Fig. 3. Contours of rate of average decrease in F in nT/yr, over the past five decades (1950-1999) for Antarctic and sub-Antarctic stations between 30-90° S in geographic and geomagnetic coordinates (from Rajaram et al., 2002).

in this component. Bormann et al. (1995) reported similar results from the magnetic variations data recorded at Novolazarevskaya and Georg Foster stations. While the decline in magnetic field is being observed in the Southern Hemisphere, it is the total field or one of the components showing the decrease. The three northerly components of the magnetic field Z (vertical), H (horizontal) and Y (easterly) were plotted to see which component is showing the maximum decline.

Figure 5 shows the variation of total field F at every 15° latitude along 11°E longitude in the Northern Hemisphere. While at most of the places the F variation is of the order of ~20 nT/yr in the increasing order, it is showing a large variation at the location of Magnetic Pole. The total field F dropped ~1000 nT between 1900 and 1940 and increased by almost the same amount in the next 40 years (1940-1980), after which it has dropped by ~500 nT in the 15 years (1980-1995) that followed. The field is more or less steady over the last 15 years at this location.

Figure 6 shows the plots of total field F obtained from IGRF for Southern Hemisphere at increments of 15° latitude, along 11°E longitude in the Sourthern Hemisphere. It is clear that the field is declining fast at most of the places between 45° and 75°S latitude. To know where exactly the decline is maximum around Maitri, total field values of F were calculated from IGRF for every 5° latitude and longitude around Maitri. It is clear that the maximum decline is observed between 60° and 75°S latitude, where the magnetic field is declining at more than 110 nT/yr. Figure 6 shows that the decline is maximum around the location of 65°S, where the field is declining at ~120 nT/yr.

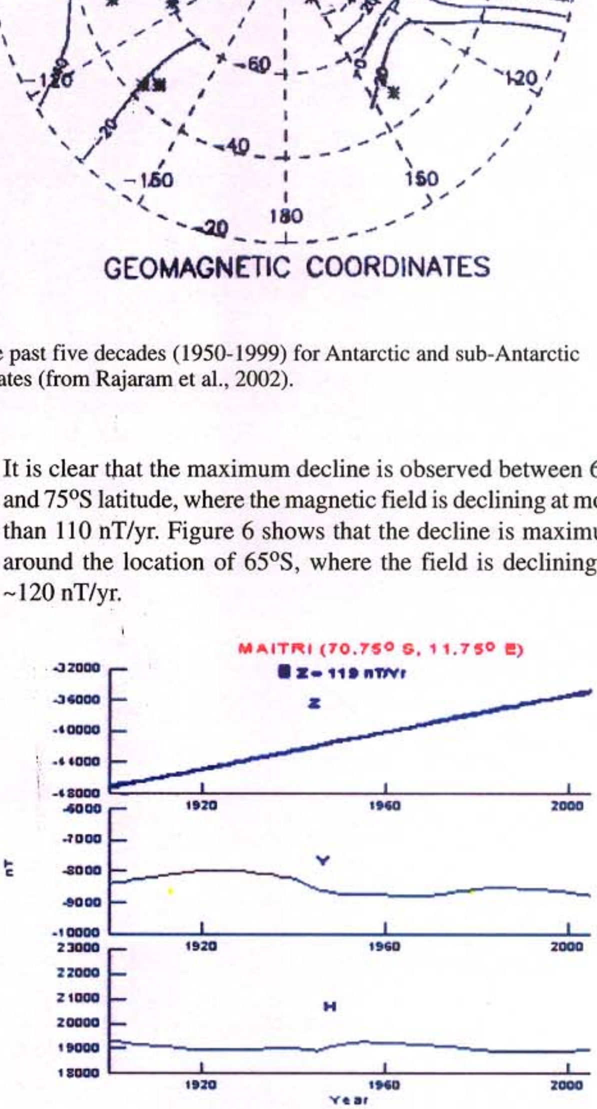

Fig. 4. The plots of Z, H and Y components for the location of Maitri derived from IGRF. It is clear that the maximum decline is observed in the Z (vertical) component only. The other two components are showing variation, but not a rapid decrease.

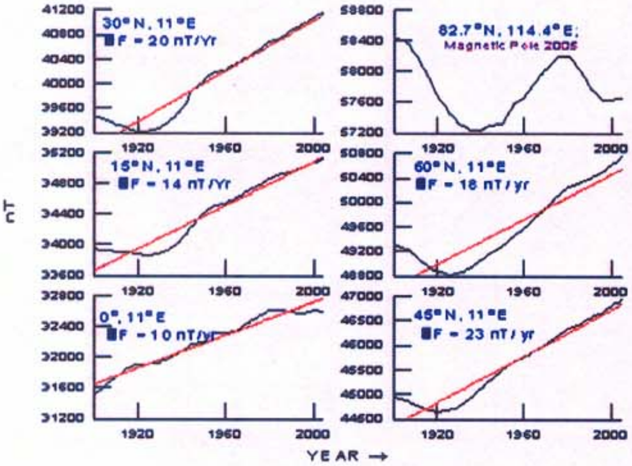

Fig. 5. Plots of total magnetic field intensity F derived from IGRF for every 15° latitude, in the Northern Hemisphere at increments along 11° E longitude.

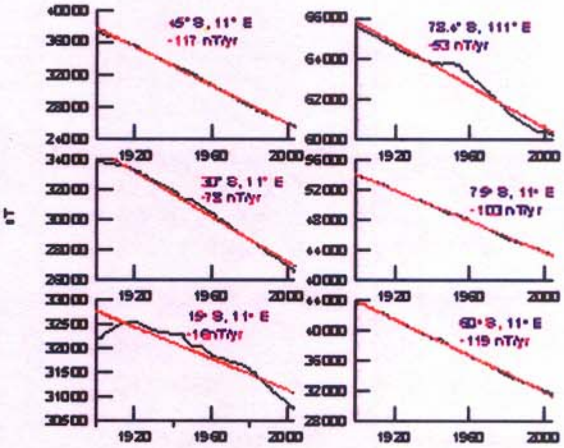

Fig. 6. Plots of total magnetic field intensity F for every 15° latitude along 11°E longitude in the Southern Hemisphere, derived from IGRF. The plots show that the total field intensity is decreasing at most of the places in the Southern Hemisphere.

Figure 7 shows the contour plot of the Earth's rate of change of magnetic force over the last century in the Southern Hemisphere. A large area in the vicinity of Maitri is seen to have a high decline rate compared to other regions in the Southern Hemisphere. This rate of decline is increasing as we move away from Maitri both towards north and south.

The movement of magnetic pole positions has been reported by various researchers in the past. A number of sudden changes in this slope were observed particularly in 1925, 1969, 1978 and 1992, defined as secular impulse or 'jerk'. The European region observed a significant jump in declination during 1969. The North American region observed a large shift

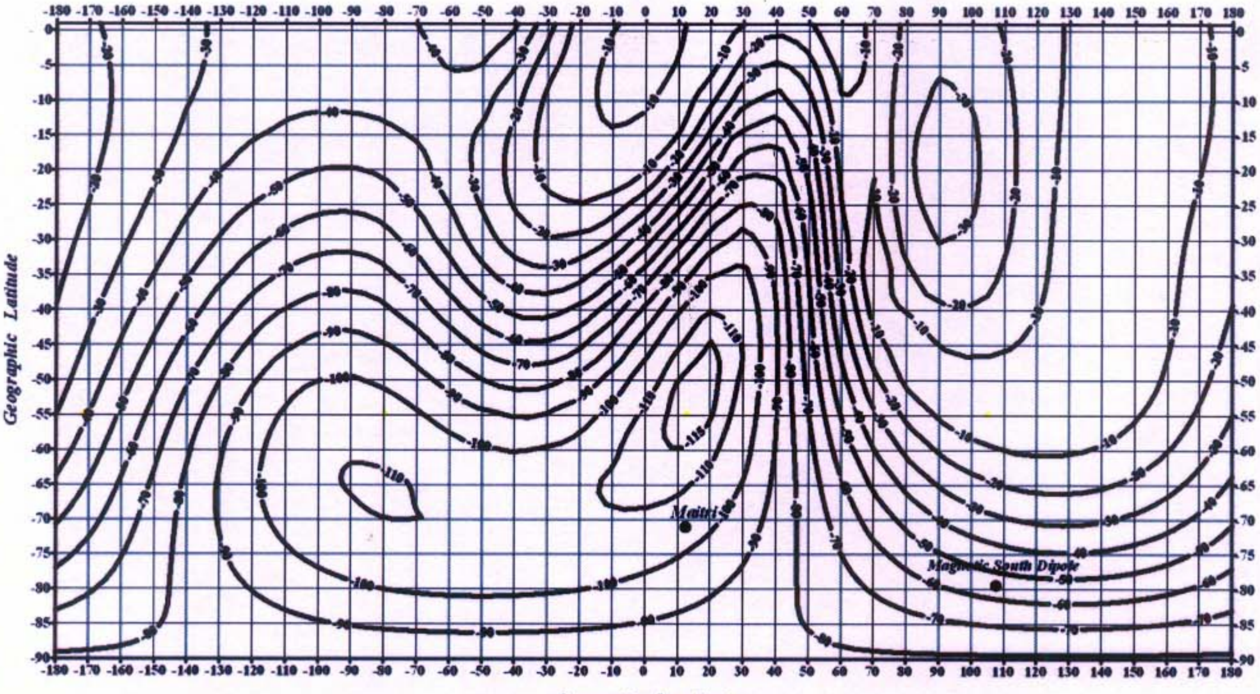

Fig. 7. Contours of Earth's rate of change of magnetic force over the last century in the Southern Hemisphere.

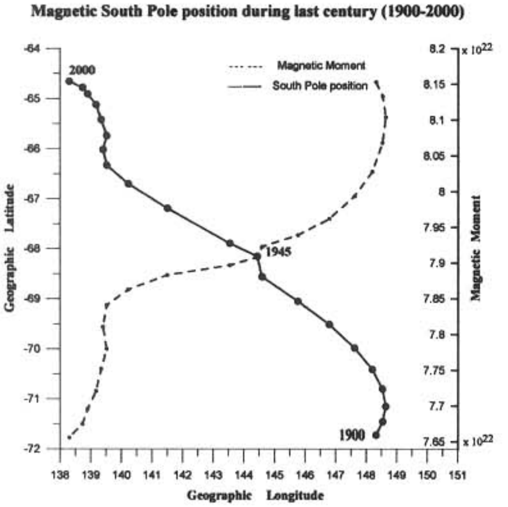

Fig. 8. A plot of the magnetic South Pole position and the magnetic moment over the last century (1900-2000).

in H component whereas changes were observed in Z component in Asian, Australian and Siberian region. Such changes were observed in Portugal as well as in Peru magnetic data (Rangarajan et al., 1996). The jerk was not observed all over the globe at the same time and the periods for the jerk in the Y component differed by 2 years in certain sectors. Whether these changes are of internal origin or of external origin, is not well understood, and are certainly not predictable.

Figure 8 shows the magnetic South Pole position over the last century. The pole has shifted by ~ 8° in latitude and ~10° in longitude during this period. The location of the magnetic pole is not fixed but it wanders by nearly 15 km every year. The Earth's field is changing in size and position and as such the two poles wander independently of each other and are not at directly opposite positions on the globe.

Discussion

The dipole moment of the Earth has been dropping rapidly over the past few centuries (Barton, 1997). He showed that this drop in axial dipole moment has continued since the 16th century (Barton, 1989). It is clear that a large region of Southern Hemisphere has suffered a large decrease in F over the last century. The maximum decrease occurs in an area covering Novolazarevskaya (Russian station), Maitri (Indian station), Sanae (South African station), Syowa (Japanese station), Argentine Island and Hermanus. The rate of decrease falls on either side of this region. This attains greater importance in the light of the work carried out by Gubbins (1987). Gubbins (1987) gave an empirical equation to show that the rapid drop in Gauss coefficient g_i^o observed over the past century is proportional to the axial dipole movement M by virtue of the relationship :

$$M = (4\pi a^3 g_i^o)/\mu_o$$

where a – radius of Earth
and μ_o – permeability of free space

A drop of 3×10^6 T km^3 has been seen in dipole moment in the last 2000 years which is equal to ~0.12 G in the horizontal field intensity H. Gubbins' plots (Gubbins, 1987) of rate of change of magnetic field with time at the core-mantle boundary in the Northern and Southern Hemisphere show that the negative variation features are concentrated at parts of Southern Hemisphere (below South Africa and parts of Antarctica), whereas the Northern Hemisphere is devoid of any such negative variation features as shown in Fig. 9. He called these

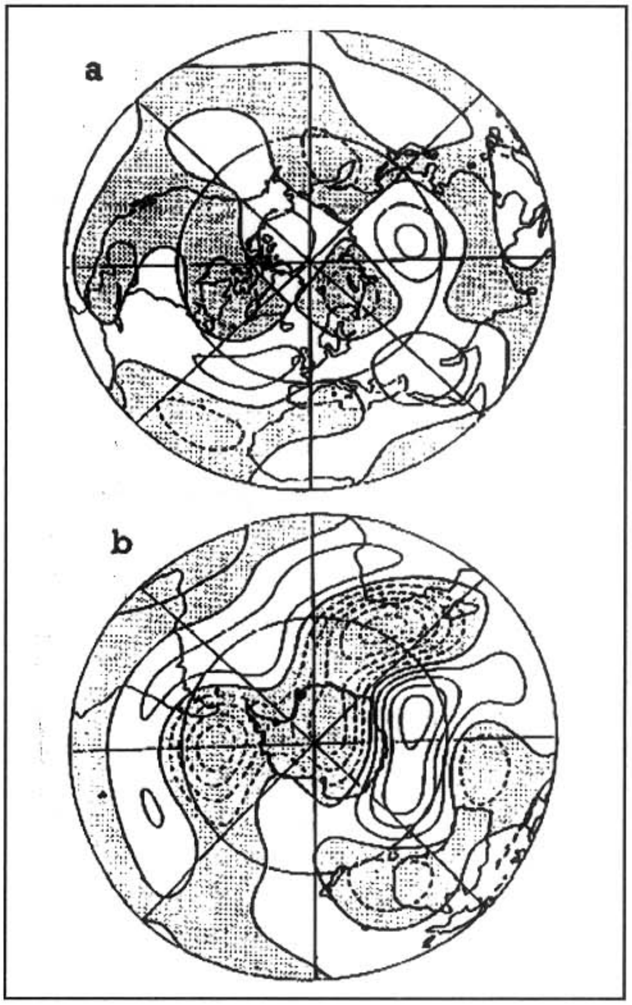

Fig. 9. Contours showing the rate of change of magnetic fields with time at the core-mantle boundary (CMB) for epoch 1945 for the (a) Northern and (b) Southern Hemispheres (from Gubbins, 1987). The component-time rate of change of Zcos T at the CMB is plotted. The Southern Hemisphere shows large negative time features (dotted contours) compared to Northern Hemisphere, which is deovid of such features.

regions as regions of reverse magnetic flux (RMF). These are the regions where the radial magnetic field direction is opposite to that expected for the current dipole. These reverse flux features have been observed to be concentrated over much of Antarctic continent and adjoining areas. These regions of reverse magnetic flux were interpreted by Bloxham and Gubbins (1985) as the expulsion of toroidal magnetic field from core into the mantle.

A supercomputer model of Earth's interior using the equations of magnetohydrodynamics was generated by Glatzmaier and Roberts (1995) and explained what happens during a magnetic flip (Fig. 10). The magnetic field increases and decreases, poles drift and occasionally, flip. The change is normal and we detect it on our planet's surface as a sign of that inner chaos. The pole reversals take a few thousand years to complete, and during that time the magnetic field does not vanish. It just gets more complicated. Magnetic lines of force near Earth's surface become twisted and tangled and magnetic poles appear at unaccustomed places.

Thomas Barnes (1971) showed with simple electromagnetic theory that the decay of the dipole moment is consistent. A six billion ampere electric current circulating in the Earth's core is required to produce the field. The electrical resistance of the core would steadily diminish the current, thus diminishing the field (Barnes, 1973). The dipole moment has decreased since 1829. This decrease has been almost completely balanced by a corresponding increase in the strength of the nondipole field, so that the strength of the total observed field has remained about constant. The decrease of energy in the dipole part has been almost completely balanced by a corresponding increase in the energy of the nondipole field, leaving the net energy of the total observed field almost constant.

The trend in the IGRF data for the period 1900-2000 is very clear. During that period the total energy - dipole plus non-dipole - in the observable geomagnetic field decreased quite significantly. While we appear to be in a period of declining magnetic field strength, it is possible to state if or when a magnetic reversal will occur. Based on the measurements of the Earth's magnetic field over the last 150 years, it is estimated that the dipole moment will decay in about 1300 years. During the past 2000 years, magnetic field strength has fallen some 50 to 65%. The rate of decline is picking up and 5% of the decline has occurred during the last 100 years alone. This decline may be a precursor to a new reversal attempt. Thus, monitoring the F values at Maitri becomes of utmost importance as this maximum decline is observed in the belt encompassing Maitri. Continuing with the observation in other regions is not possible for logistic purposes.

The Earth's magnetic field acts like a barrier and protects the Earth from cosmic rays and solar wind. Without this barrier, the solar wind could blow away the atmosphere of the Earth. The cosmic rays can destroy our optic nerve system and mutate our cells, leading to extinction of life on Earth. The magnetic field is thus directly linked to survival of human and other species. What will happen to the Earth and its natives during further decline and period of reversal is anybody's guess. Reports appearing in certain sections of the press have mentioned that scientists have started believing that the reversal has started.

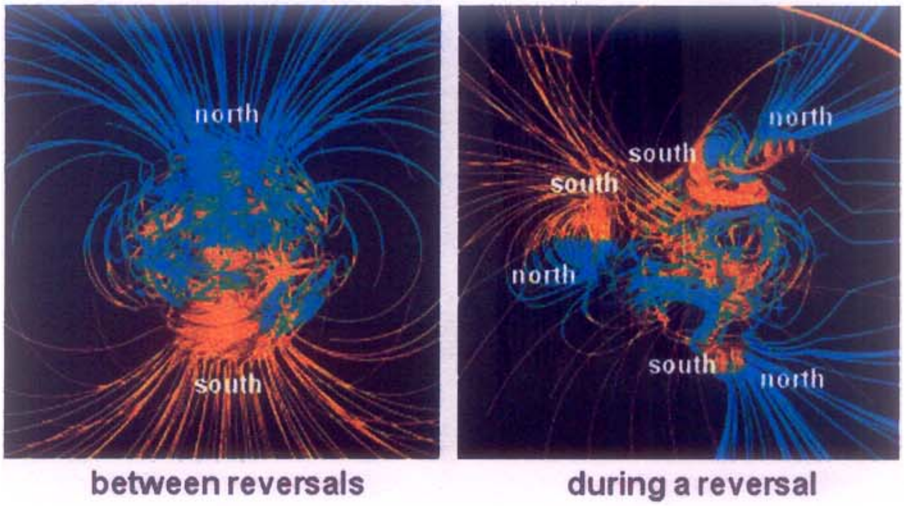

Fig. 10. Supercomputer models of Earth's magnetic field. On the left is a normal dipolar magnetic field, typical of the long years between polarity reversals. On the right is the sort of complicated magnetic field Earth has during the upheaval of a reversal (after Glatzmaier and Roberts, 1995).

Table 1. List of Southern Hemisphere stations used in this study

Geographic		Geomagnetic		ΔF	Station
Lat	Long	Lat	Long	nT yr $^{-1}$	
-78.45	106.87	-89.22	148.98	-89	Vostok
-77.85	166.78	-78.86	-67.31	-58	Scott Base
-75.52	-26.60	-66.50	26.12	-91	Halley Bay
-74.68	164.12	-77.32	-81.07	-44	Terra Nova Bay
-70.77	11.82	-66.87	56.31	-108	Novolazarevskaya
-70.32	-2.58	-64.36	46.57	-108	Sanae III
-69.00	39.58	-70.17	81.23	-94	Syowa
-68.57	77.97	-76.76	125.15	-73	Davis
-67.67	45.85	-70.20	89.11	-81	Molodezhnaya
-67.60	62.87	-73.31	107.33	-72	Mawson
-66.67	140.02	-74.94	-127.98	-33	Dumont d'Urville
-66.55	93.02	-76.69	151.80	-60	Mirny
-65.25	-64.27	-54.38	4.90	-103	Argentine Island
-62.17	-58.48	-51.48	09.44	-90	Arctowski
-54.50	158.95	-60.44	-115.51	-31	Macquire Island
-43.42	172.35	-47.40	-106.22	-35	Eyrewell
-43.25	-65.32	-32.43	05.00	-69	Trelew
-34.42	19.23	-33.78	82.97	-105	Hermanus
-31.67	-63.88	-20.88	6.59	-55	Pilar

Acknowledgement

The authors are grateful to Indian Institute of Geomagnetism for support towards geomagnetic experimentation at Antarctica and to the National Centre for Antarctic & Ocean Research (Department of Ocean Development, Government of India) for providing the necessary logistic support during annual Antarctic expeditions. The authors acknowledge using the data from website of WDC-A, USA, IGRF-2004 and the website of British Geological Survey, UK and thank Dr. Stewart Dennis, AGSO, Australia for providing Mawson annual mean data.

References

Arun, T., Patil, A. G., Dhar, Ajay and Rajaram, Girija, 2000: Rapid decrease in total magnetic field intensity at Indian Antarctic Station Maitri. *J. Ind. Geophys. Union*, **4**: 119-128.

Barnes, Thomas G., 1971: Decay of the earth's magnetic field and the geochronological implications. *Quart. J. Creation Res. Soc.* , **8:** 24-29.

Barnes, Thomas G., 1973: Electromagnetics of the earth's field and evaluation of electric conductivity, current and joule heating in the earth's core. *Quart. J. Creation Res. Soc.*, **9:** 222-230.

Barton, C. E., 1989: Geomagnetic secular variation: direction and intensity. *In :* The encyclopedia of solid Earth geophysics. D.E. James (ed.), New York, Van Nostrand Reinhold, 1328p.

Barton, C. E., 1997: International Geomagnetic Reference Field: the seventh generation. *J. Geomag. Geoelectr.*, **49**: 123-148.

Bloxham, J. and Gubbins, D., 1985: The secular variation of Earth's magnetic field. *Nature*, **317**: 777-781.

Bormann, P., Schafer, U., Kopsch, C. and Wagner, S., 1995: Geophysical investigations. *In*: The Schirmacher Oasis, Queen Maud Land, East Antarctica and its surroundings, Gotha P. Bormann and D. Fritzsche (eds), Germany, Justus Perthes, 39-57.

Chapman, S., 1951: The Earth's magnetism, Second edition, Pub. Methuen & Co. Ltd., London.

Gubbins, D., 1987: Mechanism for geomagnetic polarity reversal. *Nature,* **326**: 167-169.

Glatzmaier, G. A., and Roberts, P. H., 1995: "A three-dimensional self-consistent computer simulation of a geomagnetic field reversal." *Nature*, **377**: 203-209.

Humphreys, D. R., 1990: Physical mechanism for reversals of the earth's magnetic field during the Flood. *In*: Proc. Second International Conference on Creationism, R.E. Walsh (ed.), **II**: Creation Science Fellowship, Pittsburgh, PA. 129-142.

Nagata, T., 1961: Geomagnetic secular variation over and near the Antarctic continent, *Antarc. Rec.*, **11**: 937-944.

Nagata, T., 1982: Geomagnetic secular variation in Antarctica during 1960-1975. *J. Geomag. Geoelectr.*, **34**: 137-140.

Rajaram, Girija, Arun, T., Dhar, Ajay and Patil, A. G., 2002: Rapid decrease in total magnetic field F at Antarctic stations – its relationship to core-mantle features. *Antarc. Sci.*, **14 (1)**: 61-68.

Rangarajan, G. K., Veliz, O. and Arora, B. R., 1996: Geomagnetic secular variation and field oscillation of external origin at huancayo, Peru. *Brazil. J. Geophys.*, **14(1):** 29-40.

Yoshida, S and Hamano, Y., 1993: The westward drift of the geomagnetic field caused by length-of-the-day variation, and the topography of core mantle boundary. *Geophys. J. Int.*, **11**.