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STUDY OF TOTAL MAGNETIC FIELD INTENSITY VARIATION (F) AT MAITRI, ANTARCTICA VARIATIONS OVER 1922-1996

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Abstract

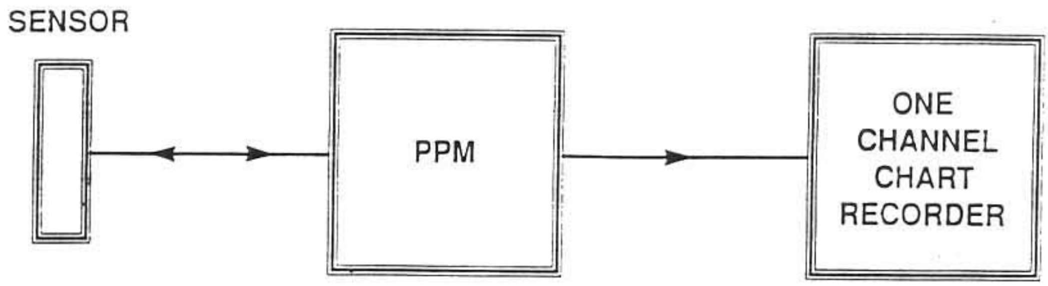
The total geomagnetic field intensity (F) was recorded at the Indian Antarctic Station, Maitri (MAI), during Jan 1996, using a Proton Precession Magnetometer (PPM). The PPM data was compared with the variations in intensity of the three orthogonal components of the geomagnetic field X, Y and Z, recorded by using a Fluxgate Magnetometer (FM). The F values as expected, showed a matching trend with the Z component during magnetically quiet conditions. During magnetically disturbed conditions however, a sizeable contribution from the other two components X and Y, was also observed. A remarkable observation was that the total field at Maitri, when compared to the value at this geographic location from previous records had declined by 9000 nT over the period 1922-1996.

Introduction

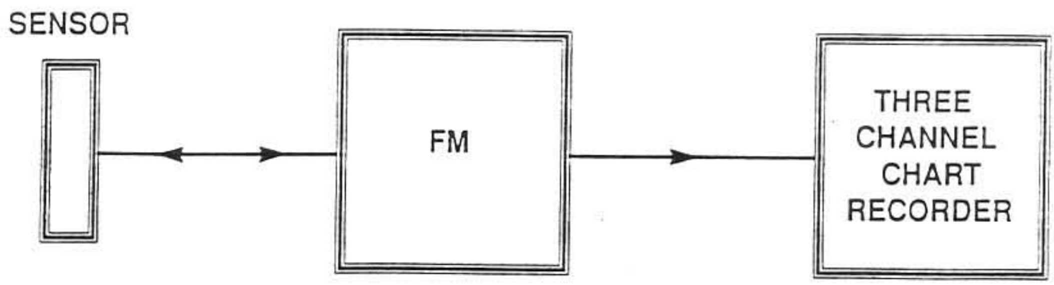
The total field (F) at Dakshin Gangotri (Geog lat. 70° 05′ S, long. 12° E), Antarctica, was first recorded in 1982, using a Proton Procession Magnetometer (PPM)(Iyengar and Rajaram, 1983). During subsequent years the PPM was replaced by a fluxgate magnetometer, recording variations in the three orthogonal components X (North-South), Y (East-West) and Z (Vertical). A PPM was once again used at Dakshin Gangotri (DG) during Jan-Mar 1986 and during Jan 1996, to record the absolute value of **F**. In both cases a fluxgate magnetometer was operated simultaneously, and the results obtained from a comparison of Δ F, Δ X, Δ Y, and Δ Z are discussed in this paper.

Experiment

India operates round the year, a permanent scientific station at Maitri (Geog lat.70° 45′ S and long. 11° 45′ E), Antarctica, in the rocky mountains of the Schirmacher Oasis. The magnetic field variations in the three orthogonal components X, Y and Z are recorded using a fluxgate magnetometer (FM). The



Block Diagram for Proton Precession Magnetometer Recordin'g Total Field F.



Block DiagramFor Fluxgate Magnetometer Recorder Three Components X, Y, Z.

Fig.1: Block diagram depicting analogue recording at Maitri of total geomagnetic field + intensity F by PPM (proton precession magnetometer) and the three orthogonal components X (north-south), Y (east-west) and Z (vertical by FM fluxgate magnetometer).

Daily Variations (DV) and Magnetic Pulsations (MP) are recorded in analog and digital form. In Jan 1996 a PPM was used to record variations in the total field (F) in analog form. These data when compared with the fluxgate magnetometer records, show some interesting results. **Fig.1** shows the block diagram of the experimental set-up for the fluxgate and proton precession magnetometers.

Observations

1 Comparison of F with X, Y and Z during magnetically Quiet (Q) conditions :

Fig.2 shows the variations in the total field intensity F recorded on 7 and 8 Jan 1996, at MAI, Antarctica. Both days are magnetically Quiet as judged from the 3-hourly Kp indices (a measure of magnetic activity primarily for the low and mid latitudes of Earth). The Σ Kp for the two days are 9- and 7- respectively, and normally any value of Σ Kp less than 10 is considered to denote a quiet day. The Kp for the three-hourly intervals 00-03, 03-06, 06-09, 09-12, 12-15, 15-18, 18-21 and 21-24 are 1-, 1_0, 1_0, 1-, 0_+, 1-, 2_0 and 2_+ respectively on Jan 7, 1996; and 2-, 1-, 1_0, 1- and 0_+ respectively for the first

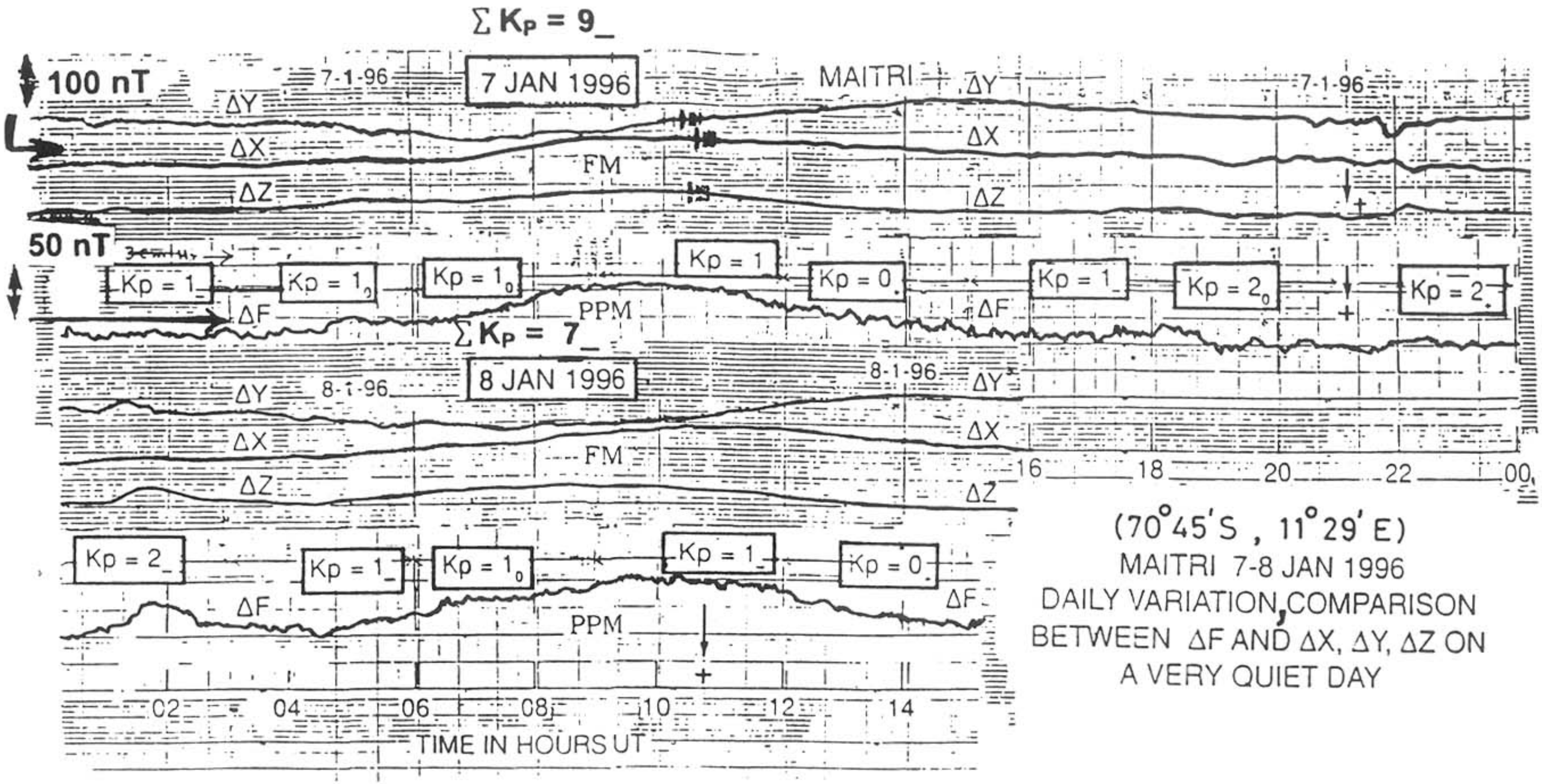


Fig.2: Variations at Maitri of Y, X, Z (top three curves) and F (fourth curve), for the two magnetically quiet days 7 Jan 1996 (00-24 hr) and 8 Jan 1996 (00-15 hr). The magnetic signatures on Y, X, Z are those of the southern limb of the southern Sq current loop

five intervals on Jan 8, 1996. Each of these Kp values is indicated on **Fig.2** for the relevant interval. The first 3 curves for each day depict variations in Y, X, and Z observed by FM while the fourth curve depicts variations in F observed by PPM. MAI experiences the magnetic effect of the southern limb of the southern Sq current system (westward current) during quiet magnetic conditions in the daytime hours, hence a decrease (upward deflection) in the vertical component (Z) during the morning and afternoon hours is observed. A similar decrease (upward deflection) is observed in the total field variation Δ F on both these days. The variation in the total field F is very similar to the variation in the vertical component Δ Z during these quiet conditions i.e. the maximum contribution to Δ F is from Δ Z rather than from Δ X and Δ Y.

Fig.3 shows such variations again during Quiet conditions, but during night-time hours of Jan 9-10, 1996. The Σ Kp values for these two days are 5+

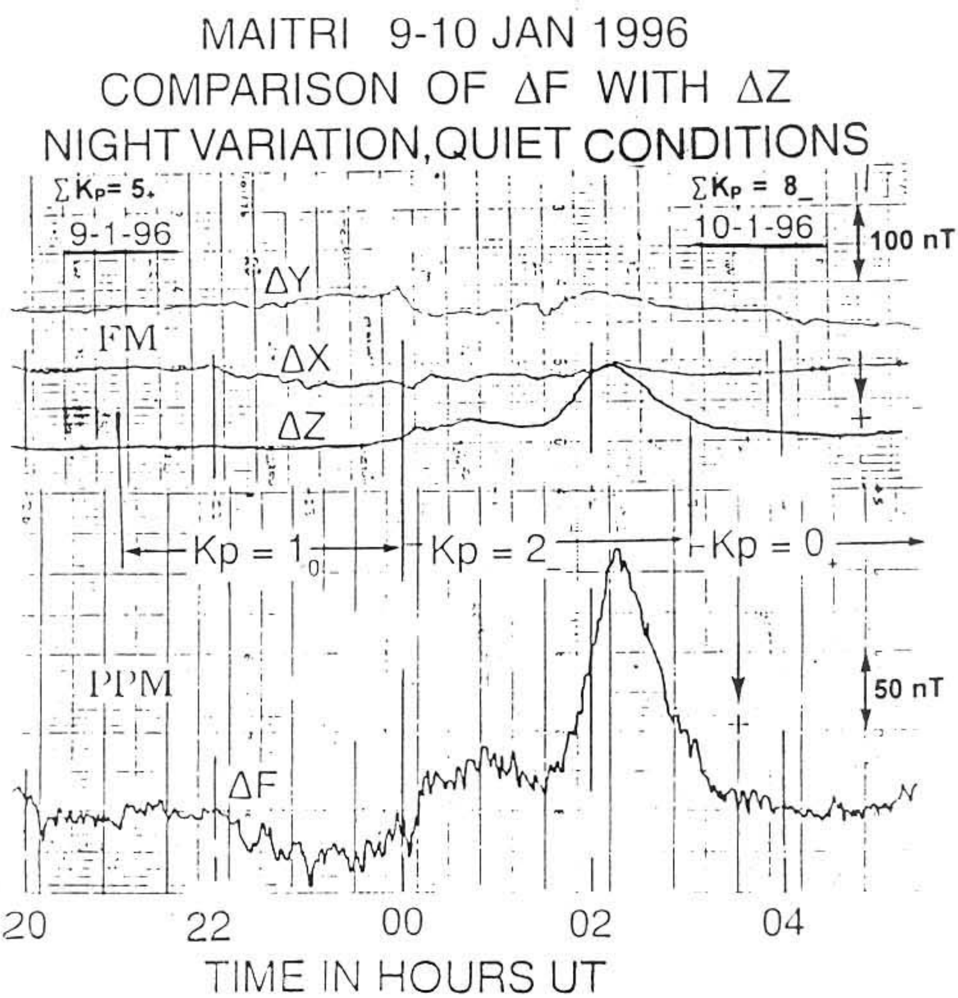


Fig.3: Comparison during quiet conditions of Y, X, Z and F during night hours (20 UT-05UT) of 9-10 Jan 1996. Notice how the variations of only the Z component follow the variations of F

and 8- respectively as indicated on the figure. A large negative dip (upward deflection) is seen in the F variations during the interval 02-04 UT; Kp values for the concerned intervals 21-00 UT and 00-03 UT are 1_0 and 2- respectively. A pronounced dip is also seen in the vertical component Δ Z at this time. We noted that a mild dip in F was seen at MAI at 02 UT on several days in Jan 1996. This may be the result of MAI experiencing the distant effect of localised disturbances in the auroral electrojet region.

2. Comparison of Δ F with Δ X, Δ Y and Δ Z during moderately disturbed conditions :

The current system in the ionosphere over MAI becomes complex with increasing magnetic activity, and a significant contribution to Δ F from Δ X and Δ Y is observed. **Fig.1** shows one such event recorded on moderately disturbed days, Jan 5, 1996, with Σ Kp = 17+, and Jan 6, 1996, with Σ Kp = 13-. The Kp indices for the 3-hourly intervals 21-00, 00-03 and 03-06 for the night of 5-6 Jan 1996 are 3-, 3- and 3- respectively as indicated in **Fig.4**. Here Δ Y is also

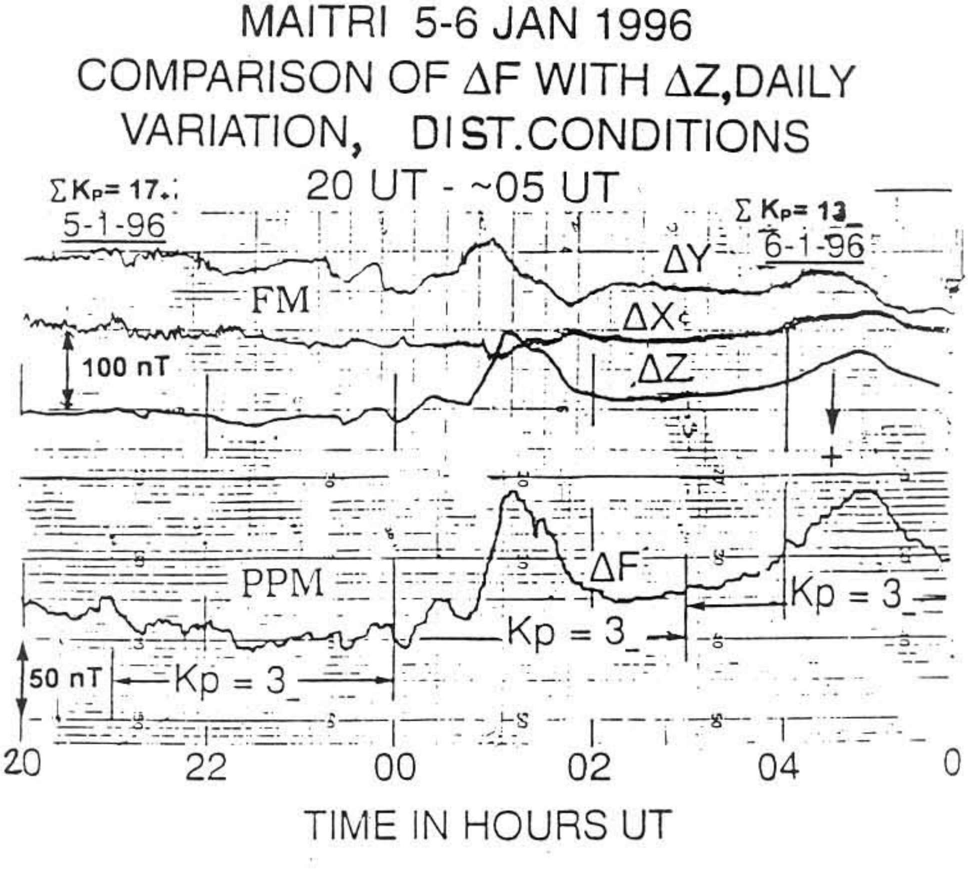


Fig.4: Comparison during moderately disturbed conditions of Y, X, Z and F, during night hours (20 UT - 06 UT) of 5-6 Jan 1996. Notice how both Y and Z components vary in concert with the F component

seen to have variations similar to Δ Z and Δ F, albeit with less intensity. The variations in Δ X are not at all similar to those of Δ Y and Δ Z.

Fig.5 shows another example of more disturbed conditions. It shows variations during the night of 19-20 Jan 1995, with 19 Jan 1996 having Σ Kp = 17_0, and 20 Jan 1996 having Σ Kp = 19_0. A large substorm with variation of 600 nT in total field was recorded and a similar negative dip (upward deflection) in the Δ Z component. Large variations are also seen in Δ X and Δ Y and these

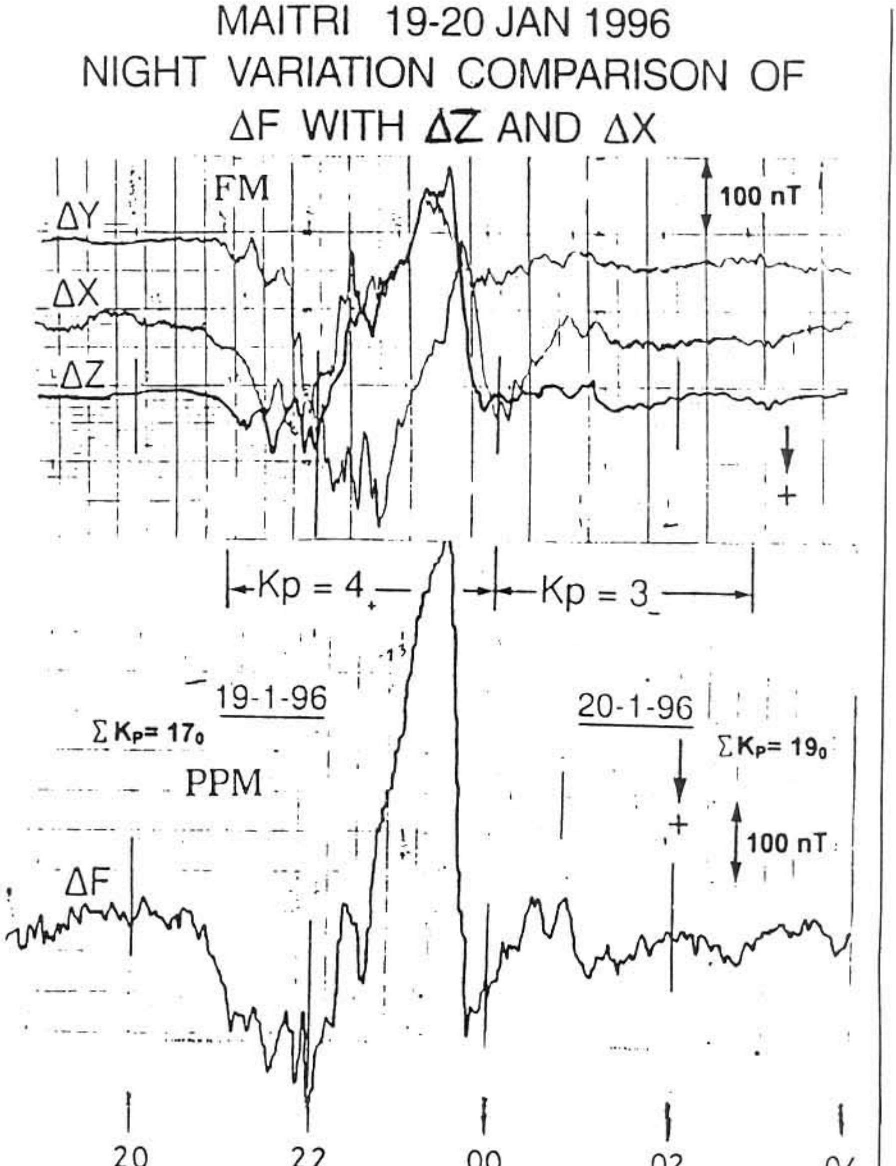


Fig.5: Substorm conditions at Maitri on the night of 19-20 Jan 1996, 20 UT - 04 UT. Notice how all three components Y, X and Z contribute to the variations in F. Large variations in Y are mainly due to field-aligned current systems, while the variations in X and Z arise from the auroral electrojet currents; both these auroral current systems are overhead of Maitri during magnetically disturbed conditions

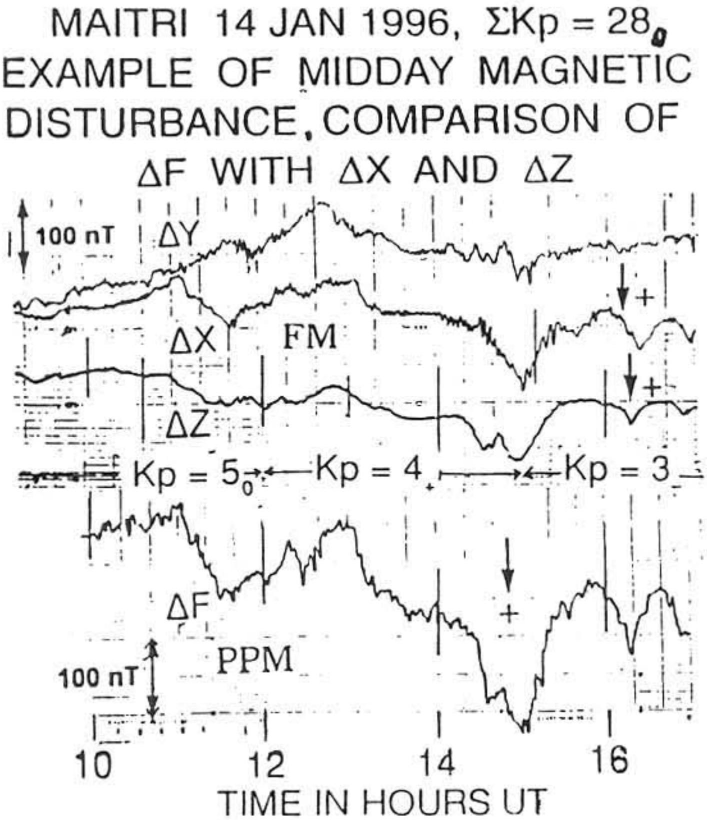


Fig.6: Variations of Y, X, Z and F during daytime hours (10 - 16 UT) of a magnetically very disturbed day 14 Jan 1996. Here too, the variations in Y, X and Z follow those of F.

show the presence of field aligned currents (fac), flowing into the auroral ionosphere over MAI.

3. Comparison of F with ΔX, ΔY and ΔZ during very disturbed conditions

Fig.6 shows daytime variations on a disturbed day 14 Jan 1996, with Σ Kp = 28_0; this interval follows the occurrence of storm conditions on 3 Jan 1996. The auroral electrojet has very likely moved equatorwards on this disturbed day, and is located directly over MAI. The large increase in ΔY in the noon hours suggests the existence of field-aligned currents over MAI. The variations also show that MAI is experiencing the effect of the eastward auroral electrojet; with positive signatures (downward deflection) in X and Z components (Hanchinal *et al.*, 1995; Banola and Rajaram, 1996). It may be noted that Δ F has also increased substantially by about 350 nT, and the variations in Δ X, Δ Y, and Δ Z, are all in phase with Δ F.

Fig.7 shows variations during very disturbed times for the night of Jan 14-15, 1996 with Σ Kp being 28_0 and 23_+ respectively for the two days. This is a very disturbed interval with the 3 hourly Kp index having values of 5+ and 5-. The signature of the westward auroral electrojet is seen in the Δ X component (upward deflection, hence a decrease) during both pre-midnight and post-mid-

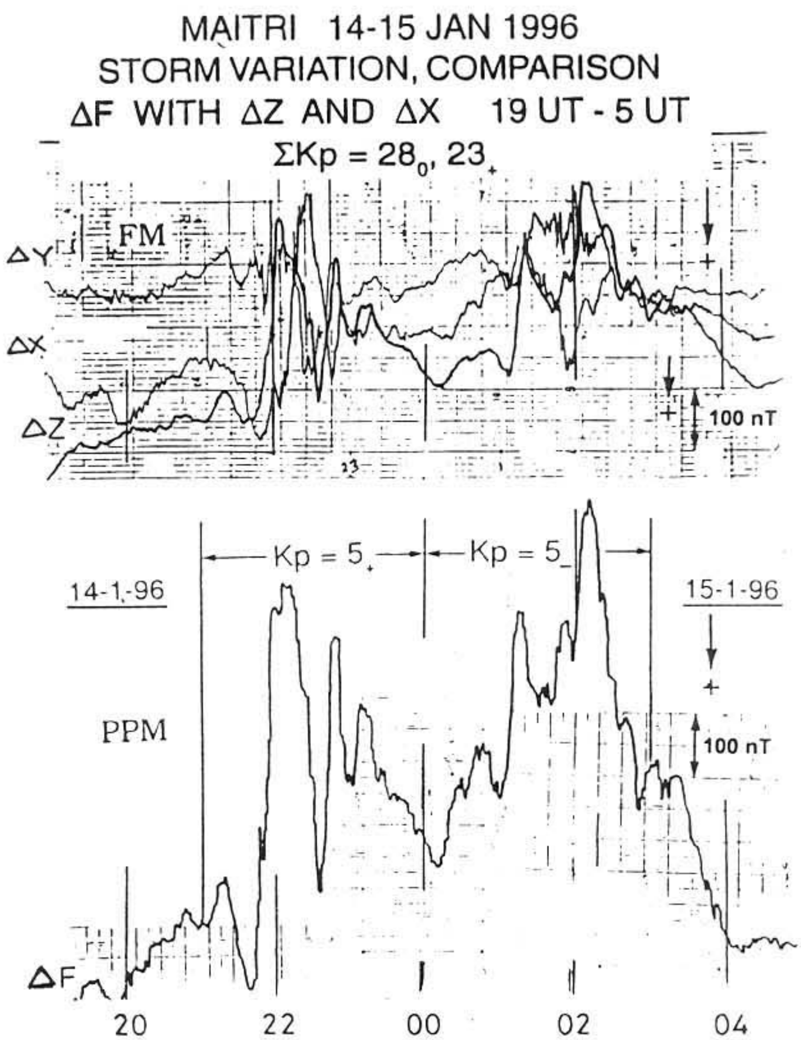


Fig.7: Storm conditions at Maitri on the night of 14-15 Jan 1996 (20 - 04 UT). The auroral electrojet and field-aligned current systems are active over MAI, and hence variations in Y, X and Z components all contribute to the variations in total field F

night hours. The large excursions in the Δ Y component suggest the presence of strong fac over MAI. Large negative excursions in Δ F (upward deflection) are in phase with the large negative changes in the Z component, as the westward auroral electrojet intensifies over MAI.

4. Contributions to Δ F from Δ X, Δ Y and Δ Z on magnetically quiet and disturbed days:

The following expressions help us to under the relationship between the quantities Δ F, Δ X, Δ Y and Δ Z.

$$F^2 = X^2 + Y^2 + Z^2 \quad \text{— Eq. 1}$$

$$2F \; \Delta F = 2X \; \Delta X + 2Y \; \Delta Y + 2Z \; \Delta Z \quad \text{— Eq. 2}$$

$$\Delta F = X/F \; \Delta X + Y/F \; \Delta Y + Z/F \; \Delta Z \quad \text{— Eq. 3}$$

Absolute values of F, X, Y and Z at MAI estimated from the IGRF 1990 model are 40,100 nT, 16,828 nT, 8589 nT and 35,797 nT respectively. Substituting these values, we get

$$F = 0.4 \Delta X + 0.2 \Delta Y + 0.89 \Delta Z \quad \text{— Eq. 4}$$

It is clear from the above equation that the major contribution to Δ F during Quiet conditions should come from the Z term. This is however, not the case during substorm and storm conditions, when the auroral electrojet current systems become very inhomogeneous with the precipitation of charged particles, and the formation of the localised current loops. Large changes are also observed in the Y and X components due to field-aligned currents feeding the auroral ionosphere. Hence during disturbed times contributions to Δ F come not only from the Z component, but from the X and Y components as well.

Declining Trend in 'F' at Maitri, Over 1922-1996

There have been reports in the past about the declining trend in the total magnetic field in the Earth over the last century at a rate of 0.05% as shown in **Fig.8** (McElhinny and Senanayake, 1982). Isomagnetic charts (i.e. lines of

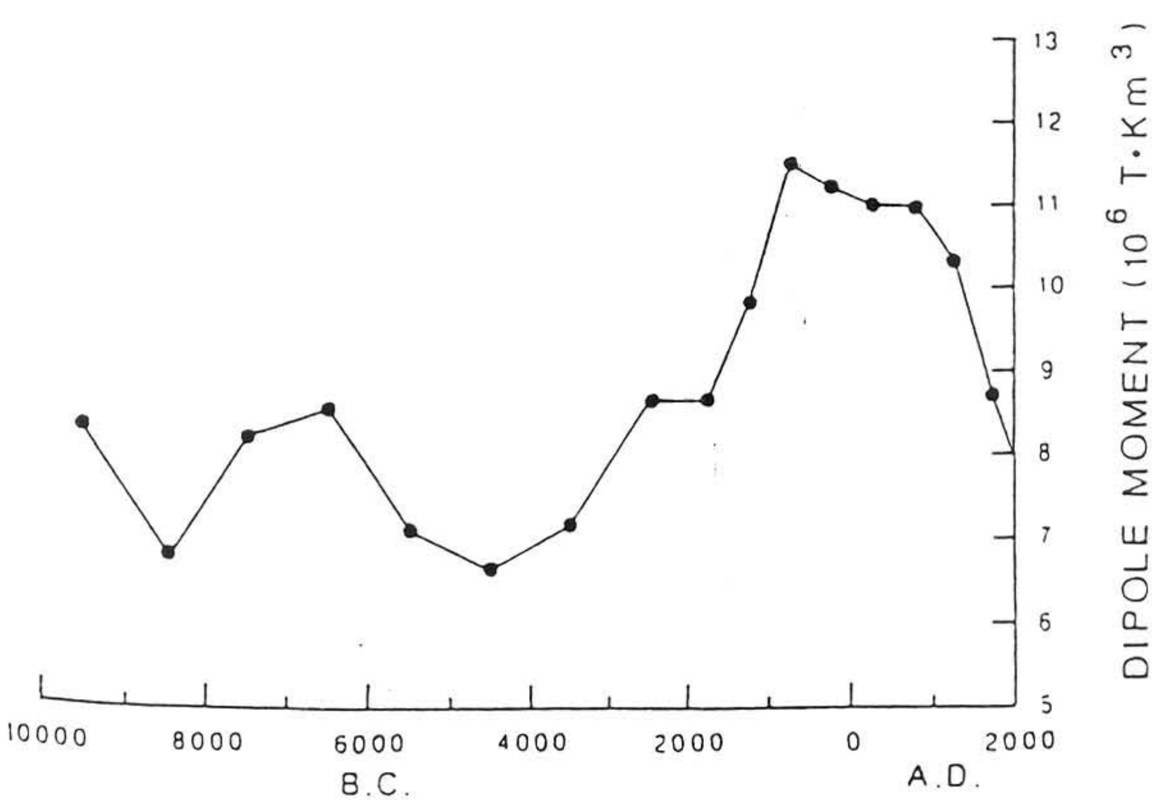


Fig.8: Variations in Dipole Moment (and hence in field intensity) of the earth's magnetic field over the past 12,000 years from archaeomagnetic data (McElhinny and Senanayake 1982). Note the considerable decrease over the past 2500 years (almost 40%).

equal magnetic field intensity) for the year 1922 are shown in **Fig.9** (British Admiralty Charts from Chapman and Bartels 1940). The value of F at the location of MAI (geographic lat. 70° 45′S, long. 11° 45′E) can be read from this map to be 48,000 nT. Similarly, the F values at the location of MAI read from **Fig.10** (after Chapman 1951), **Fig.11** (after Handbook of Geophysics 1960) and **Fig.12** (after IGRF 1990), all world maps of reference field F, give us the values of 48000 nT, 46000 nT and 40600 nT for the years 1945, 1955 and 1990 respectively. The average of the absolute F values recorded by the Indian Institute of Geomagnetism (IIG) with their PPM experiments at the Antarctic locations Dakshin Gangotri in the years 1982, 1986, and at MAI in the year 1996, were 41,250 nT, 41,000 nT and 40,000 nT respectively. All these values stated above for different years have been plotted in **Fig.13**. Clearly seen is a distinct drop of 9000 nT in total field F at MAI over the last 75 years. This is also reflected in the decline in magnetic dipole moment from archeomagnetic data shown earlier in **Fig.8** (McElhinny and Senanayake, 1982). **Fig.8** clearly shows a declining trend in the magnetic field of the Earth in the last two thousand years. If this declining trend of 0.07% per year observed over the last two centuries were to continue, the geomagnetic field should vanish in the next 1000 years. Since so little is known about geomagnetic field reversals, however, it is also possible that the field may suddenly recover and increase.

This trend of declining magnetic field is recorded at MAI and southern hemisphere stations, but is not seen in the northern hemisphere. **Fig.14** shows the secular variations of the horizontal component (H) over the last century at Niemegk, Germany (geomag. lat. 51.9° N, long. 97.7° E) Kakioka, Japan (geomag. 26.8° N, 208°E), Alibag, India (geomag. 9.5° N, 145.5° E) and Hermanus, South Africa (geomag. 33.7° S, 83° E). As seen in **Fig.14**, the field intensity does not show any specific decrease at the locations Niemegk, Alibag and Kakioka in the northern hemisphere; in contrast it shows clear decrease at Hermanus and MAI, both in the southern hemisphere.

These observations clearly indicate a rapidly declining trend of magnetic field at the southern hemisphere locations markedly in the vicinity of MAI, which is not observed in the northern hemisphere. Our observation finds support in the work of Gubbins (1987), which reports that modelling studies of the geomagnetic field indicate reverse magnetic flux features to be concentrated below the Antarctic continent. Our studies of the sharp decline in F over the past 75 yr at MAI thus indicate the importance of continuing total field observations from this Antarctic Station. Such observations will be invaluable in modelling studies of the geomagnetic field, and in understanding its magnetic polarity reversals.

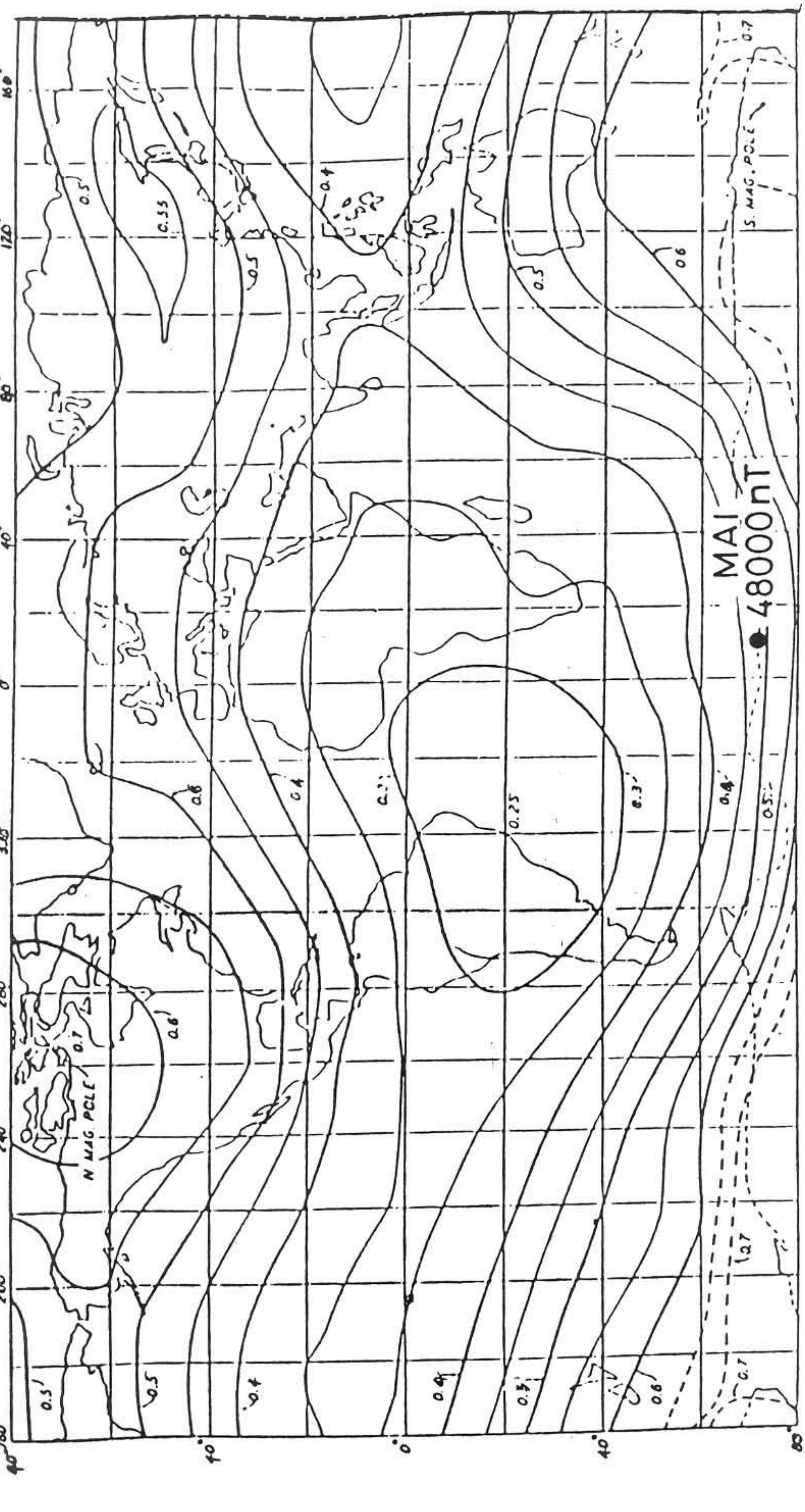


Fig.9: Isomagnetic contours of total magnetic field intensity F from the British Admirably Charts of 1922 A.D. (from Chapman and Bartels 1940).

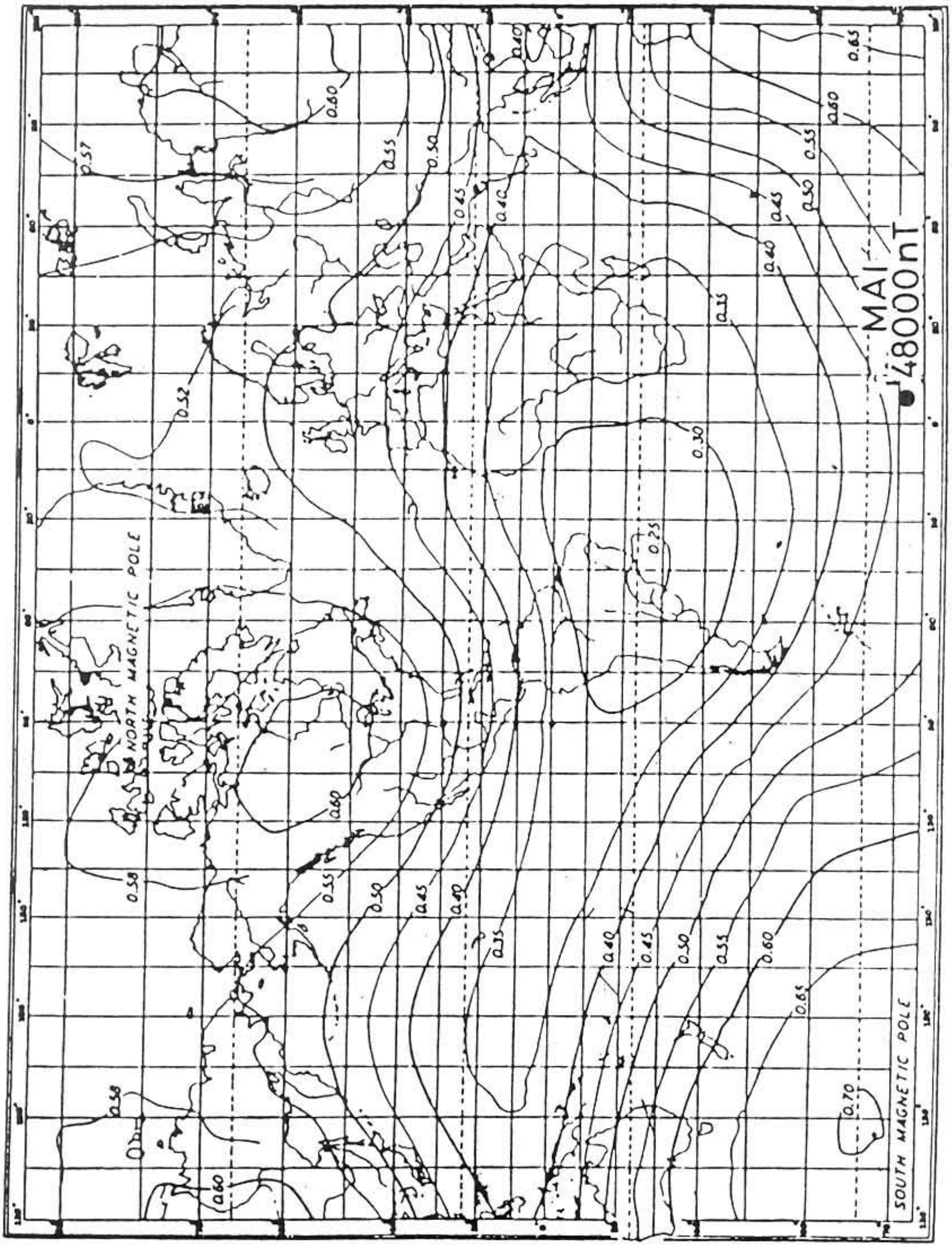


Fig.10: Isomagnetic contours of total magnetic field intensity F for 1945 (from Chapman 1951).

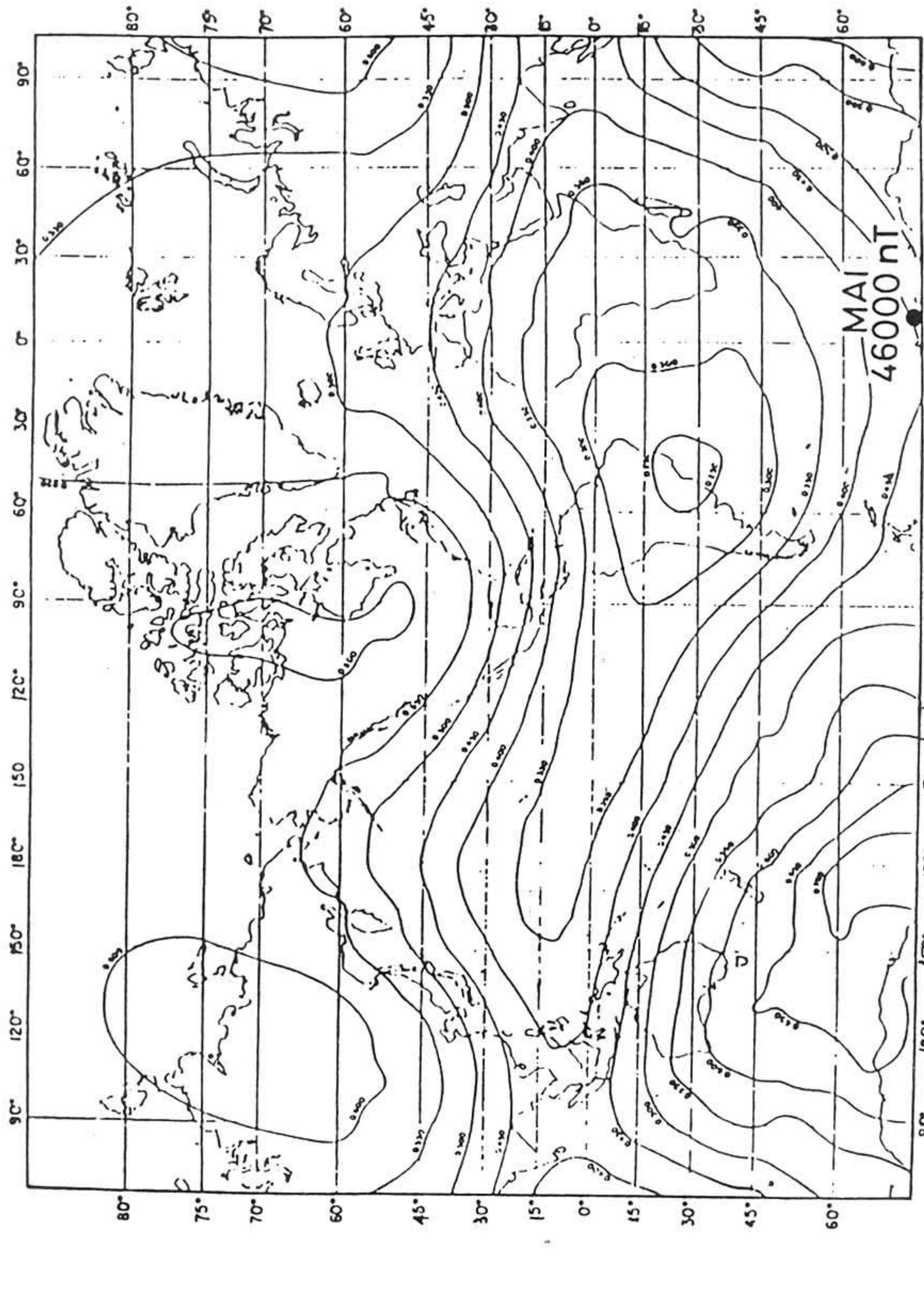


Fig.11: Isomagnetic contours of total magnetic field intensity F for 1955 (from Handbook of Geophysics 1960).

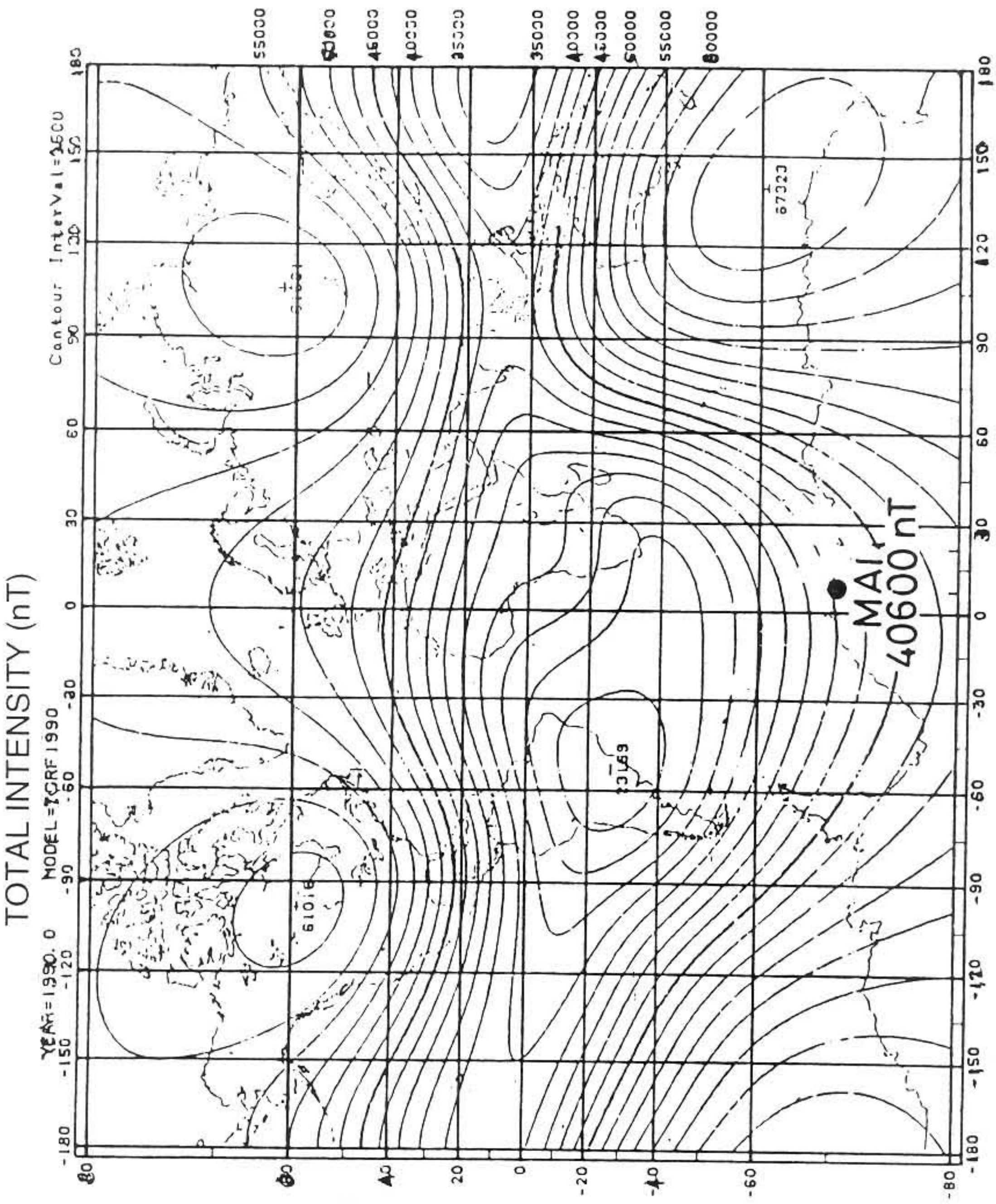


Fig. 12: Isomangetic contours of total magnetic field intensity F for 1990 (IGRF 1990 from Data Catalogue No. 23 of WDC, Kyoto, Japan).

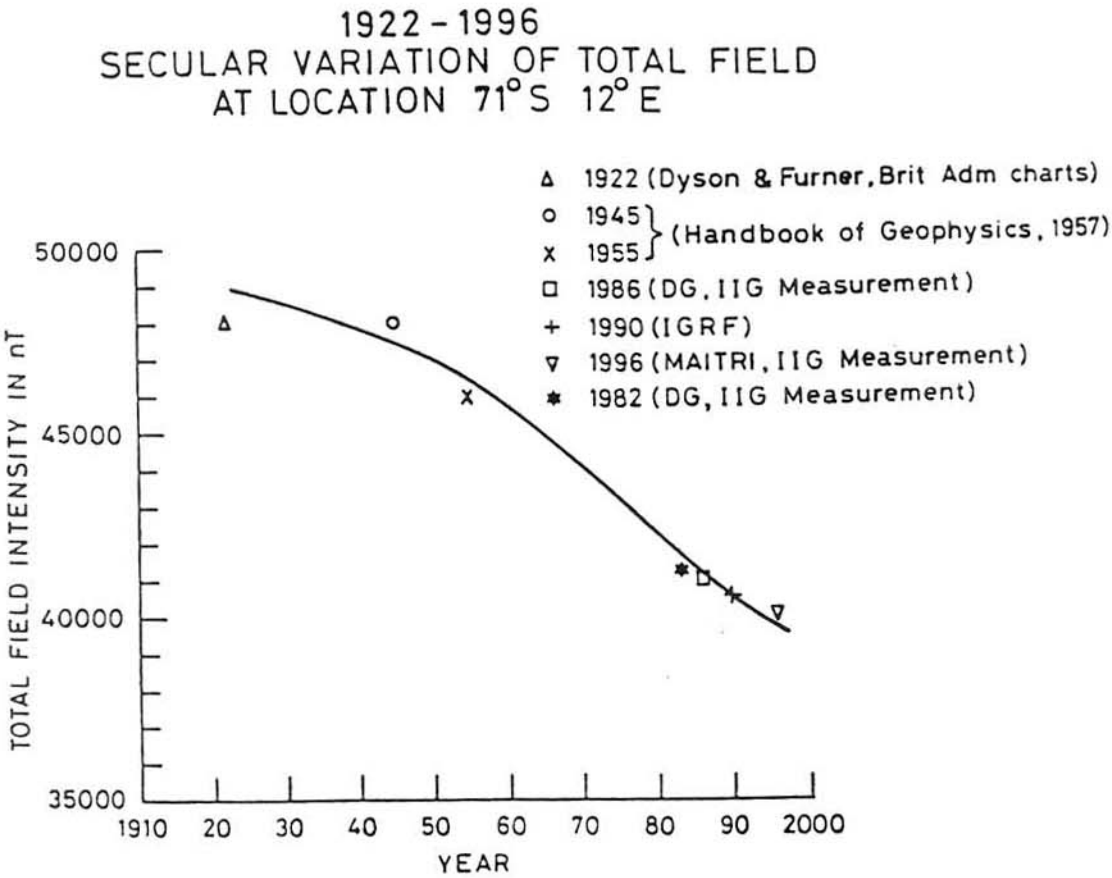


Fig. 13: Drop in magnetic field intensity F at Maitri over the past 75 years has been 9000 nT (i.e. almost 20%). The open square and inverted triangle, and the black star represent measurements at Maitri by PPM during 1982, 1986 and 1996 A.D. respectively. The remaining points are values read off from World Magnetic Charts for the years concerned, at the geographic co-ordinates of Maitri

Conclusions

From the foregoing study we conclude that :

The total magnetic field intensity F is decreasing rapidly at MAI and Hermanus in the southern hemisphere. but not at the northern hemisphere locations; this observation finds support in the work of Gubbins (1987). It also emphasises the importance of making total field intensity (F) measurements from MAI, to be used in modelling studies of the geomagnetic field.

During magnetically quiet conditions, the ΔF variations are similar to those of Δ Z variations i.e. maximum contribution to the total field F comes from the vertical component Z.

The quiet daytime variations in F and Z components show clear decrease during Jan 1996. These are due to Maitri being located poleward of the southern limb of the southern, Sq current loop.

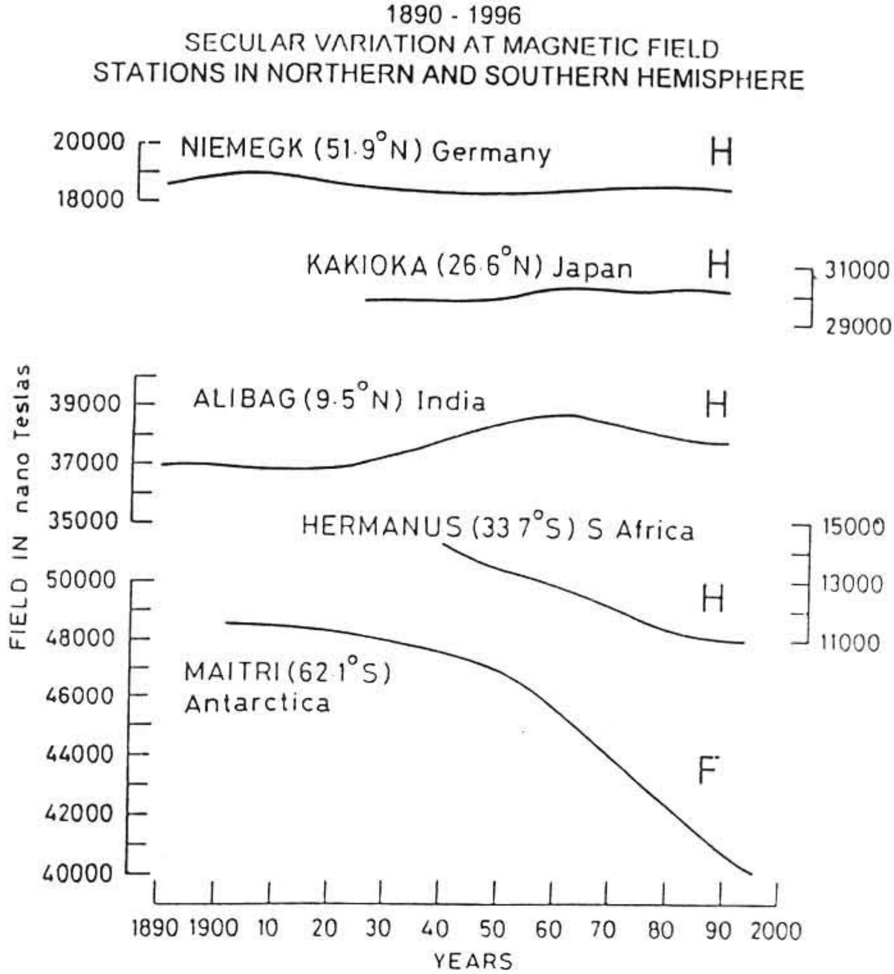


Fig. 14: Variations of the principal component of the geomagnetic field over the past century (1890-1996 A.D.) at northern hemisphere stations Niemegk, Kakioka and Alibag, and at southern hemisphere stations Hermanus and Maitri. Note how no major change is seen at the northern locations while the southern locations show a clear drop. This preferential decrease in the southern hemisphere is noticed in geomagnetic modelling studies (Gubbins 1987).

During magnetically disturbed conditions, the variations in the X and Y components also play a significant role, and contribute to Δ F because of the presence of auroral electrojet currents and field-aligned currents over Maitri.

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