—研究ノート—
Scientific Note

Change of Earth Environment Due to the Decreasing Geomagnetic Field —The Necessity of Observation in Brazilian Geomagnetic Anomaly Region—

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地球磁場の減少に伴う環境変動 —ブラジル磁気異常帯における観測の必要性—

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要旨： 最近の地球磁気の研究によると，地球磁場はこの1000年間に急速に減少しており，もし今の減少速度で減り続けると，あと1000年ほどで地球磁場がなくなってしまうと言われている．注目すべき点は，南アメリカ周辺部において，地球磁場の減少速度が特に著しいということである．この地域は南大西洋磁気異常帯として知られているように，もともと磁場強度が大変弱い所であるため，今の減少速度で推移すると，この地域の磁場はあと400年余りで消失してしまう状況にある．ところで，地球磁場はこれまで何回となく磁場反転を繰り返してきたわけであるが，近い将来，人類は大変弱い磁場環境におかれることが予想され，更には，地球磁場反転の場面に遭遇する可能性も考えられる．

他方，最近の人工衛星観測によると，地球磁場が大変弱いブラジル周辺部において，多量の高エネルギー粒子 (数MeV以上の電子及び陽子) の入射が見られることが報告されている．これらの粒子は高度数十キロメートル付近まで降下し，X線を放射していることも知られている．今後，地球磁場の減少が続くとすれば，これらの現象がますます顕著になっていくと予想される．ただ，これらの高エネルギー粒子やX線は厚い大気に阻まれ，地上までは到達していないため，地上の生態系に大きな影響を与えていないと思われる．しかしながら，超高層大気中において，これらの高エネルギー粒子が様々な電磁現象 (電磁波の発生や電子密度の変動等) を引き起こしていることが考えられる．また，最近の観測では，高エネルギー粒子の入射がオゾン層破壊を引き起こしているという報告もある．

これらの状況より，本研究は，すでに著しく磁場強度の弱いブラジル域において，超高層大気の現状を調査することにより，近い将来，地球磁場が大変弱くなった状況下における地球環境を予測することを目的としている．

Abstract **:** According to recent research on rock magnetism, the geomagnetic field intensity of our planet has been monotonically decreasing for one thousand years and it will disappear after another 1000 years if the present decreasing rate continues. It should be noted that the decreasing rate of the geomagnetic field near South America has been remarkably large. Since the total intensity of the geomagnetic field in this region is already very weak, the geomagnetic field near South America will disappear within 400 years. It is well known that earth magnetic poles have been frequently reversed during the long earth history. When the earth magnetic poles reverse, the intensity of the geomagnetic field becomes very weak. Therefore, it is considered that human beings will have to live under an extremely weak geomagnetic field in the future.

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From particle observations by satellite, a large quantity of radiation belt particles (>MeV) are precipitating into Brazilian area on account of the very weak geomagnetic field. These high energy particles, precipitating to a few tens of kilometers altitude, are radiating X-rays. If the decrease of the geomagnetic field continues, these particle precipitations will increase and the area of such phenomena will expand near the future. Fortunately, these particles and X-rays do not reach the ground because they are absorbed by the atmosphere. However, there may be a possibility that several electro-magnetic waves occurring in the upper atmosphere reach the ground. Furthermore, it is reported that high energetic solar protons induce the destruction of the ozone layer in the polar cap. So these precipitating particles may also influence the depletion of ozone in the Brazilian anomaly region.

The objective of our study is to examine the future earth's environment when the geomagnetic field becomes very weak. We can predict the future earth environment by investigating the upper atmosphere phenomena in the Brazilian region because the geomagnetic field intensity in Brazil is already extremely weak.

1. Introduction

The origin of the geomagnetic field has been examined by many researchers. Among them, the "dynamo theory" is a plausible candidate for the mechanism of the gemagnetic field. However, we cannot explain the reversal of the geomagnetic field by this model.

Figure 1 illustrates the total geomagnetic field intensity near the earth surface calculated by the 1990 IGRF model (Takeda *et al.*, 1994). In this figure, regions with large geomagnetic intensity (>60000 nT) are seen in the northern Canada, the central Siberia and the Antarctic ocean near Australia. The northern and the southern magnetic poles are in Canada and the Antarctic ocean, respectively. However, it is not known why the geomagnetic intensity is so strong in the central Siberia. On the other hand, a region of weak geomagnetic intensity is found near the southern Brazil, its magnitude is less than 24000 nT. It is also not well understood why the geomagnetic field is so weak in the Brazilian area. This region is called the Brazilian geomagnetic anomaly or the South Atlantic geomagnetic anomaly. It is considered that the geomagnetic anomalies in Siberia and Brazil may be related to the dynamics of the outer core. However, their occurrence mechanism has been not sufficiently examined yet.

According to the history of geomagnetic field variations, the earth's magnetic field is not so stable and it is always fluctuating. Figure 2 illustrates the variation of dipole geomagnetic field intensity as reported by McElihinny and Senanayake (1982). They show that the geomagnetic field intensity began to decrease about 1000 years ago and is still decreasing. The magnitude of the present geomagnetic field intensity is about 60% compared to the geomagnetic intensity of 1000 years ago. Furthermore, the decreasing rate of geomagnetic field intensity is recently accelerating; its rate is now 0.07% per year (Cain, 1978).

Figure 3 shows the variation of total geomagnetic field intensity obtained at Syowa Station from 1981 to 1994. The intensity of the geomagnetic field was 44700 nT in 1981 and decreased to 43689 nT in 1994. Thus, it decreased by about 1000 nT during 13 years and the average decreasing rate is about 77 nT per year. If the geomagnetic field intensity continues to decrease at this rate, the geomagnetic field at Syowa Station will disappear within 600 years. The rapid decrease of geomagnetic field at Syowa Station may induce an interesting phenomena in the conjugate observations between Syowa and Iceland. Since the geomag-

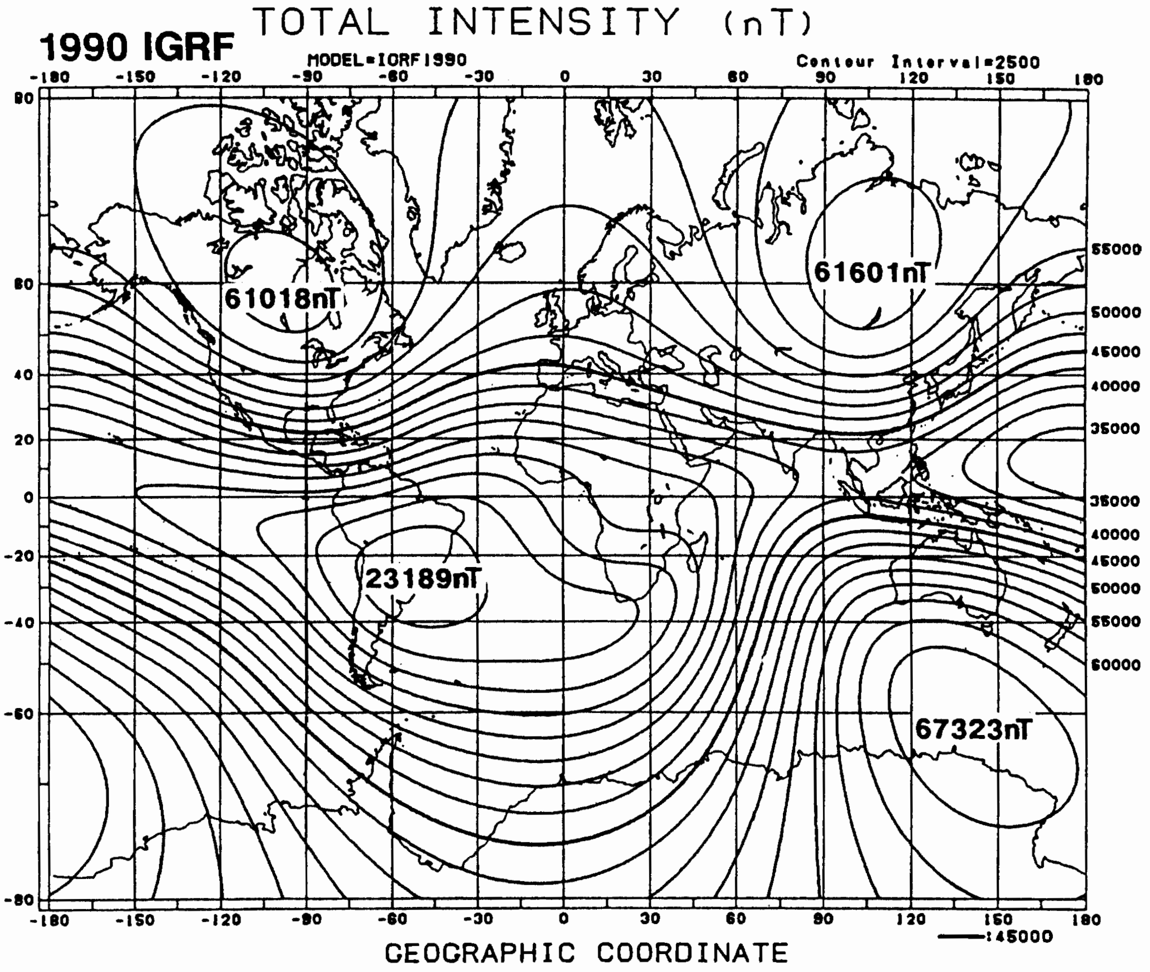

Fig. 1. Contour map of total geomagnetic intensity in 1990 IGRF model. The geomagnetic intensity in the southern part of Brazil is extremely weak (after Data Catalogue, Kyoto University, 1993).

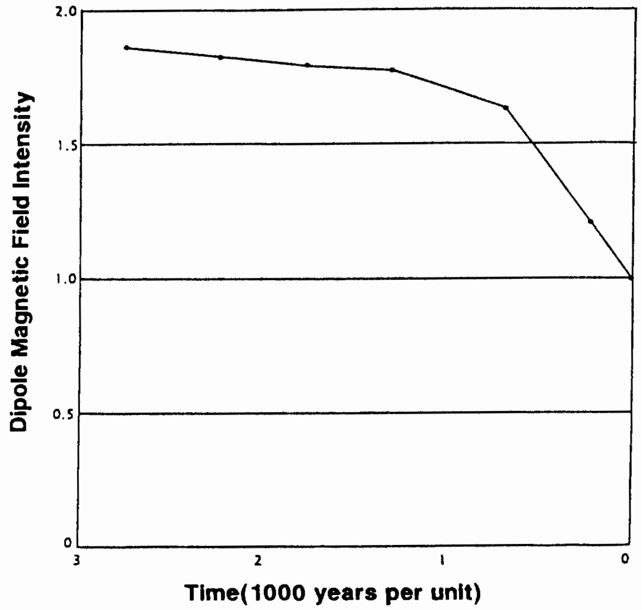

Fig. 2. Variations of geomagnetic field intensity from 3000 years ago. The decreasing of the geomagnetic field remarkably began 1000 years ago (after McElhinny and Senanayake, 1992).

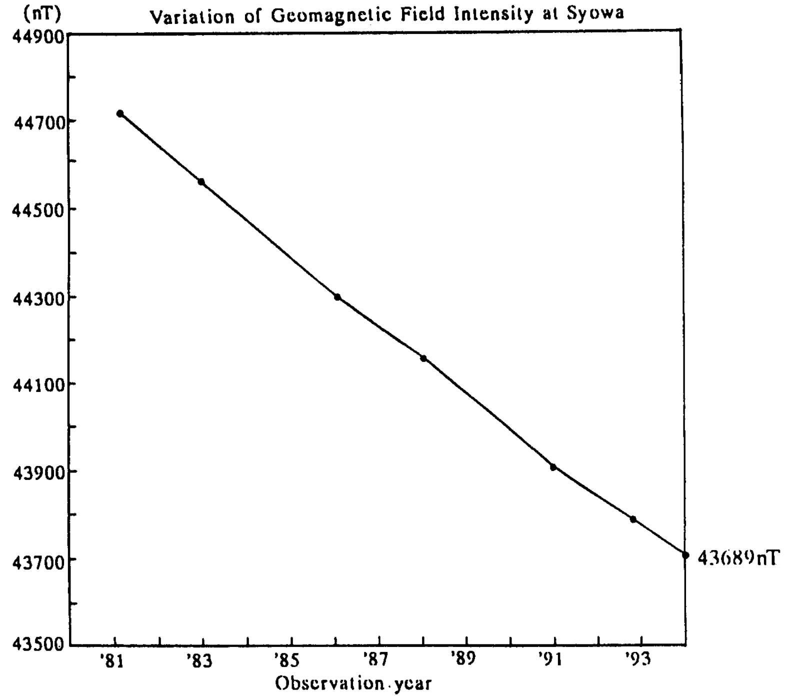

Fig. 3. Variations of total geomagnetic intensity at Syowa Station, Antarctica. The geomagnetic intensity decreased 1000 nT from 1981 to 1994 at Syowa Station.

netic field intensity in Iceland is about 51520 nT in 1996, the geomagnetic field at Syowa Station is weaker than that in Iceland by about 7830 nT. Although remarkable phenomena related to the difference of geomagnetic field intensity at conjugate stations has not been reported yet, several asymmetric phenomena must exist and can be expected to appear in quantitative conjugate observations.

The variation of the geomagnetic field is different from point to point on the earth's surface. Figure 4 shows the annual change of total geomagnetic field intensity as examined by PEDDIE (1982). From this figure, a large decreasing rate (~ -100 nT/year) is seen in the West Indian Islands, the south of Africa and the Antarctic Peninsular. These regions are surround South America where the geomagnetic intensity is extremely weak. If the decreasing rate dose not change in the future, the geomagnetic field will disappear after 400 years in these regions. The decreasing rate in the center of the Brazilian anomaly is not so large (~ -30 nT/year). It seems that the geomagnetic anomaly is expanding in the area surrounding the Brazilian anomaly region. On the contrary, on the Eurasian Continent including Japan, Siberia and Europe, the geomagnetic field intensity is increasing ($\sim +20$ nT/year). The increase on the Eurasian Continent seems to be related to the Siberian geomagnetic anomaly where the intensity is extremely large (>60000 nT).

From the record of geomagnetic field variations, reversals of geomagnetic poles have occurred many times. It is reported that the present gemagnetic field appeared 700 thousand years ago. However, short period geomagnetic reversals frequently took place within these 700 thousand years. It is also found that the decrease of geomagnetic field does not always connect to the reversal of geomagnetic poles. Therefore, we cannot predict whether the present decrease indicates the reversal of geomagnetic poles or merely fluctuation of the geo-

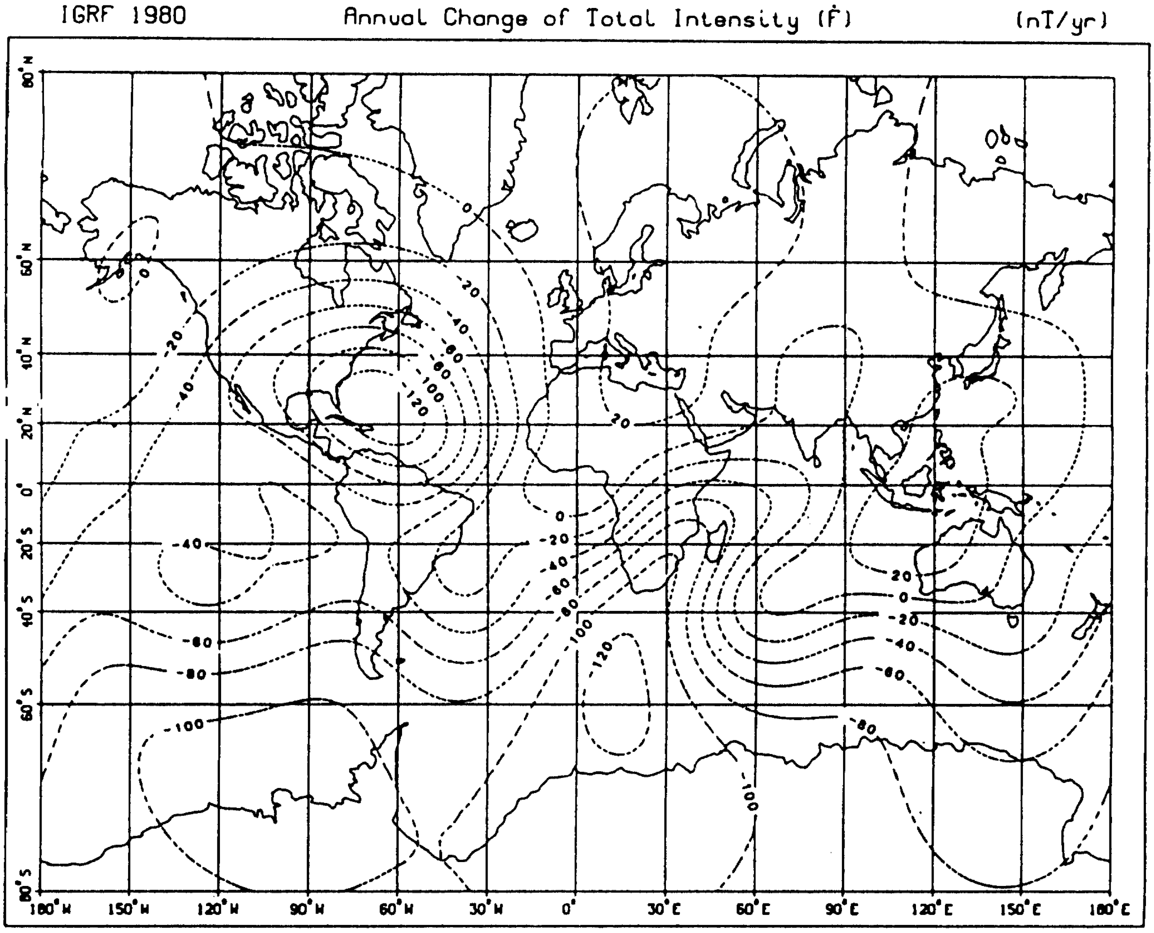

Fig. 4. Annual change of total geomagnetic intensity ($\dot{F}$) in the 1980 IGRF model. A large decreasing rate (~ −100 nT/year) is seen in the area surrounding South America (after Peddie, *1982).*

magnetic field. Some researchers speculate that a "magnetic nuclear spot" is growing under the Brazilian anomaly region. This spot is the opposite direction of the present geomagnetic field and if it becomes strong and expands much more, a geomagnetic field reversal will occur in the near future.

2. Upper Atmosphere Phenomena in the Brazilian Anomaly Region

Generally, high energy particles from the sun or from a distant galaxy cannot reach the earth's surface thanks to deflection by the geomagnetic field. However, such particles can directory enter into the polar cap region where the geomagnetic field lines are open. High energy particles are also stably trapped in the radiation belt (Van Allen belt) and surround the earth in a doughnut-shaped pattern.

Recently it has become clear that a large quantity of high energy particles are precipitating in the South Atlantic anomaly region. Figure 5 illustrates the distributions of precipitating particles observed by the "OHZORA" satellite (Kohno *et al.*, 1990). This figure shows the electron (0.91–3.2 MeV) and proton (0.64–35 MeV) data obtained at the altitude

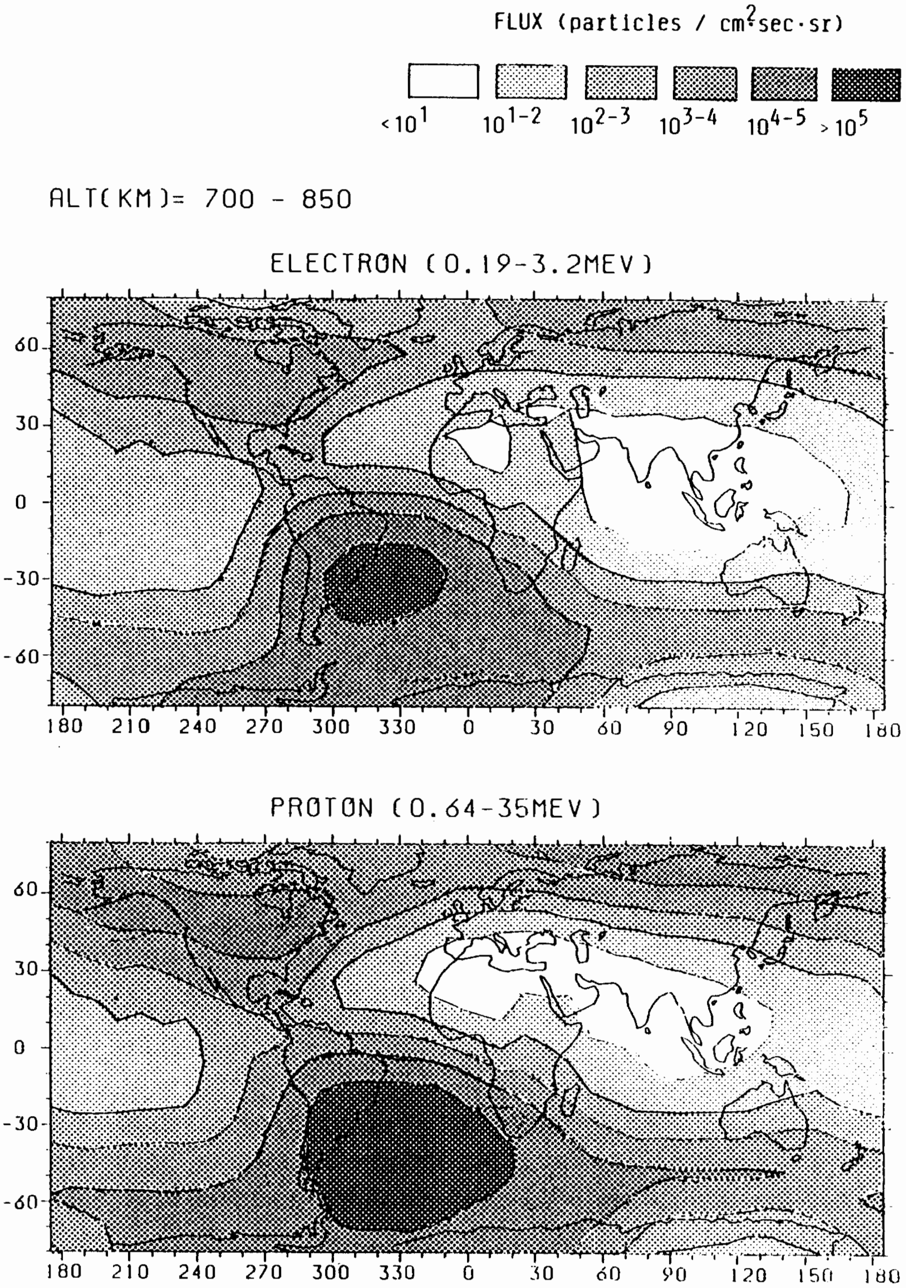

Fig. 5. Global distribution of electron (0.19–3.2 MeV) and proton (0.64–35 MeV) observed by OHZORA. No geomagnetic conditions are selected. The data used in these plots were obtained at altitude 700–850 km from Feburary 1984 to January 1987. A large number of electrons and protons ($>10^5$ particles /cm^2 s sr) are precipitating over the South Atlantic anomaly region (After KOHNO et al., 1990).

of 700–850 km. These data clearly indicate a large number of electrons and ions precipitating in the Brazilian anomaly region. The number flux of precipitating particles is larger than 10^5 particles/cm s sr in this region. Those particles can penetrate to the low altitude where they collide with neutral particles and excite X-rays. In fact intense X-rays are observed by satellites in this region.

The satellite instruments are frequently damaged by these high energy particles. Figure

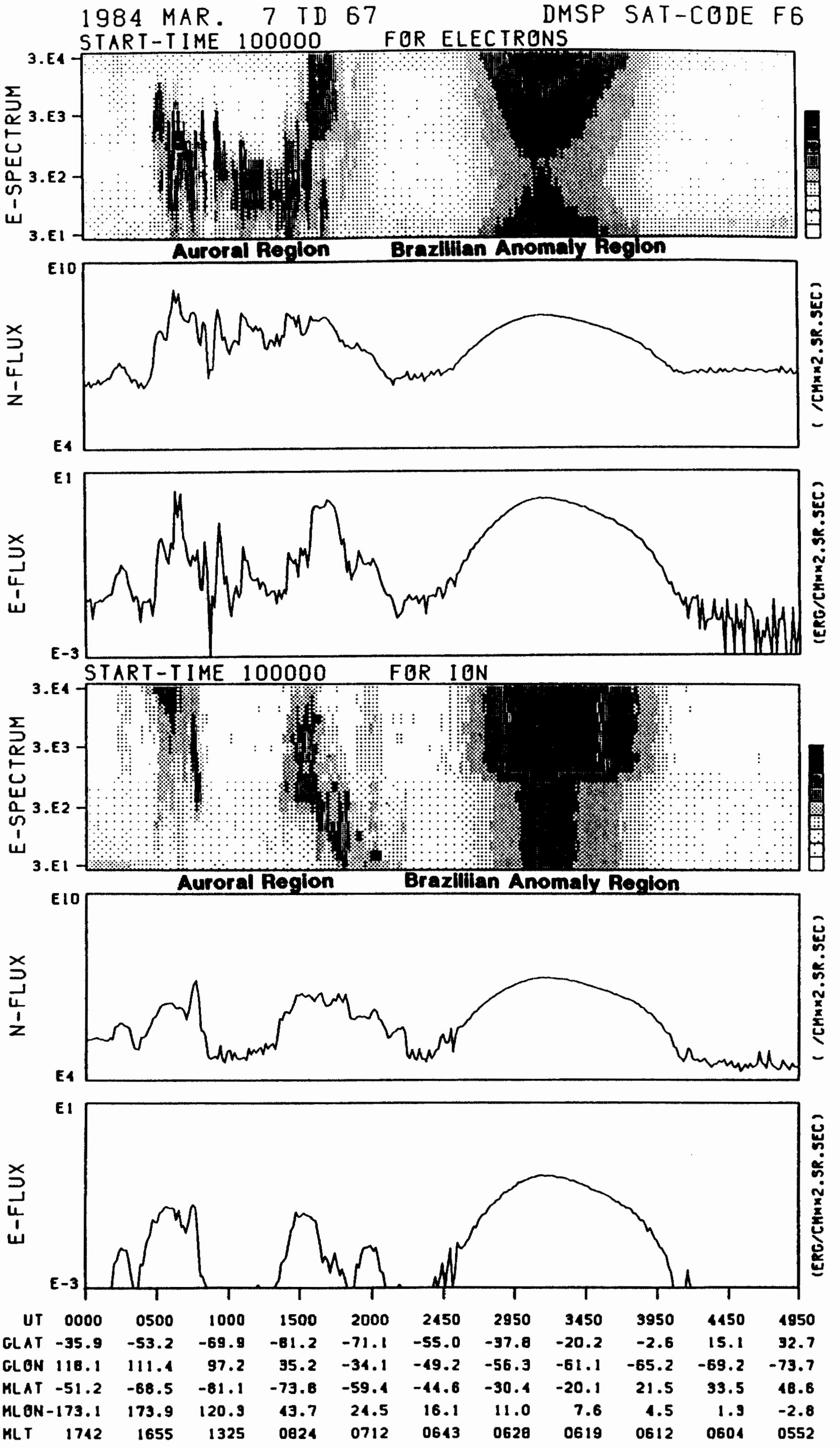

Fig. 6. Electron and proton (30 eV–30 keV) precipitation data observed by DMSP/F6. The large number flux over the Brazillian anomaly region is due to miscounting on acount of collisions between high energy particles and particle detectors.

6 shows electron and ion data in the southern hemisphere obtained by DMSP/F6. The altitude of this satellite is about 840 km and the energy range of the particle detector is from 30 eV to 30 keV. The upper three panels show the energy spectrum, number flux and energy flux for electrons. The lower three panels show the same for ions. We see that the electron and ion particles are precipitating in the aurora region (−68.5 ~ −59.4 MLAT). These particles excite optical aurora as is well known. It is noted that large electron and ion fluxes are also seen in the Brazilian anomaly region (−30.4 ~ −20.1 MLAT). However, these number fluxes do not indicate real precipitating particles. Since the precipitation electron and ion energies in this region are higher than a few MeV, these high number fluxes must be caused by 2nd electrons due to collisions between high energy particles and the satellite particle detector. This example indicates the difficulty of detection of low energy particles (<40 keV) in the anomaly region by a satellite.

Generally, high energy particles and X-rays are absorbed by the atmosphere and do not reach the ground. However, it is believed to be possible for electro-magnetic waves or optical emissions excited by these particles propagate to the ground. Electro-magnetic waves seem to be excited by synchrotron radiation and their wave frequency range may be a few tens of MHz. The luminosity of optical emission seems to be very weak even if these particles excite the emission. Since such observations have not been carried out in this region before, new and systematic observations will help to clarify the spatial and temporal effect of precipitation from the radiation belt.

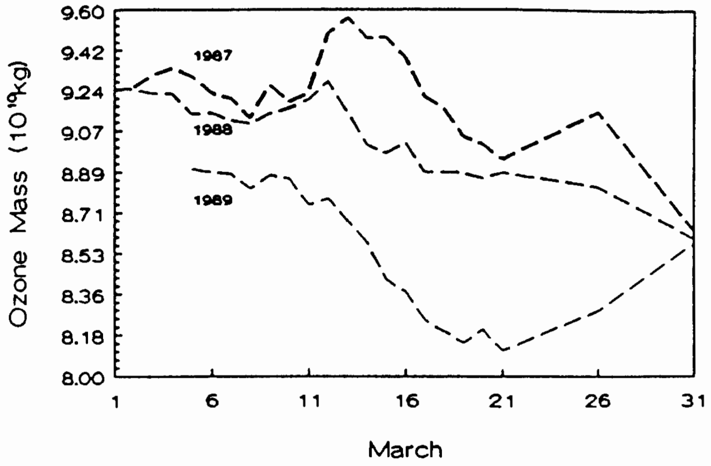

Fig. 7. Variations of total ozone intensity due to solar proton precipitation in the polar cap. The enhancement of solar protons occurred in March 6 in 1989 (After STEPHENSON and SCOURFIELD, 1992).

It has recently been reported that solar protons destroy the ozone layer (STEPHENSON and SCOURFIELD, 1992). Figure 7 illustrates the decrease of total ozone in the polar cap region due to a solar proton. The solar flare event occurred in March 6, 1989 and was followed by high energy proton precipitation in the polar cap region. The decrease of total ozone began on March 8 and the total ozone amount reached to a minimum at 8.18 × 10^{10} kg on March 21, 1989. Since the average total ozone was about 9.0 × 10^{10} kg in the preceeding years (1987, 1988) with no solar proton event, the total ozone decreased by 9% during this period. Although this event was observed in the polar cap region, it may be possible that such destruction of ozone occurs in the anomaly region because similar high energy particles are precipitating.

3. Necessity of Ground Observation in Brazilian Anomaly Region and Antarctica

From several satellites' observations, it has become clear that high energy particles are precipitating in the Brazilian anomaly region. However sufficient ground observations have not been carried out. Therefore, we do not know what kind of phenomena are occurring in the upper atmosphere above this region and how our future earth environment will be changed by particle precipitation. It seems important for human beings to make clear the variation of future earth environment in association with the decreasing geomagnetic field. This is because the geomagnetic field will become much weaker within a few hundred years and the high energy particle precipitation region will expand world wide.

Furthermore, the geomagnetic anomaly region occupies a wide area on the earth's surface, especially in the southern hemisphere. Syowa Station, Antarctica is also locates in this region. Conjugate observations for upper atmosphere phenomena had already been carried out by the National Institute of Polar Research for ten years. The magnetic field lines connect between Syowa Station, Antarctica and Hussafell, Iceland and similar conjugate phenomena are observed simultaneously. However, the magnetic field intensity is quite different between these conjugate points. Therefore, the amount of precipitating particles in both hemispheres seems to be different and several asymmetric phenomena due to the magnetic

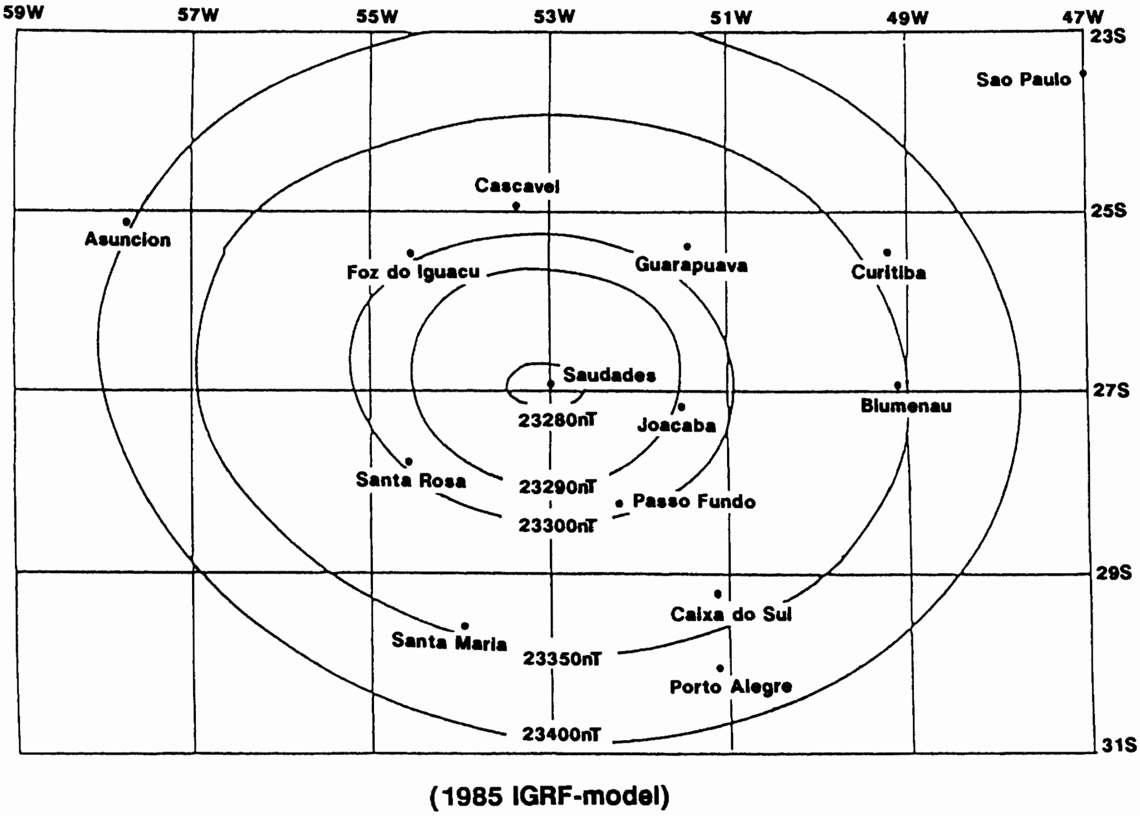

Fig. 8. Contour map of geomagnetic field intensity near the center of the Brazilian anomaly region in the 1985 IGRF model. Several instruments will be installed at INPE and Santa Maria University.

field difference must be found by this conjugate observation. Since the magnetic field intensity at Syowa Station is decreasing rapidly, several asymmetric phenomena will appear more clearly near the future.

We started the sounding of upper atmosphere phenomena in the Brazilian anomaly region in 1987. A fluxgate magnetometer and an induction magnetometer were installed at Blumenau in Brazil in cooperation with INPE (Brazil Space Science Institute). We could not find noticeable phenomena related to the geomagnetic anomaly at that time (MAKITA, 1988). High energy particles (>a few MeV) are precipitating to an altitude as low as 50 km, electric currents and geomagnetic pulsations excited as in auroral regions may not occur at such low altitude. If geomagnetic anomaly phenomena are really occur at an altitude lower than the ionosphere in the Brazilian region, it will be necessary to install new instruments in order to detect them.

Recently, magnetometers has been moved from Blumenau to Santa Maria in Brazil. Figure 8 illustrates the total geomagnetic field intensity calculated from the 1985 IGRF model. The center of the geomagnetic anomaly is located at 27°S and 53°W in geographic coordinates and its intensity is 23200 nT. The observation point of Santa Maria is 300 km south of the anomaly center and its intensity is 23350 nT. We are planning to observe several upper atmosphere phenomena at Santa Maria (MAKITA, 1994). Total ozone, airglow and other aeronomy observations will also be carried out at the INPE observatory where is located near Sao Paulo

References

CAIN, J.C. (1987): The earth as a magnet. The Solar Wind and the Earth, ed. by S.-I. AKASOFU and K. KAMIDE. Dordrecht, D. Reidel, 55–69.

KOHNO, T., MUNAKATA, K., NAGATA, K., HASEBE, N., KIKUCHI, J. and DOKE, T. (1990): Intensity maps of MeV electrons and protons below the radiation belt. Planet. Space Sci., **38**, 483–490.

MAKITA, K. (1988): Micro-pulsation at Brazillian anomaly region. Rev. Takushoku Univ., **175**, 1–18 (in Japanese).

MAKITA, K. (1994): Study of earth environment due to the decreasing of geomagnetic field. Rev. Takushoku Univ., **206**, 115–130 (in Japanese).

MCELIHINNY, M.W. and SENANAYAKE, W.E. (1982): Variations in the geomagnetic dipole 1: The past 50,000 years. J. Geomagn. Geoelectr., **34**, 39–51.

PEDDIE, N.W. (1982): International geomagnetic reference field: The third generation. J. Geomagn. Geoelectr., **34**, 309–326.

STEPHENSON, J.A.E. and SCOURFIELD, M.W. (1992): Ozone depletion over the polar caps caused by solar protons. Geophys. Res. Lett., **19**, 2425–2428.

TAKEDA, M., IYEMORI, T. and KAMEI, T. (1993): Data Catalogue. World Data Center C2 Geomagn. Data Book, **23**, 175.

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