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Solar cycle 22 control on daily geomagnetic variation at Terra Nova Bay (Antarctica)

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Abstract
Nine summer geomagnetic observatory data (1986-1995) from Terra Nova Bay Base, Antarctica (Lat. 74.69°S, Long. 164.12°E, 80.04°S magnetic latitude) are used to investigate the behaviour of the daily variation of the geomagnetic field at polar latitude. The instrumentation includes a proton precession magnetometer for total intensity |***F***| digital recordings; *DI* magnetometers for absolute measuring of the angular elements *D* and *I* and a three axis flux-gate system for acquiring *H*, *D* and *Z* time variation data. We find that the magnetic time variation amplitude follows the solar cycle evolution and that the ratio between minimum solar *median* and maximum solar *median* is between 2-3 for intensive elements (*H* and *Z*) and 1.7 for declination (*D*). The solar cycle effect on geomagnetic daily variation elements amplitude in Antarctica, in comparison with previous studies, is then probably larger than expected. As a consequence, the electric current system that causes the daily magnetic field variation reveals a quite large solar cycle effect at Terra Nova Bay.

Key words *magnetic variations – daily variation – Antarctica*

1. Introduction

The study of upper atmosphere and magnetosphere phenomena by means of geomagnetic field observations plays an important role in the understanding of the Earth's electromagnetic environment. Among ground observations, polar region measurements are a major tool of investigation since, for example, a direct access of solar wind particles and fields is possible, under certain particular conditions (see for example Akasofu *et al.*, 1983; Friis-Christensen *et al.*, 1985; Russel, 1986; Engebretson *et al.*, 1995) only in polar areas and particularly in the cusps. In these locations, in a static model of the magnetosphere (see for example Hargreaves, 1992), the Earth's magnetic field lines, closed within the lower latitude magnetosphere, are separated from those at higher latitude that are swept back tailward and can be connected to the interplanetary magnetic field. This direct connection of polar regions to the boundary between the magnetosphere and the solar wind (the so-called magnetopause) is one of the causes of some special phenomena like dayside auroral emissions and magnetic substorms. Knowledge and understanding of the physics of auroras and substorms is leading to a more complete view of the interactions and the underlying processes

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that exist among the various components of the magnetosphere-solar wind system (see for example McPherron,1991).

Magnetic field fluctuations measured on the ground in polar regions by means of magnetic observatories are therefore a tool of investigation for many plasma processes (see for example Villante *et al.*, 1997). In Antarctica, only a few observation points exist; their data have been used individually and with conjugate hemisphere data to better understand the topological behaviour of the magnetosphere (see for example Lanzerotti *et al.*, 1982, 1994; Papitashvili *et al.*, 1990).

The magnetic daily variation called S_q (from Solar and quiet) is typically represented at an observatory by the average of field values from a selection of the 5 quietest days of the month (see for example Campbell, 1989). The daily variation of the geomagnetic field as observed in the polar cap regions, cannot however simply be attributed to a polarward extension of the mid (low) latitude S_q electric current vortices that exist in the ionosphere (see for example Campbell, 1989). A special additional current contribution appears to be necessary (see for example Nishida and Kokubun, 1971; Ratcliffe, 1972). The daily polar variation can be represented also by means of an equivalent electric current system that flows in the polar region (see for example Matsushita and Xu, 1981, 1982).

In this paper, an analysis of Terra Nova Bay geomagnetic observatory data obtained after the installation of the geomagnetic observatory, at the Italian Base is reported (for a previous study on daily variation on Terra Nova Bay data see Meloni *et al.*, 1992a). The focus is on the daily variation of the geomagnetic field during solar cycle 22 and control of solar activity on daily variation behaviour.

2. The geomagnetic observatory

The Italian Base in Antarctica is equipped with a magnetic observatory that began operations in 1986/87 and is located at geographic latitude 74.695°S; geographic longitude 164.124°E; corresponding to IGRF 1990 magnetic latitude 80.04°S; magnetic longitude 307.38°E (fig. 1).

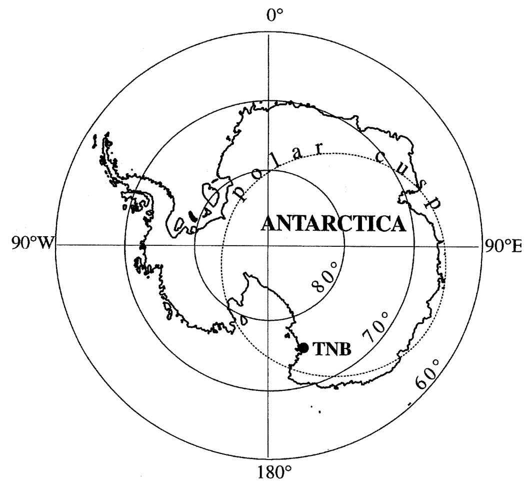

Fig. 1. Terra Nova Bay (TNB) geomagnetic observatory location.

The instrumentation includes a proton precession magnetometer for total intensity $|F|$ digital recordings; *DI* magnetometers for absolute measurement of the angular elements *D* and *I* and a three axis flux-gate system for acquiring *H*, *D* and *Z* time variation data (Azzara *et al.*, 1991; Meloni *et al.*, 1992b, 1997). Since the fluxgate magnetometer reference frame, used for components recording, was for convenience magnetically oriented in the horizontal plane, a mathematical procedure was applied for computing *H* and *D* time variation starting from the flux-gate built in reference frame orthogonal elements. The absolute measurements independently taken, were put into a mathematical procedure in order to determine baseline values for the relative flux-gate measurements; one minute absolute average values of the three elements *H*, *D* and *Z* were finally obtained (Azzara *et al.*, 1989, 1990, 1991; Bozzo *et al.*, 1992, 1994, 1995, 1996; Cafarella *et al.*, 1998). In fig. 2 *D*, *H* and *Z* magnetic field elements time variation for 1990/1991 summer expedition are shown, as an example for available

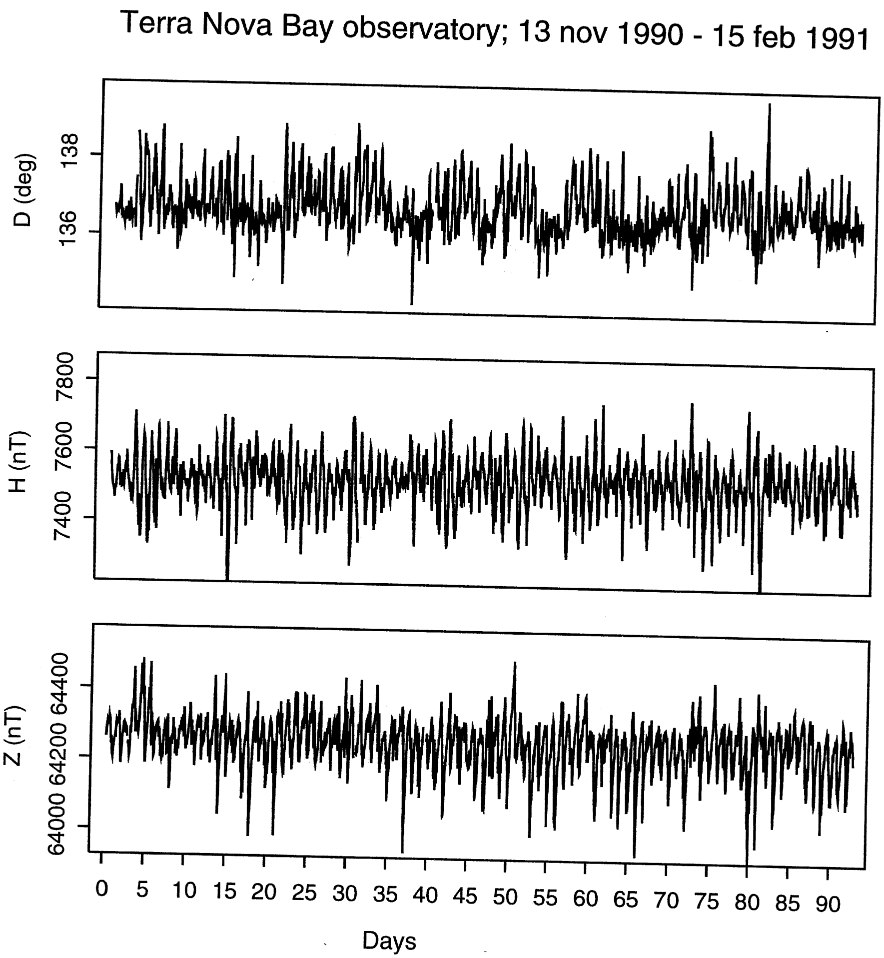

Fig. 2. Magnetic field elements hourly means as recorded at Terra Nova Bay observatory from November 13th, 1990 till February 15th, 1991.

days, by their hourly means. A clear daily variation pattern in the form of an harmonic wave appears in the total field as well as in all elements. Since the Terra Nova Bay Base is manned only during the austral summer, an automatic wintering-over system was also established to record magnetic field time variations also in the winter. However in this study only summer data from 1986-87 till 1994-95, with a baseline control defined by the absolute measurements, were used .

3. Daily variation analysis

In order to study the influence of the solar cycle on daily variation as observed at Terra Nova Bay, all individual days starting from summer hourly means were used. The mean hourly values for *D*, *H* and *Z* elements were processed and box-plot statistics (see for example Kleiner and Graedel, 1980) was performed. The characteristic pattern of daily variations at Terra Nova Bay as a result of the 1994/95 anal-

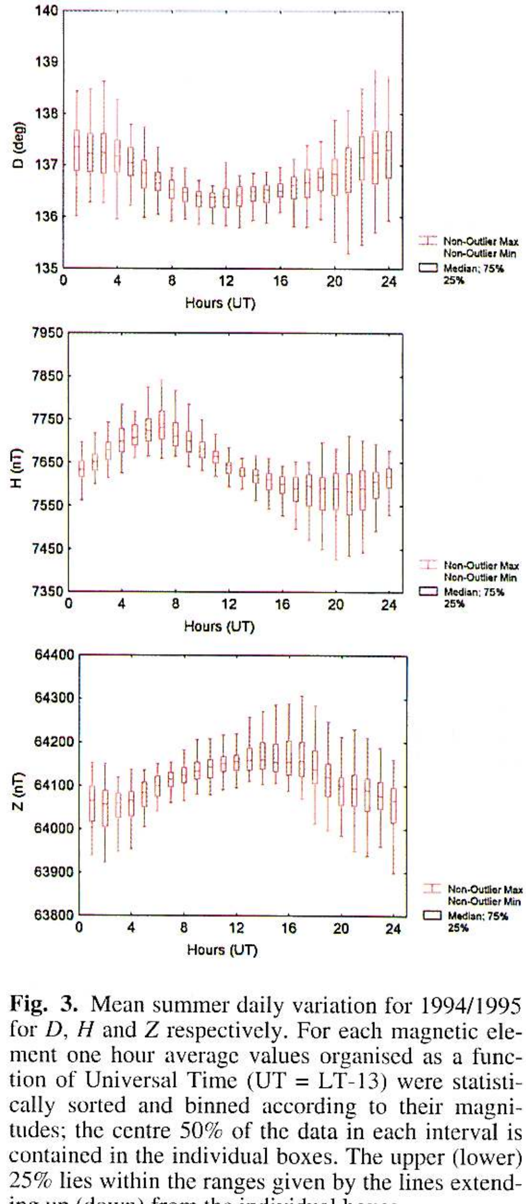

Fig. 3. Mean summer daily variation for 1994/1995 for *D*, *H* and *Z* respectively. For each magnetic element one hour average values organised as a function of Universal Time (UT = LT-13) were statistically sorted and binned according to their magnitudes; the centre 50% of the data in each interval is contained in the individual boxes. The upper (lower) 25% lies within the ranges given by the lines extending up (down) from the individual boxes.

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The evolution of the median value of daily variation amplitudes during summer through solar cycle 22 is plotted in figs. 4a-c and fig. 5b-d where the variation in the daily amplitude ranges for all elements is shown. In each panel of fig. 4a-c the median minimum level reached (circles) and the median maximum (triangles) level reached, are shown *versus* time. Since hourly values reported in this plot are absolute data, secular variation is also clearly observable in fig. 4a-c as a linear trend for each magnetic element. The range of median variation follows solar activity with a small variation range in 1986, 1987, 1991 and 1994, when sunspot number is low with respect to the other years of solar cycle 22 (fig. 5a). The median daily range (peak to peak) can be seen, for every year, in fig. 5a-d. Looking for example at the horizontal element *H*, (in panel 4b and 5c), while the range centred at 1986.5 (for convenience intended as the 1986-1987 recording period) amounts to circa 90 nT, in 1991.5 (for convenience intended as the 1991-1992 recording period) the same element range increases up to more than 290 nT. This increase, revealed in all magnetic elements, is due to the increase in solar activity during the same years as appears from the simultaneous sunspot numbers increase (fig. 5a). The ratio between the maximum range of the median and the minimum is 3.2 for *H*, 1.9 for *D* and 1.8 for *Z*.

4. Discussion

The study of time variations of the geomagnetic field in general and especially at polar latitude stations, continues to receive considerable attention. In fact the monitoring of this geophysical parameter is fundamental to magnetic

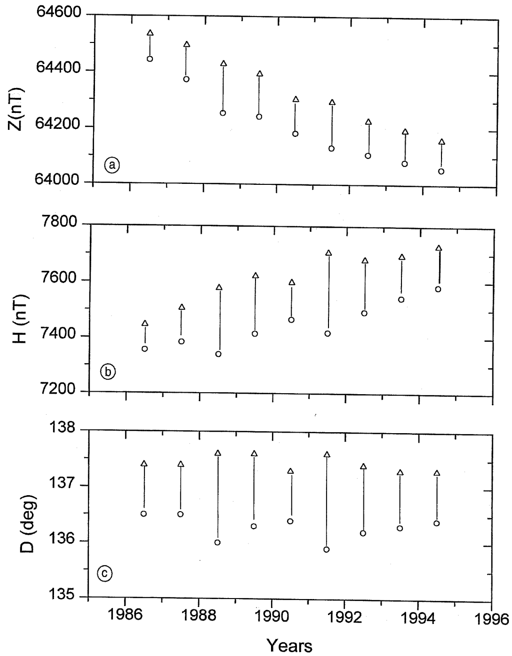

Fig. 4a-c. Vertical (a), declination (b) and horizontal (c) median daily ranges as recorded during the nine years installation.

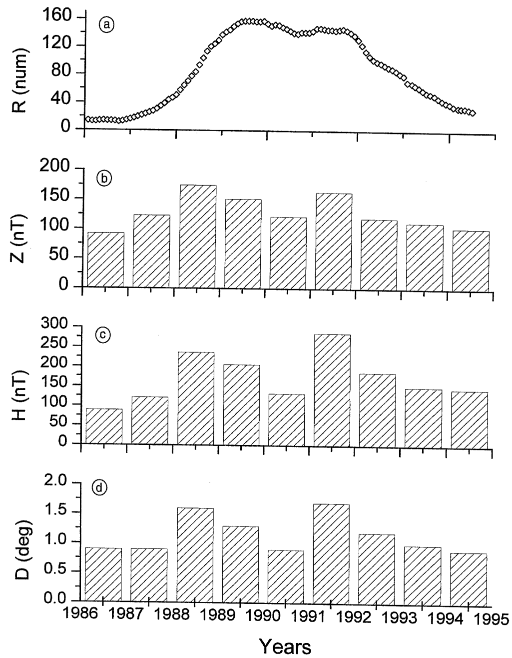

Fig. 5a-d. Sunspot number (a) and daily variation excursion from 1986/1987 to 1994/1995 summers for Z (b), H (c) and D (d) respectively.

field survey data reduction as well as to a better understanding of the Earth's magnetosphere structure and evolution, and to the study of solar control of geomagnetic activity. The diurnal variation of geomagnetic field elements is a well known phenomenon that has been extensively studied, mainly for the so-called quiet days, when other perturbing factors do not disturb the regular daily pattern. An equivalent electric current system is often used to represent the source of the observed field. The equivalent current system consists of two current vortices, one for each hemisphere, centred at about 40° latitude N and S respectively; a dynamo process in the upper atmosphere is responsible for the electric current generation. A special additional contribution to S_q appeared necessary in order to justify the polar daily variation plots; in fact the extrapolation to high latitudes of the equivalent current system was not satisfactory but a superposition of an additional field had to be taken into consideration.

This new field was called S_q^d (Solar quiet polar) or DP_2 according to various authors (Nishida and Kokubun, 1971; Ratcliffe, 1972). The quiet daily polar variation field can also presented by means of a global equivalent electric current system flowing only over the polar region (Matsushita and Xu, 1981, 1982). The probable cause of the polar current system is the magnetospheric convection that generates a quasi permanent current system in polar regions which is steadily oriented with respect to the Sun-Earth line; the Earth rotation underneath this system causes the magnetic field elements daily variation. Such a current system is generally represented by means of two contributions respectively formed by: a) a dynamo process that results in a current flowing across the pole; and b) two current cells: a counter-clockwise cell in the afternoon-evening sector and a clockwise cell in the forenoon morning sector (Akasofu *et al.*, 1983).

In this paper an analysis of part of the solar cycle 22 control on the daily geomagnetic variation has been made using the Terra Nova Bay Antarctic geomagnetic observatory. It appears that the daily current system that causes primarily the *S* field shows a quiet large solar cycle effect at Terra Nova Bay southern hemisphere station. As is well known, the solar cycle effect also appears analysing mid latitude station geomagnetic variations; it is shown that the ratio of the total equivalent current systems intensity computed for a maximum solar activity, the IGY (International Geophysical Year), to a minimum solar activity period, IQSY (International Quiet Solar Year), is approximately 2 for S_q variation (Matsushita and Xu, 1981). This amplitude ratio is, however, not yet completely confirmed for southern polar cap stations. This study points out that for the latitude of about 75° (77° magnetic) an Antarctica observatory shows that the magnetic variation amplitude ratio between quiet and perturbed years is approximately 3 for intensive element *H*, 1.8 for *Z* and 1.9 for declination. Although this analysis is limited to only a nine year period data set and to data from only one polar station, the behaviour found leads to believe that the solar cycle effect on geomagnetic daily variation amplitude for this solar cycle in Antarctica is larger than that previously expected.

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