Magnetic and solar effects on ionospheric absorption at high latitude

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Abstract
Some periods of intense solar events and of strong magnetic storms have been selected and their effects on the ionospheric D region have been investigated on the basis of ionospheric absorption data derived from riometer measurements made at the Italian Antarctic Base of Terra Nova Bay (geographic coordinates: 74.69 S, 164.12 E; geomagnetic coordinates: 77.34 S, 279.41 E). It was found that sharp increases in ionospheric absorption are mainly due to solar protons emission with an energy greater than 10 MeV. Moreover, the day to night ratios of the ionospheric absorption are greater than 2 in the case of strong events of energetic protons emitted by the Sun, while during magnetic storms, these ratios range between 1 and 2.

1. Introduction

The electron density below 80 km in the ionosphere is greatly dependent on the chemistry of this region that is in turn affected by direct solar radiation (Ranta *et al.*, 1984). Under disturbed conditions, one of the principal causes of ionization in the *D* region is due to the influx of the energetic particles penetrating the atmosphere that increase the electron density and then the ionospheric absorption. Therefore the ionospheric absorption is a suitable parameter to disclose the effects on the lower ionosphere due to the magnetic and solar activity.

During and after magnetospheric storms two types of ionospheric absorption in the D region can be observed (see, *e.g.*, Ranta et al., 1984, and references therein):

a) An ionospheric absorption increasing at high latitude during the main phase of the magnetospheric storms.

b) An ionospheric absorption increasing during the recovery phase of the magnetospheric storms, clearly separated from the first one, well known as 'Post-Storm Effects' (PSE) (Bremer, 1998) at mid-latitude.

The poleward boundary of PSE has been found to be a function of storm-time, reaching even L = 4 (Wagner *et al.*, 1982). As Terra Nova Bay is a polar station located outside the PSE poleward boundary, the first component (a) is expected to be the main effect of magnetic perturbations on the absorption data.

Another important type of absorption that can occur at high latitudes, is the so-called Polar Cap Absorption (PCA). This event is caused by energetic protons emitted by the Sun in connection with major solar flares. The main effects of PCA absorption are seen at lower altitude (60, 70 m) more than other types of absorption due for example to magnetospheric storms. The chemistry of the ionized constituents is markedly different and this

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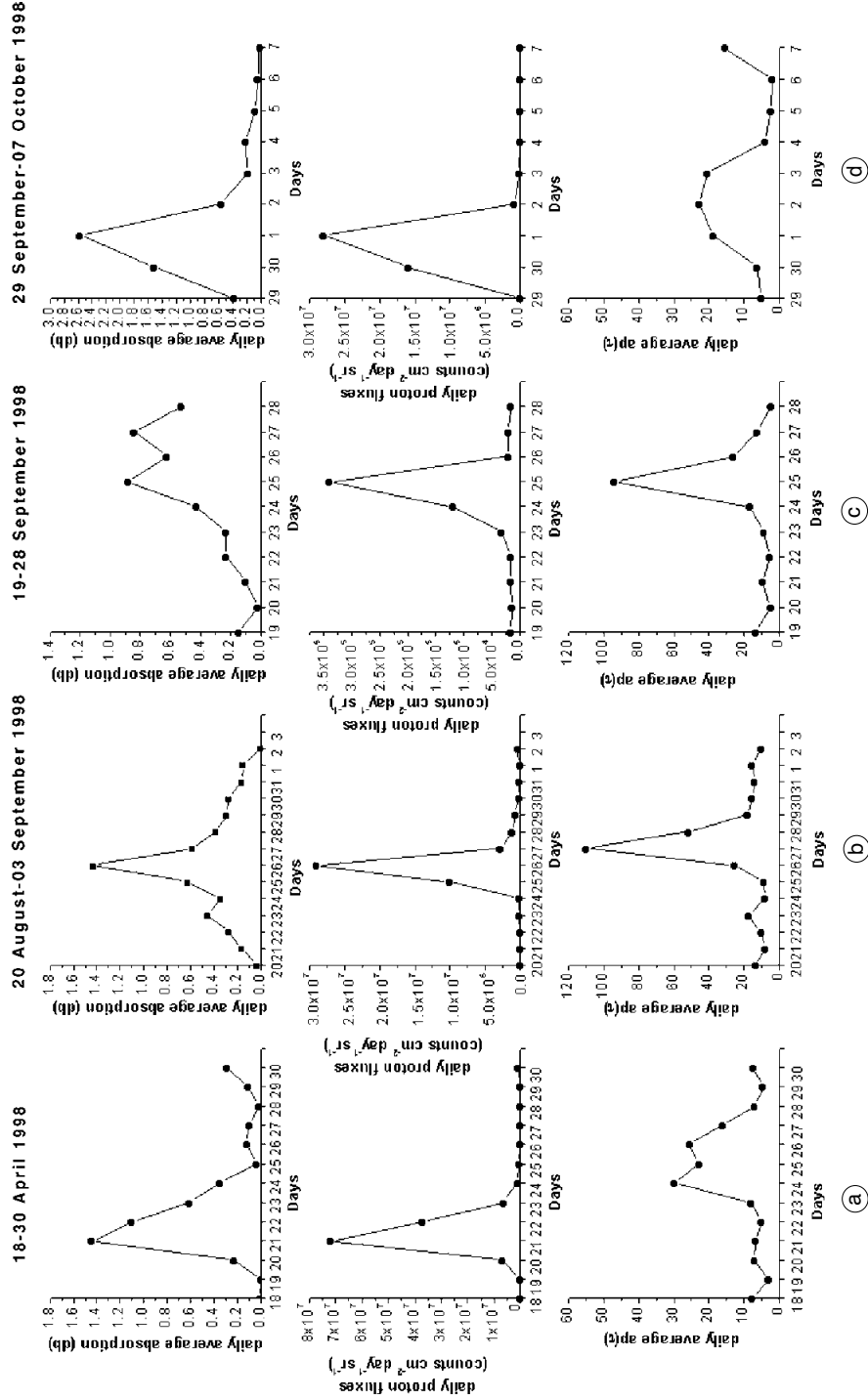
Fig. 1a-d. From the top to the bottom: temporal behaviour of the daily average ionospheric absorption, of the daily proton flux with energies > 10 MeV and of the daily average ap (τ) during the period April 18 -30 1998 (a); August 20 - September 3 1998 (b); September 19-28 1998 (c); September 29 - October 7 1998 (d).

probably gives rise to the diurnal variation of PCA. During a PCA the radio absorption measured by riometers by day is typically 2 or more times larger than by night (Ranta *et al.*, 1984). Therefore the day to night absorption ratio can be used to verify that a PCA phenomenon is occurring. The day to night ratios are calculated on the basis of the day-time and night-time ionospheric absorption values. The boundary between day (sunrise) and night (sunset) is generally determined by the solar zenith angle $\chi = 90°$. Hargreaves (1993) found that at sunset and during a PCA, a significant decay of electron density can be observed for $\chi = 96°$, corresponding to a height of about 60 km, *i.e.* the lower ionospheric region here investigated. So, in this study, the day to night ratios at solar zenith angle $\geq 90°$ were carried out for some periods of strong solar and magnetic events in 1998 (Section 2). The results are presented and discussed in Sections 3 and 4.

2. Data analysis

Ionospheric absorption data (UT), the time weighted magnetic index ap (τ) (UT), and the solar protons flux (UT) (monitored by the NOAA GOES-8 satellite in geo-synchronous orbit) were considered for the period 1st January - 31st December 1998.

Ionospheric absorption data (A2 method) are derived from 1 min cosmic noise measurements recorded at Terra Nova Bay Riometer station (30 MHz) (Cerrone *et al.*, 1996; De Franceschi *et al.*, 1997). The time-weighted accumulation index ap (τ) (Wrenn, 1987), based on the history of the geomagnetic index ap, is considered to represent the magnetic activity effects on the ionosphere. In fact, it has been shown that ap ($t \cong 0.8$), that corresponds to a 15 h time delay, is better correlated with the ionospheric parameters, at least in the F region (for details see Wu and Wilkinson, 1995; Perrone and De Franceschi, 1999; Perrone *et al.*, 2001).

Firstly, strong magnetic storms were selected on the basis of the daily mean of ap (τ) ≥ 30 (De Franceschi *et al.*, 1999). Some days before and after the onset of the storm were also taken into account to study the behaviour of the ionospheric absorption before and after the storm. This procedure disclosed the following 3 periods: April 18-30 1998, August 20 - September 03 1998 and September 19-28 1998. Another time-interval was considered from September 29 to October 7 1998, characterized by a strong protons emission event without any important magnetic activity. Figure 1a-d plots the daily mean of the ionospheric absorption (calculated from the absorption values at the first minute of each hour of the day), the daily solar protons flux with energies > 10 MeV, and the daily mean of ap (τ) for each selected period: high correlation between the absorption and solar protons flux maxima can be recognized.

The hourly mean of absorption values (calculated on the basis of 1 min cosmic noise sampling) during sunset transition between $\chi = 87°$ and $\chi = 102°$ both for the days of solar protons flux and ap (τ) maxima are reported in tables I and II. Moreover, the day to night ratios of the ionospheric absorption obtained by considering $\chi = 90°$ as sunrise and $\chi = 96°$ as sunset have been calculated (table III).

3. Results and discussion

A careful inspection of fig.1a-d leads to the following main considerations:

– The period April 18-30 shows a ionospheric absorption peak which occurred on 21st due to the solar proton event (associated with a solar flare at 20 classified as M1), that started on 20th, reached its maximum on 21st and stopped on 24th. During this period the ionospheric absorption remained relatively high. A moderate magnetic storm (April 24, ap (τ) = 30) can be observed probably due to a coronal mass ejection which started on 21st. As on 24th, the proton flux remained relatively high ($1.1 \cdot 10^6$ counts $\cdot$ cm$^{-2} \cdot$ day$^{-1} \cdot$ sr^{-1}), most likely both the solar proton event and the magnetic storm affected the ionospheric absorption value on 24th, but it is not clear which phenomenon gave the major contribution.

– From August 20th to September 3rd the ionospheric absorption that maximized on August 26th was due to the solar proton event that started on 24th (in conjunction to a solar

Table I. Hourly ionospheric absorption data as function of the solar zenith angles between 87° and 102°; the days where the solar proton flux affects the ionospheric absorption more than the magnetic storm were considered.

Date	Solar zenith angle	Ionospheric absorption (dB)
21 April 1998	87°	3.67
	90°	2.46
	93°	1.59
	96°	0.89
	99°	0.68
	102°	0.58
26 August 1998	87°	3.21
	90°	2.46
	93°	1.60
	96°	1.73
	99°	1.73
	102°	1.40
27 August 1998	87°	1.08
	90°	0.79
	93°	0.61
	96°	0.60
	99°	0.60
	102°	0.41
01 October 1998	87°	1.94
	90°	0.95
	93°	0.95
	96°	0.62
	99°	0.45
	102°	0.45

flare classified as X1/3B), reached its maximum on 26th, and stopped on 29th. The strong magnetic perturbation on August 27th should also be due to the same solar flare. The ionospheric absorption value on 27th depends on both the solar proton event and the magnetic storm, the proton flux being relatively high on 27th ($2.8 \cdot 10^6$ counts $\cdot$ cm$^{-2} \cdot$ day$^{-1} \cdot$ sr^{-1}) and the magnetic activity very strong (ap (τ) = 110) but, as in the previous case, it is difficult to assess *a priori* where the main contribution came from.

– The period September 19-28 showed an increase in ionospheric absorption starting from 24th up to 28th with two peaks on 25th and 27th. As a magnetic storm evolved between 24th and 26th with a strong maximum on 25th, just when a solar protons emission occurred (these two events were probably due to the solar flare classified as M7/3B started on 23), both the phenomena concurred to the absorption growth. Given the rather low level of proton flux ($2.2 \cdot 10^4$ counts $\cdot$ cm$^{-2} \cdot$ day$^{-1} \cdot$ sr^{-1}) and magnetic activity (ap (τ) = 13), the absorption peak observed on 27th could be better investigated by using a local geomagnetic index.

– A sudden increase in the ionospheric absorption from September 30th with a peak observed on October 1st was due to the solar proton event (associated to a solar flare occurring on 30th September of importance M2/2N.) that reached its maximum the same day.

The hourly mean values (tables I and II) and the day to night ratios (table III) of the absorption

Table II. Hourly ionospheric absorption data as function of the solar zenith angles between 87° and 102°; the days where the magnetic storm affects the ionospheric absorption more than the solar proton flux were considered.

Date	Solar zenith angle	Ionospheric absorption (dB)
24 April 1998	87°	0.67
	90°	0.59
	93°	0.49
	96°	0.45
	99°	0.51
	102°	0.51
25 September 1998	87°	0.37
	90°	0.35
	93°	0.35
	96°	0.53
	99°	0.53
	102°	0.47

Table III. Day to night ratios for proton fluxes and magnetic storm events calculated choosing $\chi = 90°$ (sunrise) and $\chi = 96°$ (sunset).

Proton fluxes events	Day to night ratios	Magnetic storm events	Day to night ratios
21 April 1998	6.52	24 April 1998	1.64
26 August 1998	2.82	25 September 1998	1.40
27 August 1998	2.00		
01 October 1998	15.79		

were considered as related to the occurring days of proton flux and of magnetic storm maxima in order to identify, as far as possible, which phenomenon causes the ionospheric absorption.

Table I shows a significant decrease of the ionospheric absorption as a function of the solar zenith angle from $\chi = 87°$ to $\chi = 102°$. In particular, at $\chi = 96°$, the absorption is at least twice smaller that calculated at $\chi = 87°$. With regard to August 27th, the day to night ratio equal to 2.0 (table III), that is the lower limit indicating a PCA phenomenon (Ranta *et al.*, 1994), suggests a ionospheric absorption essentially due to the solar proton event (started on 24th) rather than the magnetic storm. This could be supported (despite the strong magnetic activity) by the fact that on August 27th the proton flux remains very

high ($2.8 \cdot 10^6$ counts $\cdot$ cm$^{-2} \cdot$ day$^{-1} \cdot$ sr^{-1}). April 21st, August 26th and October 1st, for which the day to night ratios are greater than 2.0, confirm the occurrence of PCA phenomena.

Any significant ionospheric absorption decrease from $\chi = 87°$ to $\chi = 102°$ can be assessed for the days reported in table II. These days show a day to night ratio smaller than 2.0 that is not typical for a PCA phenomenon as expected (table III). This could suggest that on April 24th and September 25th the ionospheric absorption is more affected by the magnetic storm rather than by the solar protons event. In particular, for September 25th, the proton flux, although occurring by day, remained very small (only $3.4 \cdot 10^5$ counts $\cdot$ cm$^{-2} \cdot$ day$^{-1} \cdot$ sr^{-1}) while the magnetic activity was very strong ($ap(\tau) = 94$).

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4. Conclusions

This investigation found that the hourly mean ionospheric absorption calculated at $\chi = 96°$ is at least two times less than that calculated at $\chi = 87°$ during a PCA phenomenon. This agrees with what was found by Hargreaves *et al*. (1993), according to which the electron density is down to half its original value at $\chi = 96°$.

The hourly mean ionospheric absorption during a PCA phenomenon is always a decreasing function of the solar zenith angle (table I), except for a slight increase observed at $\chi = 96°$ on August 26th, probably due to the magnetic storm effect that started on that day (fig. 1c). A different behaviour can be observed when the ionospheric absorption is more affected by a magnetic storm rather than by a solar proton event (table II).

Table III shows that when the maximum protons flux occurs by night (21st April, 26th and 27th August) the ionospheric absorption day to night ratios are smaller than that occurring by day (October 1st).

The ionospheric absorption day to night ratio seems to be a suitable index to distinguish the ionospheric absorption due to a solar proton event from that due to a magnetic storm. The cases analysed confirm that a day to night ratio equal to or greater than 2.0 characterizes a PCA phenomenon (Ranta *et al.*, 1984).

An investigation into the absorption peak observed on September 27th (fig. 1c) could be carried out using a different geomagnetic index: as $ap(\tau)$ comes from planetary index ap, and concerns above all the F region, the use of a local polar index such as the PC index (Troshichev *et al.*, 1979) could be more suitable to characterize the magnetic storms and hence to better disclose their possible influence on the ionospheric absorption.

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