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Effects of energetic particles precipitation on stratospheric ozone in the Southern Hemisphere

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Abstract

Measurements from TOMS and UARS-HALOE are used to estimate the effects of energetic particle precipitation (EPP) over the stratosphere during two geomagnetic storms occurred in November of the years 2003 and 2004. The EPP couples the solar wind to the Earth's atmosphere and indirectly to the Earth's climate. Due to particle precipitation, the ionization and dissociation increase, and create odd nitrogen (NO_x) and odd hydrogen (HO_x) in the upper atmosphere, which can affect ozone chemistry. In this paper, statistically significant variation in total ozone content at middle latitudes of the Southern Hemisphere is observed. The variations depend on the intensity of geomagnetic disturbances and the geomagnetic longitude. A significant variation in NO_x concentration at altitudes from 30 to 50 km is observed from the profiles analysis.

Keywords: Energetic particle precipitation; Southern Hemisphere; Total ozone; NO_x

1. Introduction

The energetic particle precipitation causes in high latitudes of thermosphere and mesosphere an increase in odd nitrogen NO_x (N, NO, NO_2) via a cascade of dissociation, ionization, and recombination processes (Thorne, 1980; Rusch et al., 1981; Jackman and McPeters 2001; Randall et al., 2007; Jackman et al., 2008, 2009, 2014; Turunen et al., 2009; Seppälä et al., 2014). The NO_x lifetimes are long enough that they can descend to the stratosphere participating in catalytic processes of ozone destruction (Callis et al., 1998a; Baker, 2000). Callis et al. (1998a,b) showed over the solar cycle 21, that long intervals of electrons precipitation, with energies between a few keV to ~1 MeV, have an important effect on atmospheric chemistry. This mechanism for coupling the upper and lower atmosphere is known as the energetic particle precipitation indirect effect (Randall et al., 2007) which was examined by Solomon et al. (1982) among others, using a two-dimensional model. There is extensive evidence from

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data, too. During solar proton events, the particle precipitation into the atmosphere can produce in the upper stratosphere, ozone depletion with an increase of NO_2 at latitudes $\geqslant 45°$ (Seppällä et al., 2004, 2006; Lopez-Puertas et al., 2005).

From Jackman et al. (2008), the families of HO_x constituents are produced directly or through a photochemical sequence as a result of SPEs. These results are important in controlling the ozone at pressures less than about 2 hPa (upper stratosphere and mesosphere). Short-term ozone destruction proceeds through diverse catalytic loss cycles such as: $OH+O_3 \rightarrow HO_2 + O_2$, followed by $HO_2+O \rightarrow H + O_2$, net: $O + O_3 \rightarrow O_2 + O_2$; and $H + O_3 \rightarrow OH + O_2$, followed by $OH + O \rightarrow H + O_2$, net: $O + O_3 \rightarrow O_2 + O_2$. Furthermore, the constituents of NO_x ($NO + NO_2$) produced by SPE, lead to a catalytic ozone destruction, by short and long term, at pressures greater than about 0.5 hPa (lower mesosphere and stratosphere), via the NO_x-ozone loss cycle: $NO + O_3 \rightarrow NO_2 + O_2$, followed by $NO_2 + O \rightarrow NO + O_2$, net: $O + O_3 \rightarrow O_2 + O_2$.

Energetic protons of solar origin, with energies over than 500 MeV can drift along the magnetic lines ionizing the upper atmosphere and, in some extreme cases, the stratosphere (15–50 km) (Rozanov et al., 2012).

Jackman et al. (2009) have analyzed the influence of very large solar proton events over the long-term middle atmosphere, indicating that the impact of energetic particle precipitation in total ozone column is appreciably smaller than the ozone depletion arising from atmospheric halogen loading.

The effects of geomagnetic storms on the total ozone at middle latitudes were published in a series of papers by Laštovička and Mich (1999) and Laštovička and Križan (2005, 2009) with the following results: statistically significant effects of geomagnetic storms occur in total ozone around 50°N latitudinal circle, only for strong events (Ap > 60), in winter, under the high solar activity. They also indicate that the effects observed, mainly the redistribution of ozone, can be caused by storm-related changes in atmospheric dynamics

Table 1
Stations included in the network TOMSEPOVP used in this paper.

Stations	Latitude geographic	Longitude geographic
Dome C	−74.80N	123.50E
Terra Nova	−74.44N	164.05E
Novolazarevskaya	−70.77N	11.84E
Neumayer	−70.65N	−8.25E
Palmer	−64.77N	−64.07 E
Marambio	−64.23N	−56.72E
King George Is.	−62.18N	−58.90E
Ushuaia	−54.90N	−68.30E
Maquarie Island	−54.83N	158.95E
King Edward	−54.52N	−36.50E
Punta Arenas	−53.03N	−70.85E
Lago Rodc	−50.53N	−72.72E

Two periods with intense geomagnetic storms, during November of the years 2003 and 2004 have been chosen to analyze the effects of particle precipitation over the total ozone content and profiles of ozone and NO_x in South Hemisphere. Proton flux data have been used in order to investigate the behavior of the particles that could be involved with the phenomena studied.

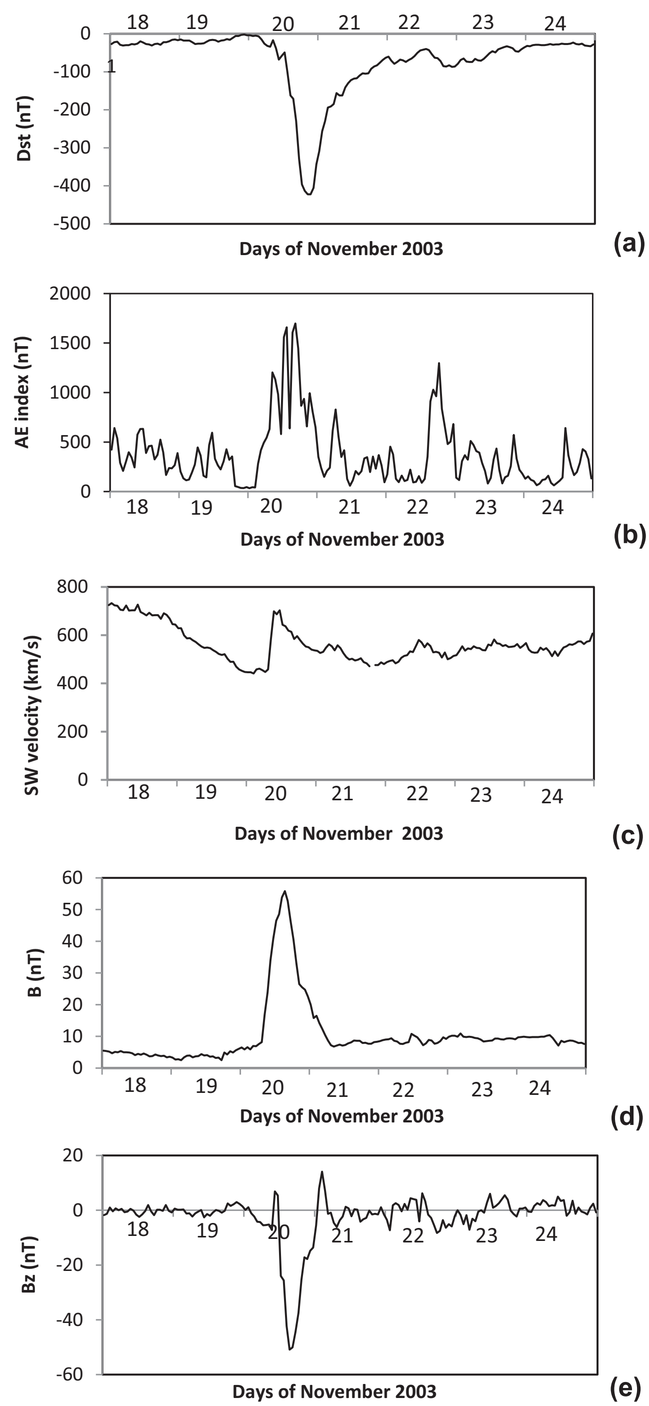

Fig. 1. Time evolution of: (a) Dst index, in nT; (b) AE index in nT; (c) solar wind velocity in km/s; (d) magnitude of interplanetary magnetic field in nT; (e) Z component of interplanetary magnetic field in nT for the period 18–24 November, 2003.

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