# Mesospheric ozone depletion due to energetic electron precipitation at the South Atlantic magnetic anomaly

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ABSTRACT. In this letter, we have investigated the effect of energetic electron precipitation at the South Atlantic magnetic anomaly on the local mesospheric ozone concentration. In the mesosphere, the ionization produced by precipitation acts as a source of odd hydrogen. Since odd hydrogen processes dominate ozone destruction in this region, a decrease in the ozone concentration should be expected during these events. Based on a simple photochemical equilibrium model, it is estimated that at large solar zenith angles the ozone concentration between about 70 and 80 km altitude in the anomaly region can be considerably depleted, mainly during large geomagnetic storms.

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## INTRODUCTION

It is now well established that energetic particle precipitation in the earth's atmosphere can be an important ionization source for the mesosphere and upper stratosphere, mainly during geomagnetically disturbed periods. The ionization produced by particle precipitation leads to a series of ion reactions which ultimately produce odd nitrogen (N, NO) and odd hydrogen (H, OH, $HO_2$). In turn, the production of odd hydrogen and odd nitrogen is believed to result in decreased ozone concentration in the mesosphere and upper stratosphere (Thorne, 1980). This effect was first suggested by Swider and Keneshea (1973) in an attempt to explain rocket observations of ozone in the mesosphere during a PCA event in 1969 (Weeks *et al.*, 1972). In the upper stratosphere, the first observation of a depletion in the ozone concentration in association with a PCA event was reported by Heath *et al.* (1977).

Other types of phenomenon that could cause similar magnitude changes in the ozone concentration are : the relativistic electron precipitation (REP) events (electron energies up to 1 MeV) which occur at subauroral latitudes during magnetospheric substorm activity (Thorne, 1977) ; the highly relativistic magnetospheric electrons (2-15 MeV) recently observed in the outer radiation belt (Baker *et al.*, 1987). Baker *et al.* (1987) have even suggested that these electrons also may contribute to recent Antarctic polar ozone depletion phenomenon.

In this letter, we use a simple photochemical equilibrium model, together with electron measurements, to estimate the variation in the mesospheric ozone concentration due to energetic electron precipitation (0.1-2 MeV) in the region of the South Atlantic Magnetic Anomaly (SAMA). We considere both magnetically quiet and disturbed (storm related) periods. We conclude that the energetic electron precipitation in this region during large geomagnetic storms can lead to a considerable removal of ozone.

## OZONE DEPLETION DUE TO ELECTRON PRECIPITATION

The energetic electron precipitation at SAMA region during magnetically quiet periods is relatively well known (Torr *et al.*, 1975 ; Sheldon *et al.*, 1988 ; Pinto and Gonzalez, 1989*a* ; Vampola and Gorney, 1973). In particular, Vampola and Gorney (1983) using the S3-2 satellite have recently determined an average ionization rate profile due to energetic electron precipitation during such periods, with values around 5 ion pairs $cm^{-3} s^{-1}$ at 75 km. This result is in agreement with those obtained by Sheldon *et al.* (1988) at $L = 4$. On the other hand, during disturbed periods there are only a few measurements. Rosen and Sanders (1971) measured an increase in the quasi-trapped electron flux at $L < 2$ during two geomagnetic storms. Imhof *et al.* (1980) measured a high correlation between quasi-trapped electron flux and *Dst* index at $L = 1.75$. Evidences of enhanced energetic electron precipitation at SAMA during disturbed periods are also provided by indirect measurements. Pinto and Gonzalez (1986*a*, *b*), from X-ray balloon measurements, Roeder (1982), from rocket observations, and Abdu *et al.* (1981), from VLF measurements, determined an increase in the precipitated electron flux in association with geomagnetic storms (for more details, see Paulikas, 1975 and Pinto and Gonzalez, 1985, 1989*a*). Based on these measurements, we can considere as reasonable to expect during disturbed periods ion rate profiles larger than the average quiet time profile by one order of magnitude (at least, in part of the SAMA). It is interesting to note that, compared with results at approximately same latitudes but ouside the SAMA (Spjeldvik and Thorne, 1975), such values would be larger by a factor of 4. Such intensification in the precipitation is supposed to be generated by a weak pitch-angle diffusion driven by cyclotron (Tsurutani *et al.*, 1975) and Landau (Pinto and Gonzalez, 1989*b*) resonant wave-particle interactions at the SAMA.

In order to estimate the decrease in mesospheric ozone concentration between 70 and 80 km altitude at the SAMA region it is necessary to consider in detail the chemistry of odd hydrogen production around this altitude. However, this chemistry is very complicated involving, at least, 37 reactions (Solomon *et al.*, 1981 ; Jackman and McPeters, 1985). Even so, the predictions of the models that considere most (or all) of these reactions are only in a relative concordance with the observations (Jackman and McPeters, 1987).

In an attempt to avoid such difficulties, but at the same time to obtain a good estimate for the depletion of ozone due to ionization by particle precipitation, Solomon *et al.* (1983) derived an analytic formula relating the percent of ozone destruction to the odd hydrogen production by particle precipitation. This formula, which applies to 70-80 km altitude, is based on the photochemical equilibrium. It shows that the change in ozone should be roughly related to the relative magnitudes of odd hydrogen production by precipitation *versus* the normal production due to photolysis of water vapor. The formula is

$$\%\ \text{decrease}\ O_3 = \{1 - [2J(H_2O)/(2J(H_2O) + FQ)]^{1/2}\} \times 100 \quad (1)$$

where $J$ represents the rate of photolysis of $H_2O$, $F$ is the number of hydrogen particles produced per ionization (approximately equal to 2 at 70-80 km (Solomon *et al.*, 1981) and $Q$ is the ionization rate. Note that since $J$ depends on the solar zenith angle, we should also expect a solar zenith angle dependent ozone depletion (Jackman and McPeters, 1985).

## DISCUSSION AND CONCLUSION

Using Eq. (1) we have estimated the ozone depletion due to electron precipitation at 70-80 km in the SAMA region. Values for three different solar zenith angles were considered. Table 1 shows the percentage ozone depletion at 75 km altitude for magnetically quiet and disturbed periods. We have adopted for the rate of photolysis the same values used by Solomon *et al.* (1983) and the $H_2O$ mixing ratio equal to 4 ppmv. One can see from Table 1 that the ozone depletion depends strongly on the solar zenith angle. Table 1 shows also that the ozone concentration around 70-80 km in the SAMA region during large geomagnetic storms can be reduced by factors as much as 30 %. Here, it is worth mentioning that although Eq. (1) is based on photochemical equilibrium, it was showed to be valid even at large solar zenith angles, when time dependent effects are supposed to become significant (see, for example, Fig. 4 of Solomon *et al.*, 1983).

Table 1

*Percentage ozone depletion at* 75 km *in the* SAMA *region.*

| | Solar zenith angle | | |
|---|---|---|---|
| | 50° | 65° | 80° |
| Quiet times | $< 1$ | 1.7 | 4.9 |
| Disturbed times | 5.1 | 14.1 | 30.2 |

In conclusion, the precipitation of energetic electrons in the SAMA region during large geomagnetic storms can periodically lead to a large enhancement in the concentration of odd hydrogen in the mesosphere, which subsequently can lead to a considerable removal of ozone. The importance of these events upon mesospheric chemistry remains to be investigated. However, because of the short residence time of the odd hydrogen at these altitudes (Crutzen and Solomon, 1980), it is questionable whether these depletions will affect the long term average concentration of the mesospheric ozone in the SAMA region.

In fact, a full one-dimensional model calculation as well as a more complete set of observations, which are beyond the scope of this letter, are probably called for to determine the reduction in mesospheric ozone by the geomagnetic storm induced precipitation into the SAMA. Future satellite studies should be aimed at making a direct comparison between the particle precipitation at the SAMA region and the associated modification of the mesosphere and upper stratosphere.

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