



THE INFLUENCE OF SOLAR PROTON EVENTS ON THE OZONE LAYER

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ABSTRACT

Our two-dimensional chemistry and transport atmospheric model was used to simulate the influence of solar proton events (SPEs) over the 1965 to 1995 time period. Extremely large particle events with huge fluxes of very high energy protons occurred in August 1972 and October 1989 and caused large increases in long-lived NO_y constituents, which affected ozone for several months to years past the events. Our simulations show that the SPE-produced NO_y constituents in the upper stratosphere caused direct ozone losses. However, interference of the NO_y constituents with the halogen loss cycles for ozone destruction actually led to some total ozone production. We predict a seasonal dependence for the impact on polar ozone, with larger (smaller) decreases predicted for SPEs occurring in the fall or winter (spring or summer). © 1999 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION

Solar proton events (SPEs) cause HO_x (H, OH, HO₂) and NO_y (N, NO, NO₂, NO₃, N₂O₅, HNO₃, HO₂NO₂, ClONO₂, BrONO₂) constituent increases in the middle atmosphere polar regions which can lead to ozone decreases in the mesosphere and upper stratosphere (e.g., Solomon et al. 1983; Jackman and McPeters, 1985; Reid et al. 1991; and Jackman et al. 1995). Since HO_x species have lifetimes of only hours in the middle atmosphere, the HO_x-induced ozone changes are relatively short-lived. Extremely large particle events with huge fluxes of very high energy protons occurred in August 1972 and October 1989 and caused large increases in long-lived NO_y constituents (e.g., Zadorozhny et al. 1992), which affected ozone for several months to years past the events (Jackman and McPeters, 1987; Reid et al. 1991; Jackman et al. 1995). We have simulated the time period 1965 through 1995 with our two-dimensional photochemical transport model and have focused on the NO_y production as well as the total ozone changes.

PROTON FLUX DATA; HO_x AND NO_y PRODUCTION

Solar particle fluxes were taken from the Interplanetary Monitoring Platform (IMP) series of satellites over the time period 1965 through 1993. The solar proton fluxes for 1965 through 1973 were provided by T. Armstrong and colleagues (University of Kansas, private communication, 1986) for relatively coarse intervals (>10 MeV, >30 MeV, >60 MeV). These solar proton fluxes were used to compute daily average ion pair production profiles using the methodology discussed in Jackman *et al.* (1990) for 1965 through 1973.

The solar proton and alpha particle fluxes for 1974 through 1993 were again provided by T. Armstrong and colleagues (University of Kansas, private communication, 1994), but for the very fine energy intervals detailed in the Appendix of Vitt and Jackman (1996). These solar particle fluxes were used to compute daily average ion pair production profiles using the methodology discussed in Vitt and Jackman (1996) for 1974 through 1993.

Complicated ion chemistry resulting from the ion pair production results in the formation of HO_x constituents. Each ion pair produces about two HO_x constituents up to an altitude of approximately 70 km. Above 70 km, the production is less than two HO_x constituents per ion pair (Solomon *et al.*, 1981). We use the production rates of HO_x constituents per ion pair as provided in Solomon *et al.* (1981, Figure 2) in all our model computations (also, see Goldberg *et al.* 1995). The HO_x constituents, with lifetimes of only hours in the middle atmosphere and effects primarily in the mesosphere and upper stratosphere, did not contribute significantly to total ozone changes.

Atomic nitrogen is produced by the primary particles or associated secondary electrons causing dissociations, predissociations, or dissociative ionizations in collisions with N₂. Following Porter *et al.* (1976) and Jackman *et al.* (1980), we assume that 1.25 N atoms are produced per ion pair for all our model computations.

We show our computations of the total number of NO_y molecules produced per year by SPEs over the 1965 through 1993 time period for the north polar stratosphere (latitudes >50°N) in Figure 1, represented by the histogram. Other sources of NO_y in this region include galactic cosmic rays (GCRs), 'in situ' oxidation of N₂O, and horizontal transport of NO_y from lower latitudes, which are represented in Figure 1 by the dash-dot-dot-dot, dash-dot, and dashed lines, respectively. The values for all these other sources were taken from Vitt and Jackman (1996). The horizontal transport of NO_y, primarily a result of oxidation of N₂O at lower latitudes, is about an order of magnitude larger than any of the other NO_y sources. There were only two years (1972 and 1989) when the annual SPE source of NO_y was larger than 5% of the horizontal transport source. Huge fluxes of extremely energetic particles characterized the SPEs of August 1972 and October 1989 which dominated the NO_y sources for those years.

TOTAL OZONE IMPACT FROM SPEs

We used the SPE production of HO_x and NO_y for 1965 to 1993 in our two-dimensional (2D) chemistry and transport atmospheric model and simulated the influence of SPEs over the 1965 to 1995 time period. Our 2D atmospheric model has been discussed before and was recently used to simulate natural and humankind influences on ozone, including SPEs (Jackman *et al.* 1996). We focus on only

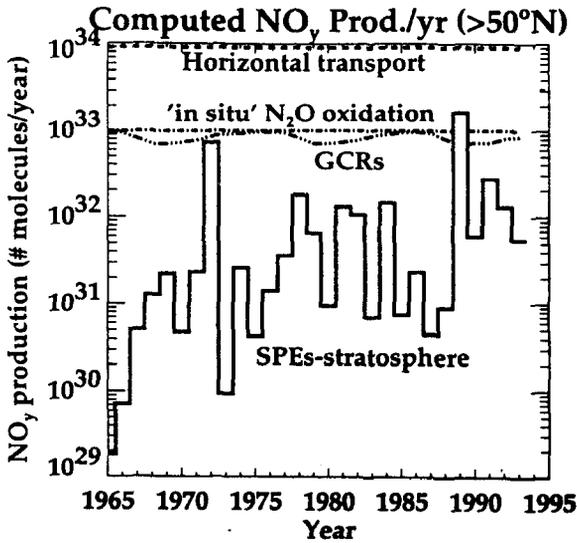


Fig. 1. Total number of NO_y molecules produced per year in the northern polar stratosphere ($>50^\circ\text{N}$) by SPEs (histogram), GCRs (dash-dot-dot-dot line), 'in situ' oxidation of N_2O (dash-dot line), and horizontal transport of NO_y from lower latitudes into this region (dashed line).

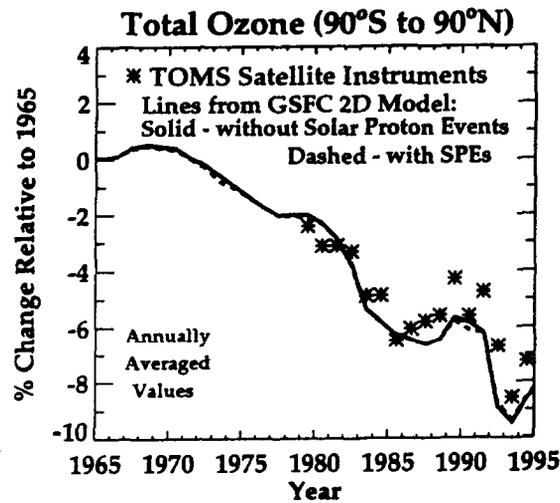


Fig. 2. Percentage total ozone changes for 90°S to 90°N in two simulations, a 'base (without SPEs)' and a 'perturbed (with SPEs)', which are represented as the solid and dashed lines, respectively. The TOMS annually-averaged total ozone measurements for the 65°S to 65°N region are represented as 'stars.'

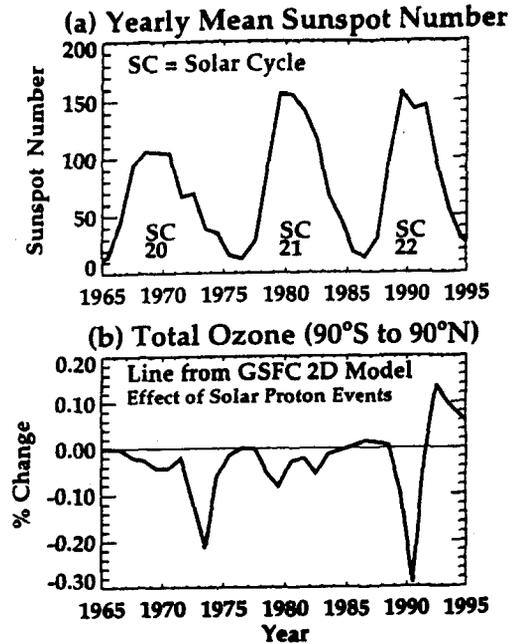


Fig. 3. (a) Yearly mean international sunspot number taken from the Solar Geophysical Data publication. (b) The total ozone percentage change between the 'perturbed (with SPEs)' and 'base (without SPEs)' simulations.

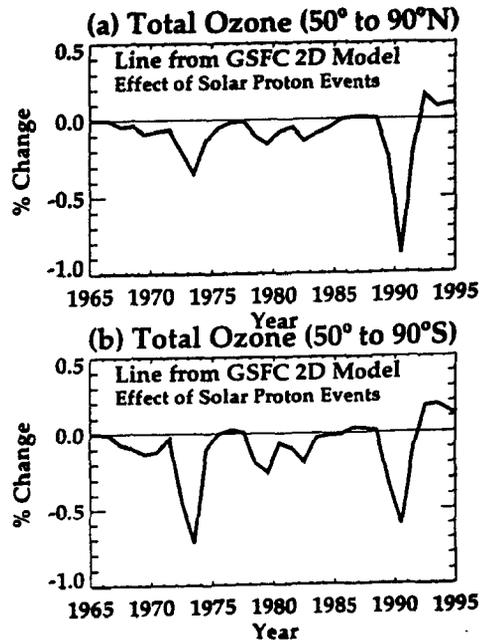


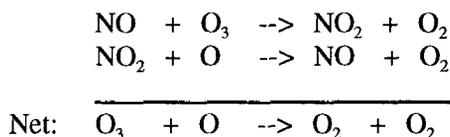
Fig. 4. The total ozone percentage change between the 'perturbed (with SPEs)' and 'base (without SPEs)' simulations for (a) the northern polar region and (b) the southern polar region.

two simulations in this study: 1) A 'base' simulation which did not include any SPEs; and 2) A 'perturbed' simulation which included the SPEs.

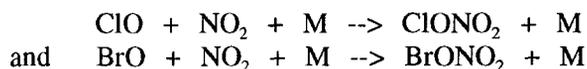
The results of these 'base' and 'perturbed' simulations for global annually-averaged total ozone are represented in Figure 2 as the solid and dashed lines, respectively. The TOMS annually-averaged total ozone measurements for the 65°S to 65°N region are represented as 'stars' in the figure. Both simulations generally agree with the measurements, although certain years (notably 1980, 1984, 1989, and 1991) are not well modeled. See Jackman *et al.* (1996) for further discussion of model/measurement comparisons.

There are only minor differences between the two model simulations, the largest being in the early 1970's and early 1990's. This shows the small influence that SPEs have on global total ozone.

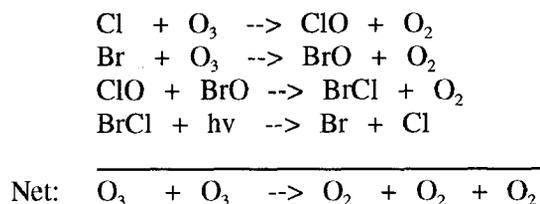
The difference between the 'perturbed' and 'base' simulations is presented in Figure 3b, with the yearly mean sunspot number given in Figure 3a. The largest decreases are computed to occur in 1973 and 1990, the years following the huge SPEs in August 1972 and October 1989. These ozone decreases are mainly caused by the increase in stratospheric SPE-produced NO_y constituents driving the well-known catalytic reaction cycle:



Slight increases in ozone are computed in 1986 and 1987 with even larger increases computed in the 1992-1994 time period. These increases are primarily the result of SPE-produced NO_y constituents being transported to the lower stratosphere and causing interference with the Cl_y (Cl , ClO , ClONO_2 , HOCl , HCl , Cl_2O_2) and Br_y (Br , BrO , BrONO_2 , HOBr , HBr) constituents in this region. The most important of these interference reactions are:



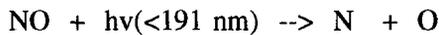
These reactions short-circuit the catalytic loss of ozone caused by the halogens in the lower stratosphere. For instance, one of the halogen-driven ozone catalytic destruction cycles important in the lower polar stratosphere is:



Formation of the halogen reservoirs, ClONO_2 and BrONO_2 , at the expense of the halogen radicals, ClO and BrO , will decrease this halogen-driven ozone catalytic loss and result in slight increases in ozone due to SPEs.

Since solar protons primarily precipitate in the polar caps ($>60^\circ$ geomagnetic), SPEs mostly cause stratospheric polar changes. This is best indicated in Figures 4a and 4b, where the total ozone percentage changes for the polar latitude regions 50° - 90° N and 50° - 90° S, respectively, are shown. Total ozone decreases greater than 0.5% are computed for the northern polar region in 1990 and for the southern polar region in 1973 and 1990. The different hemispheric influence is apparent in 1973 and 1990, with larger effects computed in the southern and northern hemispheres, respectively.

These divergent hemispheric influences are caused by the different months of occurrences for the huge SPEs in 1972 and 1990. The August 1972 SPEs occurred in southern polar winter and northern polar summer. The lower sunlight in the southern winter conserved more of the SPE-generated NO_y since the NO_y loss mechanism



followed by $\text{N} + \text{NO} \rightarrow \text{N}_2 + \text{O}$

occurred at a much slower rate than in the northern summer. The downward motion in the southern winter also prevented significant NO_y loss as the NO_y constituents were transported to the lower stratosphere where the lifetime of the NO_y family is months to years. The upward motion in the northern summer led to very significant NO_y losses as the NO_y constituents were transported to larger NO_y loss regions in the upper stratosphere. The largest total ozone decreases were thus computed to be in the southern hemisphere in 1973.

In contrast to 1972, the October 1989 SPE occurred in southern polar spring and northern polar fall. The southern hemisphere experiences more sunlight in October than the northern hemisphere. The large scale stratospheric circulation is also changing at this time of year, with downward motions starting in the northern polar hemisphere (leading to a larger conservation of NO_y constituents) and upward motions starting in the southern polar hemisphere driving NO_y constituents up to higher altitudes where the ultraviolet sunlight is more intense (leading to larger losses of NO_y constituents). The largest total ozone decreases were thus computed in the northern hemisphere in 1990.

CONCLUSIONS

We simulated the influence of solar proton events (SPEs) on NO_y and total ozone over the 1965 to 1995 time period with a two-dimensional chemistry and transport atmospheric model. Our simulations showed that the extremely large particle events in August 1972 and October 1989 caused the largest increases in long-lived NO_y constituents. These huge events affected total ozone for several months to years past the events by causing direct ozone decreases from NO_y -induced losses. Polar ozone decreases are predicted to be larger for SPEs occurring in the fall or winter, and smaller in the spring or summer. We also computed that interference of the NO_y constituents with the halogen loss cycles for ozone destruction actually led to some total ozone production that was especially notable in the time period 1992-4, a few years after the October 1989 SPEs.

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