Atmospheric Effects during Solar Storms

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Abstract: Recent satellite data have revealed a correlation between the Sun's activities and the Earth's atmosphere. Many scientists have been conjectured a more direct connections between solar variability and the Earth's atmosphere from satellite data analysis. During solar storms, more energetic particles reach the Earth's atmosphere and this phenomenon have effects on the Earth's atmospheric environment. Consequently, scientists suggest that these variations will affect a global climate change. In this study, we investigate the confirmative research results of atmospheric effects due to solar activities, especially solar storms.
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1. Introduction

The Sun is the dominant energy source for the entire Earth system. It warms the Earth, heating the lands and ocean, and changes the Earth's atmospheric environment. The Sun maintains the Earth's atmosphere, generates clouds, and cycles our home planet's water. It drives the wind, ocean currents and atmospheric circulation. The Sun's energy sustains and natures all life including plant, animal, and human.

The factors entering the global climate change, including greenhouse gases, aerosols, and atmospheric circulation, are driven by solar radiation, and they influence each other by complex feedbacks [Rottman et al., 2001; SORCE, 2001].

During the last few decades the observation of the Sun has revealed many new facts with the help of satellites such as Helios, Yohkoh, Ulysses, Nimbus, ACRIM, UARS, and SOHO. SOHO is investigating the physical processes that form and heat the Sun's corona, maintain it and give rise to the expanding solar wind, solar storms, and the interior structure of the Sun. Observing the Sun is becoming increasingly important because it affects the Earth system in many ways.

Energy balance equations predict that if the Sun varies by a modest amount, say 1%, the global average surface temperature will change by about 0.7 °C. Some empirical models estimate that the Sun varied by nearly 0.5% since pre-industrial times. Climate models indicate such a change may account for over 30% of the warming that has occurred since 1850. Feedbacks can enhance the Sun's influence. The amount and distribution of important greenhouse gases (H_2O, CO_2, and O_3) vary in response to radiation changes. Water vapor and ozone are especially sensitive to changes in the Sun's ultraviolet radiation, and both observations and models show a close relationship of their concentrations to solar irradiance. Different wavelengths of solar radiation are absorbed at different altitudes. A complete understanding of the solar influence will consider the entire coupled system (land, ocean, and atmosphere) [Rottman et al, 2001; SORCE, 2001].

Solar storms consist of coronal mass ejections and solar flares. Solar flares are explosions on the Sun that happen when energy stored in twisted magnetic fields (usually above sunspots) is suddenly released. These solar flares contain Gamma rays and X-rays, plus energetic particles (protons and electrons). Coronal Mass Ejections (CMEs) are huge bubbles of gas ejected from the Sun. CMEs can occur with or without solar flares and also threaten the Earth's atmosphere. When protons like these bombard the upper atmosphere, they break up molecules of gases like nitrogen and water vapor, and once freed, those atoms react with ozone molecules and reduce the layer. A lot of impacts on ozone are very subtle and happen over long periods of time. But when these solar proton events occur we can see immediately a change in the atmosphere, so we have a clear cause and effect [Jackman et al., 2001].

2. Confirmative Research Results

A solar flare with associated CMEs occurred in mid-July 2000 and caused solar storms (solar proton events; SPE). Not since October 1989 has the Earth's atmosphere been subjected to such an intense flux of solar protons. These solar storms are natural occurrences that produce HO*x* (H, OH, HO_2) and NO*x* (N, NO, NO_2) constituents in the polar middle atmosphere, which are capable of influencing ozone. HO*x* constituents produced from solar storms are relatively short lived and lead to short-term ozone decreases lasting several hours to a few days in the mesosphere and upper stratosphere [Swider and Keneshea, 1973; Frederick 1976; Solomon et al., 1983; Jackman and McPeters, 1985, Jackman et al., 2001]. The longer-lived SPE-produced NO*x* species may influence the stratosphere over periods of months to years, depending on the season in which the SPE occurred, and can impact ozone and the other NO*y* constituents (N, NO, NO_2, NO_3, N_2O_5, HNO_3, HO_2NO_2, $ClONO_2$, $BrONO_2$) over these time periods [Rusch et al., 1981; Jackman et al., 1990; Reid et al., 1991; Jackman et al., 2001].

NASA's Halogen Occultation Experiment (HALOE) was launched on the Upper Atmosphere Research Satellite (UARS) spacecraft September 15, 1991 as part of the Earth Science Enterprise Program. Its mission includes improvement of understanding stratospheric ozone depletion by measuring vertical profiles of ozone, hydrogen chloride, hydrogen fluoride, methane, water vapor, nitric oxide, nitrogen dioxide, aerosols, and temperature. The Solar Backscatter Ultraviolet (SBUV/2) instrument was launched aboard the NOAA-14 satellite on December 30, 1994 and its mission is to observe the ozone layer.

The study's investigators (Jackman et al., 2001) used measurements from the HALOE instrument aboard the UARS and the SBUV/2 instrument aboard the NOAA-14 satellite to obtain data on amounts of atmospheric gases like ozone and oxides of nitrogen in different layers of the atmosphere in the Northern Hemisphere. In order to analyze data, Jackman et al. (2001) compared readings before and during the event.

When the Sun's protons hit the atmosphere they break up molecules of nitrogen gas and water vapor. When nitrogen gas molecules split apart, they can create molecules, called nitrogen oxides, which can last several weeks to months depending on where they end up in the atmosphere. Once formed, the nitrogen oxides react quickly with ozone and reduce its amounts. When atmospheric winds blow them down into the middle stratosphere, they can stay there for months, and continue to keep ozone at a reduced level.

Protons similarly affect water vapor molecules by breaking them up into forms where they react with ozone. However, these molecules, called hydrogen oxides, only last during the time period of the SPE. These short-term effects of hydrogen oxides can destroy up to 70% of the ozone in the middle mesosphere. At the same time, longer-term ozone loss caused by nitrogen oxides destroys a maximum of about nine percent of the ozone in the upper stratosphere. Only a few percent of total ozone is in the mesosphere and upper stratosphere with over 80% in the middle and lower stratosphere.

The July 14~16, 2000, SPE caused very significant changes in middle atmospheric constituents during and after the event. The measured temporal influence of this SPE is captured in the UARS HALOE NO and NO_2 and the UARS HALOE and NOAA 14 SBUV/2 ozone observations at northern polar latitudes. This is the first time that the temporal behavior of the three constituents NO, NO_2, and ozone were all measured simultaneously during a proton event.

This SPE offers an opportunity to test theories of middle atmospheric photochemistry caused by a large particle precipitation event. The focus of Jackman's (2001) this study is on the summer polar Northern Hemisphere (NH) constituent effects during and shortly after the July 2000 SPE. Significant effects in the polar Southern Hemisphere (SH) due to this large SPE, which occur weeks to months after the event, are discussed in Randall et al. (2001).

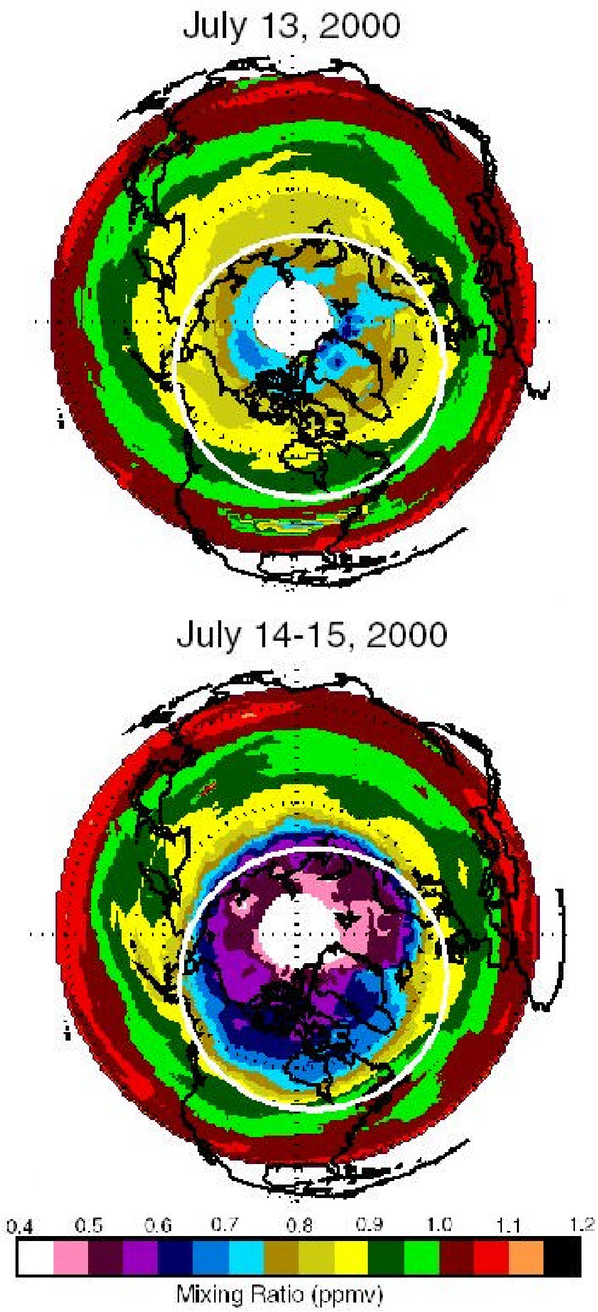

Figure 1. NH polar ozone comparison in ppmv before (July 13, 2000) and during the solar storms period (July 14~15, 2000) at 0.5 hPa [Jackman et al., 2001]

The July 2000 SPE impact on mesospheric ozone is illustrated in Figure 1, which shows the NH polar ozone maps from NOAA 14 SBUV/2 for the 0.5 hPa level. In order to produce a daily map, the SBUV/2 ozone data was interpolated along the orbital tracks and filled between successive orbits using the Delauney triangulation method discussed in Stolarski et al. (1997). The plot on the top indicates ozone amounts on July 13, before the SPE. The plot on the bottom indicates ozone amounts on July 14~15, during the maximum intensity of the SPE. The polar cap (> 60^o geomagnetic), where the solar protons are predicted to interact with the atmosphere, is indicated by the thick white oval. This figure illustrates the very significant reduction in the ozone amounts at this level in or near the polar cap during this SPE. The ozone reduction slightly outside the polar cap near 90° E longitude is probably caused by the Earth's magnetic field being perturbed somewhat during this very significant solar disturbance [Jackman et al, 2001].

3. Discussion and Conclusions

Jackman et al (2001) confirms a theory that large solar storms rain electrically charged and high-energy particles down on Earth's atmosphere and deplete the upper-level ozone for weeks to months thereafter. Their study examined impacts of a series of large solar explosions on the atmosphere in the NH. If we look at the total atmospheric column, from our head on up to the top of the atmosphere, this solar storm depleted less than one percent of the total ozone in the NH. While impacts to humans are minimal, these findings are important scientifically. This is an instance where we have a huge natural variance. We have to first be able to separate natural effects on ozone, before we can tease out humankind's impacts.

In January 25, 2003, NASA launched the Solar Radiation and Climate Experiment (SORCE) satellite and it provides further detailed measurements of the Sun. By using two satellites (UARS and SORCE) data, we can obtain a more accurate result of atmospheric effects during solar storms. For better understanding of atmospheric effects using these satellite data, we have to investigate many specific days for a long time.

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