# Simulation of the impact of the Halloween event on chemical species in the stratosphere using a chemistry-climate model

H. Akiyoshi,[*1,*2] Y. Motizuki,[*1] Y. Nakai,[*1] T. Imamura,[*2,*3] and Y. Yamashita[*2]

The effects of solar activity on the stratosphere and troposphere are of significant interest, but there is concern that they may be masked by various inherent variations,[1] such as variations originating from sea surface temperature, convective activity in the troposphere, and various wave activities in the stratosphere and troposphere. To clarify the solar influence on the stratosphere and troposphere, we planned a multi-ensemble numerical experiment using three-dimensional chemistry-climate models (CCMs). As a first step, we simulated a solar proton event in the satellite observation era, the Halloween event in October 2003, to verify one of our CCMs.

The model to verify is the CCSRNIES MIROC3.2 CCM. The model includes detailed stratospheric chemistry.[2] The simulation was performed by including the increase in NOx due to the Halloween event in the 60–90°N/S regions of the model. The increase in NOx was calculated from the time series of the vertical distribution of the ion pair production rates ($N_2^+$, $e^-$) due to the Halloween event,[3] using the G-value of only the following radiolysis reactions producing neutral N atoms[4] for simplicity:

$$N_2 \rightarrow N^+ + N + e^-$$
$$N_2 \rightarrow N(^4S)$$
$$N_2 \rightarrow N(^2D)$$
$$N_2 \rightarrow N(^2P)$$

In this simulation, the temperature and horizontal wind speed of the CCM were assimilated to observational values using a method of nudging. The observational values were taken from the ERA-Interim reanalysis data. The atmospheric composition for 2003 was used.

Figure 1 shows the change in ozone mixing ratio (as a percentage relative to the values on October 25) during the Halloween event and for several days afterwards. At altitudes above 1 hPa (approximately 48 km), in both the Antarctic and Arctic regions, the difference between the observed and simulated values is large, particularly during the Halloween event (see the area enclosed by the dotted rectangle in the figure). However, at altitudes below 1 hPa, although the absolute values of the changes have some differences, the temporal and spatial changes are well reproduced. The difference in the blue color areas is a maximum of about 20% (mostly 10%), whereas the difference in the red color areas at approximately 50 hPa in the Antarctic region is at most 50%.

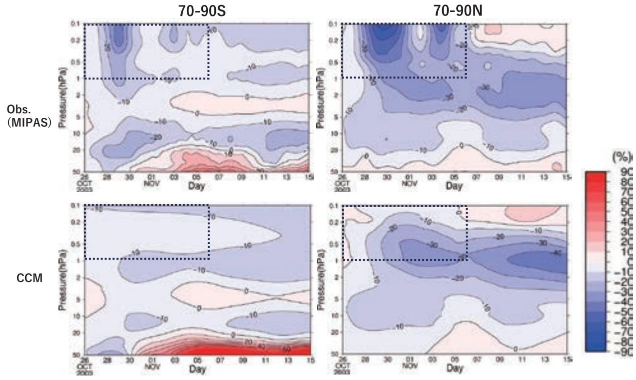


Fig. 1. Change in $O_3$ mixing ratio relative to that on Oct. 25 during and after Halloween event. Colors indicate $\{O_3 - O_3(\text{Oct. } 25)\}/O_3(\text{Oct. } 25) \times 100(\%)$. Dates from Oct. 26 to Nov. 15 are indicated on the horizontal axis.

The differences observed at altitudes above 1 hPa are likely primarily owing to the absence of ionic reactions in the CCM. Hirasedo *et al.* (2025)[5] developed and used a chemical box model that introduced 147 neutral and 605 ionic reactions in the atmosphere to compare the ozone concentration during the Halloween event with/without ionic reactions. The results showed that when ionic reactions were included, the ozone concentration decreased significantly during the event, but several days after the event, the ozone concentration recovered to a certain extent and became close to the concentrations calculated without ionic reactions. This demonstrates that the change in ozone concentration several days after the event can be fairly reproduced using only neutral reactions. Because our objective is to investigate ozone and climate change in the stratosphere during a few years after proton events, the use of this CCM without ionic reactions may be justified.

Both the observation and CCM show an increase in ozone concentration at 50–20 hPa (approximately 20–27 km) in the Antarctic region, which indicates that the increase in NOx due to solar proton events weakens ozone destruction owing to high concentrations of active chlorine, reducing the ClO concentration in the polar vortex.[6]

We found that the changes in ozone concentrations after the Halloween event calculated using our CCM, which does not explicitly include ionic reactions, are considerably consistent with those observed in the

*1 RIKEN Nishina Center
*2 Earth System Division, National Institute for Environmental Studies
*3 Tokyo Metropolitan Research Institute for Environmental Protection

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stratosphere.

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