Variation in chemical composition induced by solar energetic particle events in the middle atmosphere

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Recently, the influences of super solar flares on the earth environment have been extensively investigated. One of the areas of focus in such investigations is the change of chemical composition in the terrestrial atmosphere induced by energetic particles generated in the super solar flares. The bombardment of solar energetic particles (SEPs) to the atmosphere is called an SEP event, where a large amount of X-rays, gamma-rays, protons, and heavier ions from the surface of the sun intrude the terrestrial atmosphere. In particular, high-energy protons come down into the stratosphere and induce dissociation of nitrogen molecules followed by an increase of odd nitrogen oxides (NOx) and reactive odd nitrogen species (NOy). Consequently, the increase of NOx and NOy affects the ozone concentration over a period longer than SEP events.

We have performed simulations to investigate variation in chemical composition in SEP events by solving a large number of rate equations for the concentrations of chemical species in air.[1)] We adopt 77 chemical species including ions and about 480 chemical reactions (ionic reaction processes, neutral reactions, photolysis, etc.) in the present simulation. A large number of ionic processes, including recombination in the stratosphere, were treated for the first time, to the best of our knowledge. No transport processes are taken into account. This model is referred to as the Box-model hereafter. We carried out calculations using commercial software for solving complex chemical reaction systems (FACSIMILE, MCPA Software Ltd).

In order to estimate the yields of prompt products by the SEP protons, we used the G-values (amount of products per absorbed energy of 100 eV) investigated by radiolysis studies[2,3)], based on the assumption that the prompt product yields are determined only by the energy deposit of the SEP protons in air. The prompt products are assumed to be charged products (positive atomic ions, positive molecular ions, and electrons) and neutral products (ground-state and the metastable atoms) generated from nitrogen and oxygen molecules in air. The energy deposit was estimated using the calculations of ion-pair creation by the SEP protons[4)]. During an SEP event, both the photochemical reactions induced by the UV and visible radiation from the sun and the reactions induced by the SEP protons are considered in the simulation. The variation in chemical composition in an SEP event is estimated as the difference between the result obtained through simulation including the radiolysis processes due to the SEP protons and that obtained under consideration of only photochemical reactions using the same initial condition.

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Figure 1 shows a tentative result of the variation in the ozone concentration at the 50 km altitude in the northern polar region for the SEP event in October-November 2003. The energy deposit in the SEP event continued for six days. A sharp decrease of the ozone concentration is observed immediately after the SEP event starts. On the third day of the event, when the energy deposit also reaches the maximum, the decrease of the concentration reaches the maximum and increases back gradually after that. The ozone concentration does not completely recover and remains depleted for a few weeks or more. This depletion of the ozone presumably corresponds to a very slow recovery of the NOx concentrations. The NOx concentration begins to increase when an SEP event starts. It continues to increase for four days and is almost maintained constant after the SEP event. The depletion of ozone is thought to continue after the SEP event since the ozone is consumed in the catalytic reaction cycle involving NOx, e.g., $NO+O_3 \rightarrow NO_2+O_2$.

In the near future, we will investigate the global and long-term influence of SEP events on the atmospheric chemical composition. In our approach, we will estimate short-term variations during an SEP event using our Box-model, and the estimated variations will then be input into a three-dimensional (3D) chemical climate model (CCM)[5)] as instantaneous perturbation of the chemical composition. This is because the transport of chemical species treated in 3D is essential for investigating the global and long-term influence.

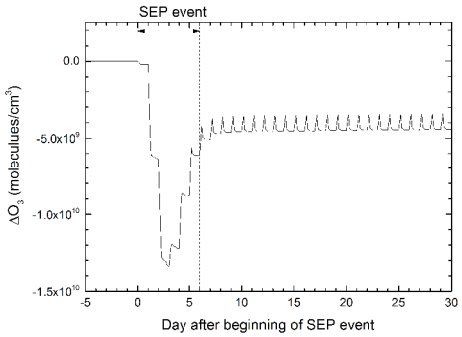

Figure 1. Tentative result for the variation in the ozone concentration at the 50km altitude caused by SEP (see text).

References

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