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Numerical prediction of changes in atmospheric compositions during SEP events at Mars

#Yuki Nakamura[1,3],Naoki Terada[2],Francois Leblanc[3],Hiromu Nakagawa[4],Shotaro Sakai[5],Sayano Hiruba[6],Ryuho Kataoka[7,8], Kiyoka Murase[7,8]
[1]Geophysics, Tohoku Univ.,[2]Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.,[3]LATMOS-IPSL, CNRS,[4]Dep. Geophysics, Grad. Sch. Sci., Tohoku Univ.,[5]Dept. Geophys., Science, Tohoku Univ.,[6]Tohoku University,[7]NIPR,[8]Polar Science, SOKENDAI

Solar energetic particles (SEPs) are high-energy particles that consist mainly of electrons and protons with energies from a few tens of keV to GeV ejected from the Sun associated with solar flares and corona mass ejections. SEPs that precipitate into planetary atmospheres experience many types of collisions with atmospheric particles during their entry, causing increased ionization, excitation, dissociation, heating and changes in ion and neutral compositions [e.g. Solomon et al., 1981; Leblanc et al., 2002]. The effects of SEPs on atmospheric compositions are of great importance because SEPs could cause destruction of ozone, and production of hydrogen cyanide that is essential in prebiotic synthesis of amino acid [e.g. Solomon et al., 1981; Airapetian et al., 2016].

The effects of SEPs on ozone concentration at polar region of the Earth has been intensively studied for the past decades. For instance, during the enormous solar flare that occurred in late October 2003, NOx and HOx concentrations were enhanced and ozone concentration was depleted by 40% at the polar lower mesosphere [e.g. Jackman et al., 2005]. Increased ionization and dissociation of atmospheric N2 and O2 molecules led to the production of NOx and HOx, which catalytically destroyed ozone at the polar mesosphere.

Recently, the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft has discovered global diffuse aurora on the nightside of Mars during SEP events, indicating that more energy could be deposited in the deeper atmosphere than previously thought due to the interaction of SEPs with the Martian atmosphere [Schneider et al., 2015]. However, the effects of SEPs on the atmospheric chemistry of Mars has not yet been understood by both observations and models.

We have developed a Monte Carlo model and a photochemical model to investigate the effects of SEPs on the atmospheric compositions at Mars. The Monte Carlo model solves transport of protons, hydrogen atoms and secondary electrons in the Martian atmosphere to calculate ionization rate during SEP events. The photochemical model solves 171 chemical reactions including photoionization, ion chemistry, and neutral chemistry with respect to HOx and ozone.

We have performed a simulation of the effects of a large SEP event on atmospheric compositions on Mars. The proton flux observed at Earth during the enormous solar flare of October 2003 [Mewaldt et al., 2005] was used as input to the Monte Carlo model. We found that concentration of water cluster ions increased up to 10^{10} cm^{-3} below 70 km altitudes, which is in good agreement with the previous study [Sheel et al., 2012] that predicted the SEP effects on the ionosphere of Mars. We found that HOx increased by a factor of 10 and ozone decreased by a factor of 10 in the altitude range from 20 km to 60 km. This is the very first estimation of the effects of SEPs on the atmospheric neutral compositions at Mars, indicating that the similar effects on HOx and ozone could be expected on Mars as on Earth, such as increased ionization leads to the formation of water cluster ions and following production of HOx, which destroy ozone.