Comparative study of proton and oxygen ion supply into the inner magnetosphere during a geomagnetic storm

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It is observationally known that the contribution of oxygen ions to the ring current increases with increasing size of magnetic storms, although protons are the main component of the ring current ions during small storms. The protons and oxygen ions are considered to have different source and supply mechanisms. The protons mainly come from the solar wind through the plasma sheet, and oxygen ions originate from the terrestrial ionosphere. However, detailed properties of the ion supply and their dependence on ion species (such as depth and timing of ion penetration into the inner magnetosphere) are far from well understood. To characterize the ion supply to the ring current during magnetic storms, here we investigate the properties of energetic proton and oxygen phase space densities (PSDs) during a geomagnetic storm observed by the Van Allen Probes mission. We examine a magnetic storm that occurred during the period from April 23 to 25, 2013. Using energetic ion and magnetic field data obtained by the RBSPICE and EMFISIS instruments onboard Van Allen Probes, we studied the temporal variations of protons and oxygen ions PSD radial profiles.
We calculated the first adiabatic invariant, mu, and PSD for ions with a pitch angle of about 90 degrees (We selected data of a telescope with a pitch angle which is the nearest 90 degrees in all telescopes and is in range of 70 -110 degrees for each time.). Proton and oxygen PSDs for specific mu values (mu= 0.3, 0.5, 0.8, 1.0 keV/nT for proton, mu= 0.5, 0.8, 1.0 keV/nT for oxygen) were obtained as a function of L for each orbit of Van Allen Probes during the storm. The results show that both proton and oxygen ions penetrated directly down to L ~5 during the main phase of the magnetic storm (minimum Dst greater than -65 nT). The penetration boundary of protons were located at smaller L at dusk than at dawn. Protons with smaller mu values (mu= 0.3 and 0.5 keV/nT) penetrated earlier than those with larger mu values (mu= 0.8, 1.0 keV/nT). It seems consistent with the energy dependence of the Alfven layer. In contrast, the timing of O+ penetration is almost the same for all mu values (mu= 0.5, 0.8 and 1.0 keV/nT). The observations also show that O+ ions penetrated more deeply in L and earlier in time than H+ ions.
These results suggest that the source of the transported oxygen ions is located closer to the Earth than that of the protons (i.e., the inner edge of the plasma sheet).
Variations of the oxygen E-t diagram during the second main phase of the storm show enhancement of flux in energy over ~100 keV closer to the Earth than protons inner edges. The magnetic fluctuation with about 0.01 Hz is also enhanced during the second main phase of the storm closer to the Earth than protons inner edges. We suggest that deeper penetrations of oxygen ions are caused by interaction between oxygen ions and Pc5 magnetic fluctuations.
Our results thus demonstrate the importance of the contribution from high energy oxygen ions to the storm-time ring current.

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