Simulation of the total ion loss evolution on Mars with a global hybrid model: Implications for the planet's hydrosphere

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The evolution of the Martian H2O inventory since the late Noachian period about 3.5 - 3.7 Gyr ago is investigated. For obtaining the total O+ and O2+ loss rates from the present to 3.5 Gyr ago, we applied a comprehensive 2-D global hybrid model of the solar wind interaction with Mars. The entire Martian-solar wind interaction region is simulated by including the ionosphere, ionopause transition layer, and the magnetosheath for solar activity periods at present (1 XUV), 2.5 Gyr (3 XUV) and 3.5 Gyr (6 XUV) ago. Our model includes ion loss processes originated by solar wind pick up, detached plasma clouds triggered by the Kelvin-Helmholtz instability and viscous processes at the Martian ionopause. For the reconstruction of the Sun's X-ray and extreme ultraviolet (XUV) radiation and solar wind mass flux with time, we use actual data from the observation of solar-like stars of different ages. Our study yields average total O+ ion loss rates of about 2 times 10^24 s^-1 at present, about 6 times 10^25 s^-1 2.5 Gyr and about 5 times 10^26 s^-1 3.5 Gyr ago. Our study indicates that the obtained loss rates for the 6 XUV case 3.5 Gyr ago may have been overestimated by previous test particle models by about a factor of two. We found that ion loss processes caused by the viscous processes around the ionopause should have played a significant role during early Martian periods before 2 Gyr ago. The loss of H2O from Mars over the past 3.5 Gyr is estimated to be equivalent to a global Martian H2O ocean layer with a depth of about 10 m resulting in a present H2O-ice reservoir which is exchangeable with the Martian atmosphere of an equivalent global layer with a depth between 7 - 10 m.