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Statistical response of middle atmosphere composition to solar proton events in WACCM-D simulations: the importance of lower ionospheric chemistry

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Atmospheric effects of solar proton events (SPEs) have been studied for decades, because their drastic impact can be used to test our understanding of upper stratospheric and mesospheric chemistry in the polar cap regions. For example, odd hydrogen and odd nitrogen are produced during SPEs, which leads to depletion of ozone in catalytic reactions, such that the effects are easily observed from satellites during the strongest events. Until recently, the complexity of the ion chemistry in the lower ionosphere (i.e., in the D region) has restricted global models to simplified parameterizations of chemical impacts induced by energetic particle precipitation (EPP). Because of this restriction, global models have been unable to correctly reproduce some important effects, such as the increase in mesospheric HNO_3 or the changes in chlorine species. Here we use simulations from the WACCM-D model, a variant of the Whole Atmosphere Community Climate Model, to study the statistical response of the atmosphere to the 66 strongest SPEs which occurred in the years 1989–2012. Our model includes a set of D-region ion chemistry, designed for a detailed representation of the atmospheric effects of SPEs and EPP in general. We use superposed epoch analysis to study changes in O_3, HO_x ($OH + HO_2$), Cl_x ($Cl + ClO$), HNO_3, NO_x ($NO + NO_2$) and H_2O. Compared to the standard WACCM which uses an ion chemistry parameterization, WACCM-D produces a larger response in O_3 and NO_x and a weaker response in HO_x and introduces changes in HNO_3 and Cl_x. These differences between WACCM and WACCM-D highlight the importance of including ion chemistry reactions in models used to study EPP.