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Energetic particle precipitation into the middle atmosphere: measurements and model predictions

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Precipitation of energetic particles – protons and electrons from large solar coronal mass ejections, the aurora, or the radiation belts – significantly affects the chemical composition of the atmosphere from the lower stratosphere to the lower thermosphere. The primary reactions are excitation, dissociation, and ionization of the main components of the atmosphere (N2 and O_2), followed by fast ion-chemistry reactions forming NO_x (N, NO, NO_2) and HO_x (H, OH, HO_2, 2 H_2O_2). Both NO_x and HO_x contribute to catalytic destruction of ozone in the middle atmosphere, NO_x in the stratosphere (below $\sim$45 km), HO_x in the mesosphere (above $\sim$45 km). The impact of energetic particle precipitation onto the composition of the middle atmosphere, especially on the NO_x budget and stratospheric ozone, has been investigated in a number of studies in the past, but there are still many open questions, both regarding the processes that lead to chemical changes during the particle events, and the long-term impact of those events on stratospheric composition and dynamics.

We use models of different complexity from a one-dimensional ion-chemistry model to a global three-dimensional chemistry and transport model combined with observations of atmospheric trace gases from different satellite platforms to investigate the impact of energetic particle precipitation onto the chemical composition of the middle atmosphere. Focus of our investigations are, on the one hand, ion-chemistry processes during particle events, and on the other hand, the contribution of energetic electron precipitation to the middle atmosphere NO_x and ozone budget. We find that some of the observed trace-gas changes during large solar particle events can only be explained by complex ion-chemistry. Models driven by ionization rates derived from observed electron and proton fluxes predict a large direct impact of energetic electrons onto the upper stratosphere and mesosphere, both during large solar proton events, and during geomagnetic storms; in contrast to the model predictions, observational evidence for a direct impact of energetic electrons to altitudes below 80 km is sparse and ambiguous. However, observations also show that the downwelling of NO_x from the auroral region above 80 km during polar winter can affect the NO_x budget of the polar stratosphere more than even very large solar events.