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The influence of precipitating solar and magnetospheric particles on the entire atmosphere - Simulations with HAMMONIA

J. Kieser (1), H. Schmidt (1), J. M. Wissing (2), and M.-B. Kallenrode (2)
(1) Max Planck Institute for Meteorology, Hamburg, Germany, (2) University of Osnabrück, Osnabrück, Germany

Precipitating electrons, protons, and alpha particles enter the Earth‘s atmosphere at high latitudes caused by solar and magnetospheric activity. They can lead to ionization, dissociation, dissociative ionization and excitation of molecules and atoms of the upper and middle atmosphere. These particle-induced interactions result in the production of odd hydrogen and odd nitrogen constituents and in further changes of the chemical composition, which in turn cause changes of the atmospheric energy budget and dynamics. Past numerical studies of the influence of precipitating energetic particles on atmospheric chemistry mostly have been concentrating on effects of solar protons in the stratosphere and mesosphere. It is still unclear how important the production of nitrogen oxide by magnetospheric electrons in the lower thermosphere and its possible downward transport in the polar night is for the chemical budget of the middle atmosphere. We study the influence of precipitating electrons, protons and alpha particles of solar and magnetospheric origin on the entire atmosphere during the solar storms in October/November 2003 using the general circulation and chemistry model HAMMONIA (Hamburg Model of the Neutral and Ionized Atmosphere). The model treats atmospheric dynamics, radiation and chemistry interactively for the altitude range from the Earth‘s surface to the thermosphere (approximately 250 km). In addition to 153 chemical reactions associated with 50 neutral species an E-region ion chemistry module has been developed and implemented with 30 reactions involving the five positive ions O^+, O_2^+, N^+, N_2^+, NO^+, and electrons. Ionization, dissociation and excitation by precipitating energetic charged particles, photons in the extreme ultra-violet spectral range from 0.05 - 121 nm, and by photoelectrons are considered. Rates for ion pair production caused by precipitating solar and magnetospheric protons, electrons and alphas are provided by AIMOS (Atmospheric Ionization Module Osnabrück) for the entire atmosphere. Our model computations point out the substantial impact of precipitating energetic particles on the polar middle and upper atmosphere. Simulations show significant enhancements in the lower thermospheric, mesospheric, and upper stratospheric NO_x content during the particle event. The NO_x increase causes ozone depletion and subsequently a temperature response. Our results show that both the southern and northern mesospheric NO_x content is elevated over several weeks after the event, while in the stratosphere long term effects appear only in the winter hemisphere. Since a significant contribution of ionization caused by alpha particles is confined to the polar cap during the particle event, where solar protons dominate, the influence of alpha particles is secondary. Further, our model results indicate a relatively weak influence of precipitating electrons during the particle event where protons dominate. During quiet times, however, electrons play the major role in NO_x production in the polar middle and upper atmosphere. This illustrates that neglecting electrons in studies of precipitating particles may lead to a significant error in the assessment of chemical background conditions.