Project: **1435**
Project title: **Solar activity and dynamics of the mesosphere and lower thermosphere**
Principal investigator: **Markus Kunze**
Report period: **2025-07-01 to 2026-04-30**

Activity 2025/2026

During the reporting period, all of the granted 6090 Node-hours were used for simulations with the upper-atmosphere ICOsahedral Non-hydrostatic (ICON) (Zängl et al., 2015) general circulation model (UA-ICON) (Borchert et al., 2019, Kunze et al., 2025). This total amount was mostly used on test simulations to accompany the integration of the MECCA ion-chemistry, photo-, and particle-ionization to UA-ICON. By end of March 2026, the developments were finalized, and some Node-hours were used for a first test case. However, the simulations listed in the previous application for computing time are still a core requirement for the project and need to be moved to the next reporting period.
Some results were presented at the ICCARUS 2026 meeting and further results will be presented at the 16th Quadrennial Solar-Terrestrial Physics Symposium (STP-16) in June 2026.

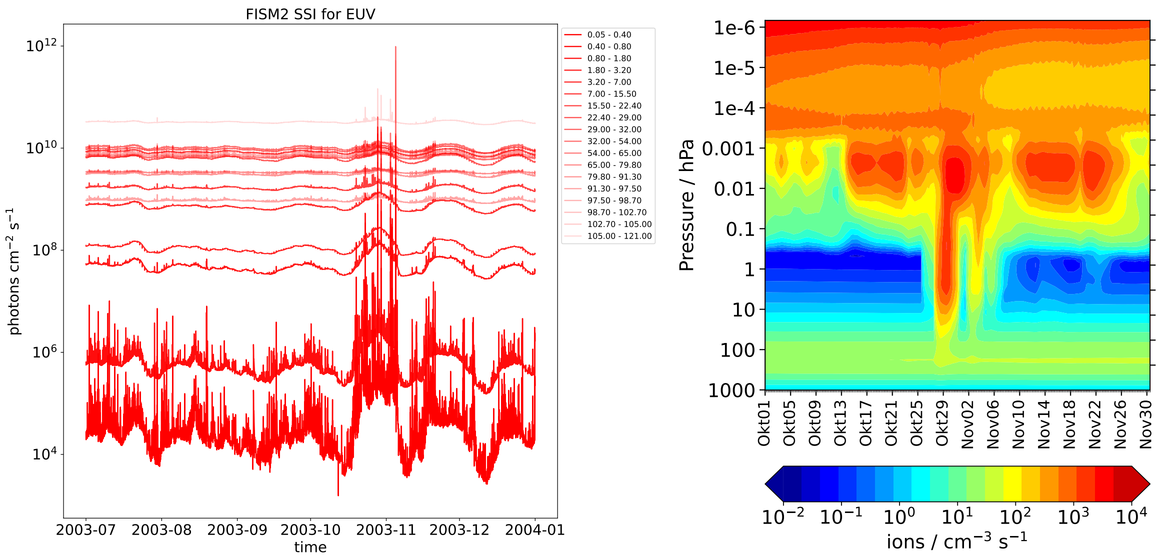

Figure 1: (left) Time series of FISM2 SSI integrated into 18 bands as used for the EUV parametrizations in 5 minutes intervals. (right) Time/altitude area-weighted (40–90°N) ionization rate development as the combination of CMIP7 particle forcing from solar proton events, medium energy electrons, and galactic cosmic rays.

A first test case with an intense solar storm is successfully simulated with the updated model system UA-ICON/ART/MECCA. Large increases in spectral solar irradiance (SSI) and energetic particle precipitation (EPP) are observed in conjunction with flares and coronal mass ejections (CMEs). A period of high solar activity occurred from mid-October to early November 2003, known as the Halloween solar storm, with a CME and several solar flares with intensities reaching the X28 class on November 4 (Fig. 1, left). The event was followed by solar proton events (SPEs) and geomagnetic storms in the Earth's magnetosphere shortly after the CME (Fig. 1, right). Both SSI increases during solar flares and increases in EPP from SPEs and medium energy electrons (MEE) lead to higher ionization in the thermosphere and mesosphere and subsequently to the production of NOx and HOx, which in the polar regions propagate downward and have the potential to destroy ozone.
The UA-ICON setup has a R2B4 horizontal resolution, a ∼150 km top, and interactive chemistry through ART with MECCA, including basic ion chemistry for molecular and atomic nitrogen and oxygen. The meteorology during the simulation is specified from ERA-5 reanalyses up to 50 km, where the nudging

fades out, allowing the mesosphere and lower thermosphere to develop freely.
Daily SSI, as recommended for CMIP7 from Lyman-α to the near-infrared, and 5-minute resolved FISM2 SSI for X-ray/extreme ultraviolet (Figure 1, left) are used as solar irradiance forcing. The EPP forcing, in terms of ion pair production rates (IPRs), is a combination of IPRs recommended for CMIP7 for GCRs, SPEs, and MEEs (Figure 1, right).

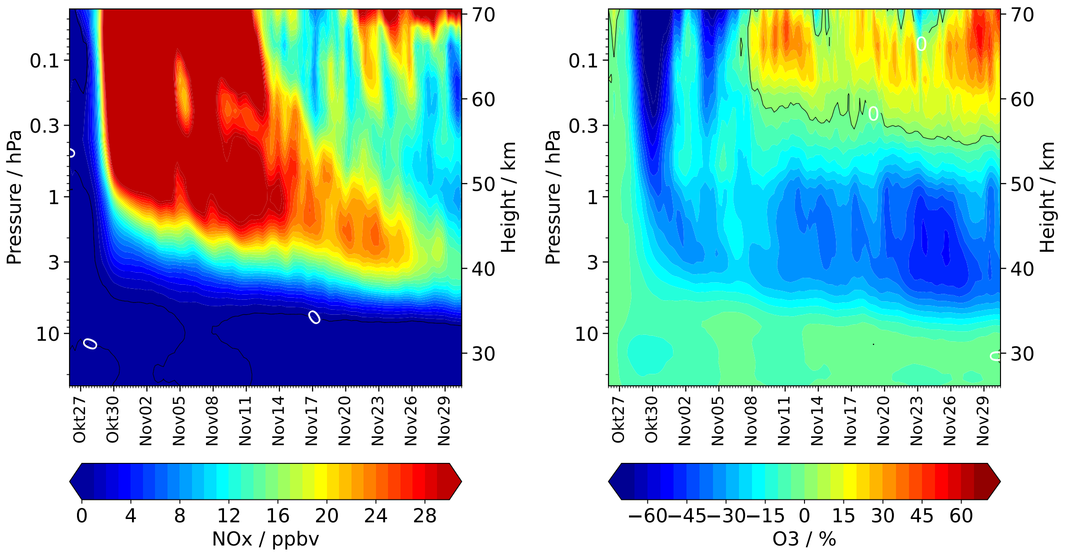

Figure 2: Temporal evolution of 70–90°N area–weighted changes relative to 26 October 2003. (left) Change of NOx mixing ratio in ppbv, (right) percentual ozone changes.

There is large increase in NOx (NO + NO_2) coinciding with the increase in ion-pair production by protons on 28–30 October, leading to the disscociative ionisation of N_2 and subsequently to NOx production. The increased NOx mixing ratios are transported downward to the stratosphere (Fig. 2, left). The large ozone anomalies (Fig. 2, right) are the result of the NOx catalytic cycle of ozone destruction. The simulated ozone anomalies are in good agreement with published MIPAS satellite observations following the Halloween-event (Funke et al., 2011).

References

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