Project: **1435**

Project title: **Solar activity and dynamics of the mesosphere and lower thermosphere**

Principal investigator: **Markus Kunze**

Report period: **2024-07-01 to 2025-04-30**

Activity 2024/2025

During the reporting period, all of the granted 5481 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., 2025a). This total amount was used on test simulations to accompany the ongoing model development. The simulations listed in the previous application for computing time are still relevant.

Some results were presented at the HEPPA-SOLARIS meeting 2024, and the ICCARUS 2025 meeting and will be presented at the European Geophysical Union General Assembly 2025 (EGU25) (Kunze et al., 2025b).

Updated historical forcing datasets for the 7th phase of the Coupled Model Intercomparison Project (CMIP7) are now available for evaluation. These include daily varying spectral solar irradiance (SSI) and total solar irradiance (TSI). Here, we show the effects of SSI from the NASA NOAA LASP (NNL) Solar Spectral Irradiance Version 1 model (NNLSSI1), which uses the new solar reference SSI TSIS-1 (Version 2) (Coddington et al., 2023), in comparison to the CMIP6 SSI dataset (Matthes et al., 2017). Figure 1 shows the percentage differences between the CMIP7 and CMIP6 SSI datasets for the original spectral resolution and binned to the resolution of radiation parametrizations of UA-ICON. Using the new TSIS-1 reference spectrum, in the CMIP7 SSI dataset, energy from the near-infrared (NIR) spectral region shifts to the ultraviolet (UV) and visible spectral region, compared to the CMIP6 SSI dataset. The effects of changing from the CMIP6 SSI dataset to the new CMIP7 recommendation are analyzed from UA-ICON simulations. We apply UA-ICON with numerical weather prediction (NWP) physics package in a global horizontal resolution of R2B4 (~160 km), with 120 levels up to a top height near 150 km and a vertical resolution of 700 m between ~13.8 – ~40.5 km (finer below and coarser above). The setup of Kunze et al. (2025a) is used, with tuned non-orographic and orographic GW parametrizations in a perpetual January mode.

The energy shift, as shown in Figure 1, has an impact on the short-wave heating rates (SW-HR) by UV absorption in the Harley and Huggings bands of O_3, as shown in Figure 2 (top row) with a significant increase in SW-HR with up to 0.45 K d^{-1} in the upper stratosphere and lower mesosphere. In the thermosphere, the slightly smaller SSI in the Schumann-Runge continuum (130 – 175 nm) and the Lyman-α (far UV, FUV), led to decreasing SW-HR from O_2 absorption of -1 K d^{-1}. The decrease in SW-HR in the extreme UV (EUV) spectral region by more than -4 K d^{-1}, is caused by differences in the prescribed atmospheric profiles (N_2, O_2, and O) for the upper atmosphere. These are interpolated from HAMMONIA pressure level data to the height level grid of UA-ICON. Due to the initiated temperature differences in the simulation using the CMIP7 SSI compared to the simulation using the CMIP6 SSI, the pressure on the height levels changes, which effectively reduces the N_2, O_2, and O volume mixing ratios on the height level grid. As these tracers are taken into account for the EUV SW-HR calculation, the EUV SW-HR is smaller in the simulation with CMIP7 SSI, although the F10.7 cm flux, used for scaling the internal solar flux of the parametrization, is the same for both simulations.

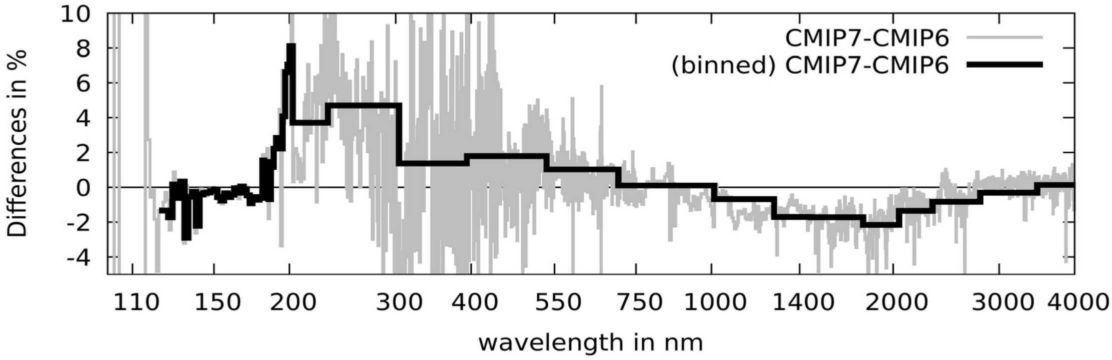

Figure 1: Percentage changes in SSI between CMIP7 and CMIP6 for the original spectral resolution of the datasets and binned to the spectral resolution of UA-ICON's SW-radiation parametrizations. The SSI are yearly averaged for the solar minimum 2009.

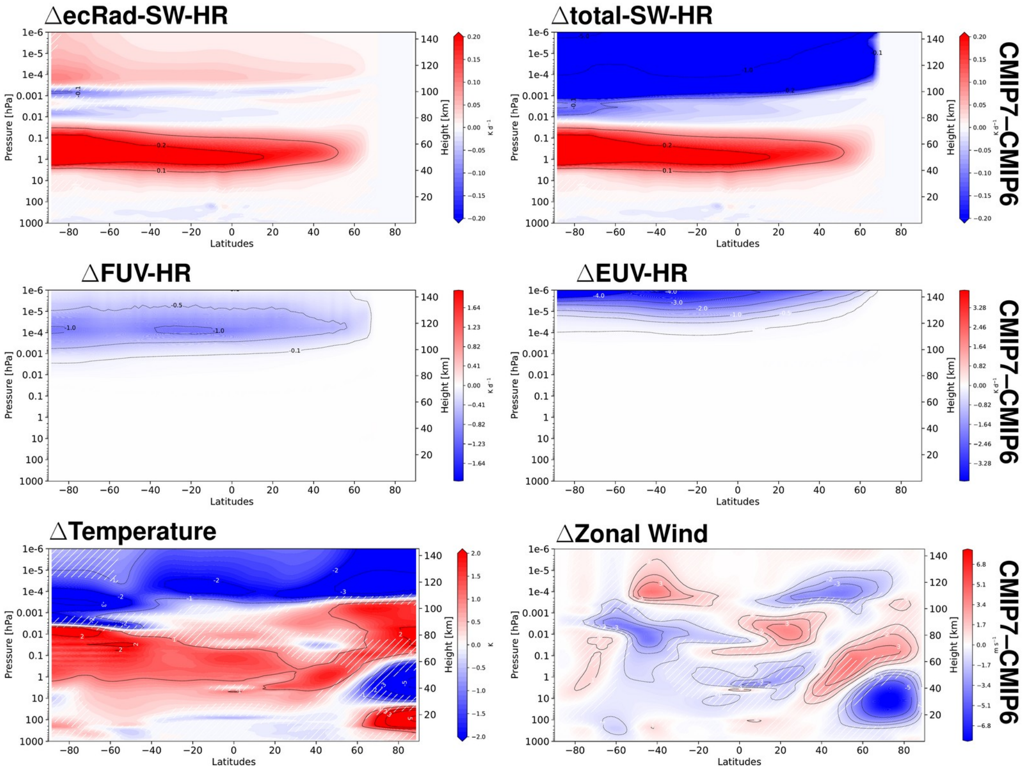

Figure 2: Climatological differences in January between UA-ICON simulations using the CMIP7 SSI and the CMIP6 SSI datasets during solar minimum of 2009.

This emphasizes the importance of using interactive chemistry in simulations of the upper mesosphere and lower thermosphere with varying SSI. Whereas with prescribed tracers, the changes in heating rates are partly caused by indirect tracer changes, these are more consistent when using interactive chemistry, where changes in the SSI directly influence the photolysis of tracers. With simulations using interactive chemistry, the atmospheric composition changes are consistent with the SSI changes and the subsequent temperature changes and dynamics give a much more realistic picture.

References

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