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Historical Forcing Datasets

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Authors:

**Bernd Funke (IAA-CSIC), Stephanie Fiedler (UH),
Stefan Bender (IAA-CSIC), Alon Azoulay (UH)**

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About

The climate system is changing rapidly and some regions have seen increases in extremes beyond what is expected from climate model simulations. To support targeted climate adaptation strategies, EXPECT will enable trustworthy assessments and predictions of regional climate change including extremes by developing a prototype operational capability for integrated attribution and prediction of climate. This ambitious goal is closely aligned with the WCRP Lighthouse Activity on Explaining and Predicting Earth System Change.

EXPECT will identify and quantify the mechanisms by which physical processes govern regional climatic changes, including extremes, on inter-annual to multi-decadal time scales. It will do so by exploiting newly available climate simulations and Earth Observations (EOs), and by combining machine learning (ML) with physical methods. The research will target fundamental knowledge gaps related to atmospheric circulation and land-atmosphere interactions, which represent major limitations in current climate predictions and projections, and in particular in understanding changes in European summer extremes.

To underpin the research, and benefiting the wider research community, EXPECT will develop tools to efficiently analyze a variety of large data sets in combination that are hosted in different repositories across institutions. This will facilitate the exploitation of recent investments into high-resolution climate models and EO data. EXPECT will further build data science capacity for the scientifically robust, efficient and reproducible analysis of the massive data assets, including novel ML approaches, and provide training for the climate science community and the next generation of researchers in particular.

EXPECT will thus deliver significant scientific and technological advances for society and the climate science community that will last well beyond the project, in support of WCRP's strategic objectives.

Executive summary

This deliverable finalizes Task 1.3 of WP 1 by providing the historical forcing data sets for the solar and anthropogenic aerosol input to be used for new climate simulations conducted within the project. The datasets have been produced in close collaboration and with feedback from the CMIP7 Climate Forcing Task Team. They have been uploaded to the official CMIP7 forcing repository input4MIPs.

1 Solar irradiation and particle forcing

The dataset contains the forcing data from solar irradiation and energetic particle precipitation. The irradiation forcing is provided spectrally resolved in terms of solar spectral irradiance (SSI) and integrated as total solar irradiance (TSI). The energetic particle forcing is provided for galactic cosmic rays (GCR), solar energetic protons (SEP), and medium-energy electrons (MEE).

1.1 Dataset period

We provide data for the historical forcing (1850—2023) with daily and monthly resolution. We also include pre-industrial control forcing data which includes time-averaged historical data corresponding to 1850—1873 mean conditions (solar cycles 9 and 10).

1.2 File Contents

Coordinates

The data files contain the particle ionization data on 61 pressure levels and 32 geomagnetic latitude bins. The spectral irradiance is provided on 3890 wavelength bins. The bin centres and edges are given as coordinates. The time coordinate contains the respective number of days or months for the daily and monthly forcing files. The pre-industrial forcing contains a single time stamp.

Radiative forcing data

The forcing data includes the SSI in $\text{W/m}^2/\text{nm}$ and TSI in W/m^2 , both normalized to 1 AU, based on reconstructions generated with the new empirical NASA NOAA LASP (NNL) Solar Spectral Irradiance Version 1 model, NNLSSI1 (Coddington and Lean, 2025, <https://www.ncei.noaa.gov/products/climate-data-records/solar-spectral-irradiance>).

Particle forcing data

Particle forcing is included for cosmic rays, solar protons, and medium-energy electrons in $1/\text{g/s}$. The cosmic-ray ionization is calculated with the CRAC:CR11 model using neutron monitor data and reconstruction based on sunspot number. The solar-proton ionization data are derived from GOES observations and projections using random solar cycles for the past. Medium-energy electron ionization is derived from the Ap geomagnetic index which is fed into an empirical model to calculate the particle fluxes and ionization profiles.

Auxiliary data

We provide the Sunspot number, historical data until Dec 2023. We also provide the geomagnetic Kp and Ap indexes used for calculating the ionization rates, and the

F10.7 radio flux. Data sets also contain the solar cycle numbers and the solar cycle phase. Additional calendar variables are provided for convenience.

1.3 Data Access

The solar forcing files for CMIP7 are available from the official input4MIPs data base at https://aims2.llnl.gov/search?project=input4MIPs&versionType=all&&activeFacets=%7B%22source_id%22%3A%5B%22SOLARIS-HEPPA-CMIP-4-6%22%5D%7D. The individual files can be accessed via the following persistent handles:

Time resolution	Identifier
daily	hdl:21.14100/805fcd35-52b8-4bbd-a068-123927cca2a0
monthly	hdl:21.14100/e9d1fa50-1a40-45fc-835c-8b5a10c4635f
PI control	hdl:21.14100/5efc5064-da1f-4b66-9bef-26d991446b48

The detailed file content description can be found at https://www.solarisheppa.kit.edu/img/CMIP7_metadata_description_4.6.pdf.

2 Historical Anthropogenic Aerosol Forcing for CMIP7 (SPv2.1)

2.1 Dataset period

We provide the parameterization dataset for historical anthropogenic aerosol forcing for use in CMIP7, covering 1850-2023 inclusive (Fiedler and Azoulay, 2025). The dataset is intended for use with the Simple Plumes module (Stevens et al., 2016) and includes the parameters required to generate time-evolving anthropogenic aerosol forcing.

2.2 File Contents

Coordinates

The dataset is provided as a compact parameter file. It defines nine predefined plumes representing major anthropogenic emission regions. The plumes correspond to the following regions: Europe, North America, East Asia, India, Northern Central Africa, South America, South Asia, Southern Central Africa, and Australia.

Aerosol optical properties and effects on cloud droplets

The dataset provides the parameterization underlying the Simple Plumes representation of anthropogenic aerosol optical properties and their effects on cloud droplet number concentration. It includes plume geometry, spatial structure, vertical distribution parameters, seasonal cycles, and optical properties at source such as aerosol optical depth, single scattering albedo, asymmetry parameter, and Angstrom exponent.

Annual scaling factors are provided for each plume to represent the evolution of anthropogenic aerosol forcing. These scaling factors are derived from historical SO₂ and NH₃ emissions from the CEDS v_2025_04_18 emissions inventory (Hoesly et al., 2025).

When used with the Simple Plumes parameterization, the data file enables reconstruction of anthropogenic aerosol optical properties and associated cloud droplet number changes for climate model experiments consistent with emission data used in CMIP7.

2.3 Data Access

Fiedler, S., & Azoulay, A., CMIP7 Climate Forcings Dataset: Simple plumes for anthropogenic aerosols (SPv2.1) [Data set]. Zenodo, doi: 10.5281/zenodo.15283189, <https://doi.org/10.5281/zenodo.15283189>, 2025.

2.4 References

Hoesly, R., Smith, S., Ahsan, H., Prime, N., O'Rourke, P., Crippa, M., Klimont, Z., Guizzardi, D., Feng, L., Harkins, C., MCDONALD, B., & Wang, S., CEDS v_2025_04_18 Gridded Emissions Data 0.5 degree (v_2025_03_18) [Data set]. Zenodo, doi: 10.5281/zenodo.15127477, <https://doi.org/10.5281/zenodo.15127477>, 2025

Stevens, Bjorn, et al., Simple Plumes: A parameterization of anthropogenic aerosol optical properties and an associated Twomey effect for climate studies, Geoscientific Model Development Discussions, 10, 433-452, 2026.

Fiedler, Stephanie, et al., First analysis of climate forcing and response to updated historical anthropogenic aerosol with the new CMIP7 model ICON XPP, Journal of Advances in Modeling Earth Systems, 17.10, e2025MS005067, 2025.