



Historical forcing datasets

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1 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.

2 Executive summary

We provide an updated representation of historical aerosol trends from the simple plume (SP) parameterization for aerosol optical properties and their effects on clouds (MACv2-SP) using the new historical emission data from Coupled Model Intercomparison Project phase 7 (CMIP7) for 1850-2020s. Similarly, the solar irradiance and energetic particle forcing has been updated and extended based on the latest observational data (e.g., TSIS-1) and theoretical models. To ensure consistency with CMIP7, all historical forcing data development within EXPECT were coordinated with the CMIP Climate Forcings Task Team and fed back into the CMIP7 forcing generation. Other updated historical forcing data for use in CMIP7 have been acquired and made available to the EXPECT consortium.

3 Solar irradiation and particle forcing

3.1 Models

The spectral solar irradiance (SSI) and total solar irradiance (TSI) data from 1874 onwards are provided by the NNL/CDR3 data set (Coddington et al., 2024), before that date, the same algorithm was used with reconstructed input back to 1850 to complete the time series.

The medium-energy electron ionization rate data are provided by driving the ApEEP model (v2024, trained on POES/MEPED data; van de Kamp et al. (2016), van de Kamp et al. (2018)) with (reconstructed) Ap geomagnetic index (Mandea et al., 2011) input from 1850 until 2023.

The proton and galactic cosmic ray ionization rates are both calculated using the CRAC:CRII model (Usoskin et al., 2010). In the case of protons, the input is taken from GOES and IMP-8 data, as well as available SEP data from 1968–2023. For times before 1968, the ionization rates are reconstructed using solar cycle matching. The galactic cosmic ray ionization is derived from neutron monitor measurements from 1951 until 2023, and uses open solar flux reconstruction using geomagnetic indices before that time. Figure 1 summarizes the models used and the accompanying data provided in the forcing dataset.

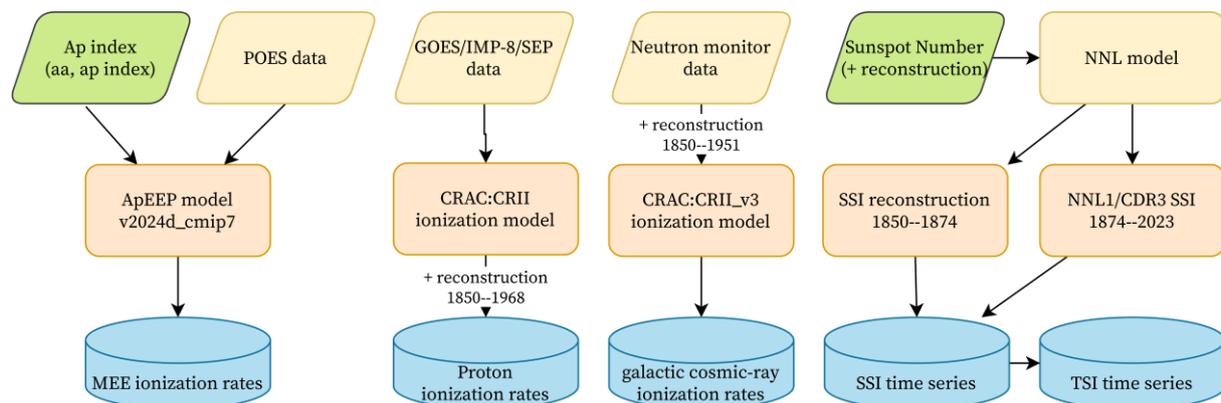


Figure 1: Models used for solar forcing inputs (orange) with their input data (green, provided; yellow, not provided here), and the final data sets in the forcing files (blue).

3.2 Auxiliary Data

Besides the model-derived SSI, TSI, and ionization data, the data set contains the following solar and geomagnetic data taken from the appropriate data bases:

- 1-AU adjusted 10cm solar radio flux F10.7
- geomagnetic indices Ap, Kp
- smoothed sunspot number
- solar cycle number and phase

3.3 Data Access

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

4 Aerosol forcing

4.1 Models

The SP parameterisation for anthropogenic aerosol optical properties and associated effects on clouds is used (Stevens et al., 2017). The historical scaling of the input data has been updated and extended in preparation for use in CMIP7 experiments (Fiedler and Sudarchikova, 2024). Unlike the country-aggregated emissions in Stevens et al. (2017), the temporal scaling for the updated historical period is now done based on gridded emissions of SO₂ and NH₃ following Fiedler et al. (2019). This is done for method consistency with a large set of available scenarios produced for CMIP6 and CovidMIP, and the SP data to be produced for CMIP7 in the framework of EXPECT. Updated historical emission data are taken from Hoesley et al. (2024). The spatial maps show the global distribution of the anthropogenic aerosol optical depth and the factor for inducing aerosol effects on clouds from the updated SP data for two selected years (Fiedler et al., in review).

Completed tests of the updated and extended SP data include comparisons between the new and the CMIP6 variant of SP data. These tests involve performing an ensemble of historical experiments with the new climate model ICON-XPP, estimating effective radiative forcing for different aerosol patterns, analysing statistics of aerosol optical depth, and computing trends with different extensions and SP scenarios. The comparison used a large number of observational data sets as references. Findings from the work have been summarised in a manuscript (Fiedler et al., in review) and the data is publicly available via zenodo (Fiedler and Sudarchikova, 2024). Work with the updated SP data is continued at BSC and ECMWF.

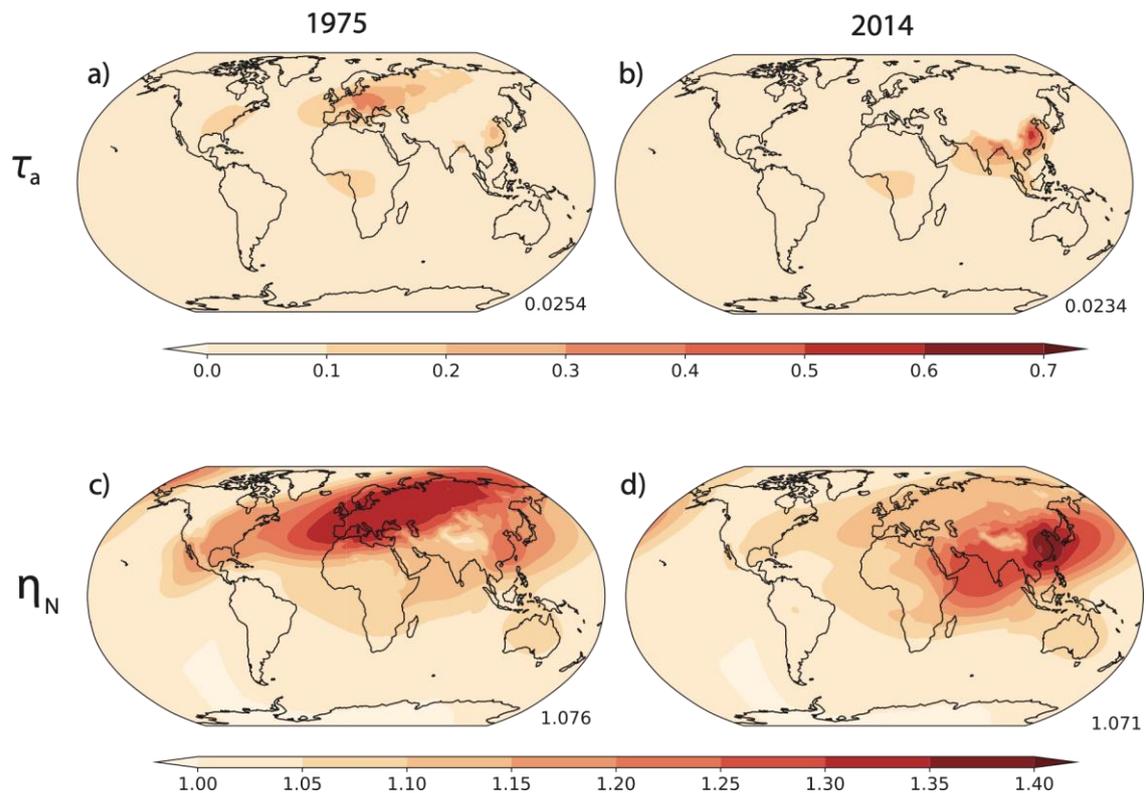


Figure 2: Annual mean of (top) anthropogenic aerosol optical depth and (bottom) factor for inducing aerosol effects on clouds for the years (left) 1975 and (right) 2014 (Fig. 1 from Fiedler et al., in review).

4.2 Data access

Fiedler, S., & Sudarchikova, N. (2024). CMIP Climate Forcings Dataset: Simple plumes for anthropogenic aerosols (Version SPv2) [Data set]. Zenodo.
<https://doi.org/10.5281/zenodo.14512962>

5 Other forcing datasets

Hoesly, R., Smith, S. J., Prime, N., Ahsan, H., Suchyta, H., O'Rourke, P., Crippa, M., Klimont, Z., Guizzardi, D., Behrendt, J., Feng, L., Harkins, C., McDonald, B. C., Mott, A., McDuffie, E. E., Wang, S., & Nicholson, M. B. (2024). CEDS v_2024_10_21 Release Gridded Emissions Data 0.5 degree (v_2024_10_21) [Data set]. Zenodo.
<https://doi.org/10.5281/zenodo.13952845>

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