# Data README for "Climatic fluctuations modeled for carbon and sulfur emissions from end-Triassic volcanism"

(http://doi.org/10.5880/PIK.2020.002)



When using the data please cite:

J. P. Landwehrs, G. Feulner, M. Hofmann, and S. Petri. Model output for the publication: "Climatic fluctuations modeled for carbon and sulfur emissions from end-Triassic volcanism". *GFZ Data Services*, 2020b. doi: 10.5880/PIK.2020.002

The data are supplementary material to:

J. P. Landwehrs, G. Feulner, M. Hofmann, and S. Petri. Climatic fluctuations modeled for carbon and sulfur emissions from end-Triassic volcanism. *Earth and Planetary Science Letters*, 2020a. doi: 10.1016/j.epsl.2020.116174

**Abstract:**

In "Climatic fluctuations modeled for carbon and sulfur emissions from end-Triassic volcanism" we study the potential climatic impacts of pulsed volcanic carbon and sulfur emissions from the Central Atlantic Magmatic Province at the end of the Triassic when one of the major extinction events of Earth history occurred. The data presented here is the model output on which the results of this manuscript are based. Also included are different pre- and post-processing scripts (mostly using the Python programming language) i.a. to analyse the model output and to generate the included figures. The model output is provided in different netcdf files. The data is generated using the coupled ocean-atmosphere model CLIMBER3alpha (Montoya et al. 2005) which models climate globally on a 3.75° x 3.75° (ocean, lon.x lat.) and 22.5° x 7.5° (atmosphere) grid. This Readme contains a short description of the included files.

# 1 Pre-Processing: Model Configuration, Boundary Conditions and Emission Scenarios

▶ Emission Scenarios

- **emission_scenarios/** contains the Python script emission_scenario.py which was used to generate the emission pulse forcing files of which some examples are included in emission_scenarios/examples/. The script generates a eruption history file (e.g. eruptions_multi_1200y_125GtS_250MtS.nc) from which the EVA model (Toohey et al. 2016) calculates the resulting evolution of the Aerosol Optical Depth (AOD). The AOD is then converted in emission_scenario.py into a radiative forcing expressed as a reduction of the annual mean solar constant which is stored in e.g. solarv_multi_1200y_125GtS_250MtS_rev_0p1.dat.
- **eva/** contains the two files mo_EVA.f90 and eva_namelist of the EVA model (v1.0) which was obtained from https://github.com/matthew2e/easy-volcanic-aerosol. These were slightly modified. In mo_EVA.f90 the nonlinear AOD scaling, as described in the supplementary information to Landwehrs et al. (2020a), was modified (all changes are indicated by the mo_EVA.diff). In eva_namelist the respective eruption history input file and the scenario duration needed to be modified.

▶ LOSCAR Configuration

- **loscar/** includes triasjura.inp, where the LOSCAR model (v2.0.4.2, Zeebe 2012, see also https://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/LoscarModel.html) is configured for the run presented in Fig. 5 of the main paper. For this run, the carbon emission input file emission_scenarios/examples/carbon_emission_1Myr_22100GtC_3rd4thPulseLong.dat is used. The calculated pCO2 is stored in loscar_new_pco2a.dat.

▶ CLIMBER3alpha Configuration

- **climber/continental_configuration_vegetation/** contains the triassic.i script (Yorick programming language), which reads the paleotopography reconstructed by Scotese (2014) for 200Ma and generates (with manual adjustments) the kmt.dta and oro.dat files which specify ocean floor depth and land surface orography in CLIMBER3alpha. Furthermore, the vegetation pattern is defined here by hand and stored in p2_vegetat_obs.dat. These three files are used as input for all equilibrium and perturbation simulations in Landwehrs et al. (2020a) and are included in climber/c3beta_tria_200Ma_1500ppm/. The directory climber/continental_configuration_vegetation/ furthermore contains bahcall_2001_ssm.dat which contains the long term evolution of solar luminosity provided by Bahcall et al. (2001) and is used to determine the solar constant at 200Ma.
- **climber/** also contains directories of the several equilibrium (climber/c3beta_*/) and volcanic perturbation simulations (climber/pulse_*/) analysed in Landwehrs et al. (2020a) which are further described below (Sec. 3). The forcing files carbon_emission*.dat (for the carbon emission rates in each model year) and/or solarv*.dat (for the reduction of the annual mean solar constant which reflects the effect of stratospheric aerosols) are included in the directories of the respective pulse experiments.

## 2 Model Output

- **climber/** contains a directory for each simulation run that is analysed in Landwehrs et al. (2020a).
  - c3beta_tria_200Ma_*ppm/ belong to equilibrium climate simulations for fixed pCO2 (1000/1500/2000ppm) without the coupled marine biogeochemistry module
  - c3beta_tria_200Ma_biogeo_pulse_*ppm_restart/ belong to equilibrium climate simulations with the active marine biogeochemistry module in which the marine carbon cycle parameters were adjusted to yield a pCO2 of ∼1000/1500/2000ppm.
  - pulse_control_*/ are control runs that continue these equilibrium simulations with zero emissions to quantify the model drift.
  - pulse_c_*ppm_*GtC_*ka/ are volcanic pulse perturbation runs with only carbon emissions, starting from 1000/1500/2000ppm pCO2, with 2500/5300/7500GtC carbon emission and a scenario duration of 5 or 12ka
  - pulse_rev_s_1500ppm_125GtS_5ka/ is a volcanic pulse perturbation runs with only sulfur emissions, starting from 1500ppm pCO2, with 125GtS total stratospheric sulfur injections and a scenario duration of 5ka
  - pulse_rev_s_single_1500ppm_*MtS/ are volcanic perturbation runs with a single stratospheric sulfur injection event, starting from 1500ppm pCO2 and an injection of 9/50/100/200/250/500/1000MtS
  - pulse_rev_s_schmidt_*MtS_0p44_*yrs/ are two volcanic perturbation runs that were conducted to reproduce the "Deccan scale" scenario of Schmidt et al. (2016). It is assumed that 1200MtS are emitted over 10 or 50yrs (totalling 12 000MtS or 60 000MtS) of which 44% actually form stratospheric aerosols. pulse_corr_s_schmidt_12000MtS_0p44_10yrs/ is a similar run, only with an stratospheric aerosol forcing that was calculated without the modification of the AOD scaling described in the Supplement of Landwehrs et al. (2020a).
  - pulse_rev_cs_*ppm_*GtC_*GtS_*ka/ are volcanic pulse perturbation runs with both carbon and sulfur emissions. Starting from 1000/1500/2000ppm pCO2, 2500/5300/7500GtC and 50/125/250/500GtS are emitted over a scenario duration of 5 or 12ka. The exception is pulse_rev_cs_1500ppm_5300GtC_10GtS_5ka_sparse/ where only 10GtS are distributed over fewer stratospheric sulfur injection events.
- each of these directories contains several netcdf files into which the model output was stored. History files contain annual or seasonal mean values of model variables over the course of the whole simulation run, while snapshot files contain monthly data for specific model years (only for last day of each month, not monthly mean). The variables stored in history and snapshot files differ partially. Therefore, data from snapshot files was occasionally merged as annual means in all_snapshots_*.nc files. Only the data files necessary to produce the figures included in Landwehrs et al. (2020a) and its Supplement were included here to keep the data package at a manageable size.
  - ocean files: history.nc, snapshots.*.01.01.dta.nc, all_snapshots_mom_annual.nc
  - atmosphere files: history_p2.nc, snapshots_potsdam2.*.01.01.dta.nc
  - sea ice files: history_isis.nc, snapshots_isis.*.01.01.dta.nc

## 3 Post-Processing: Plotting and Analysis

- **plots/** contains the two Jupyter Notebook files 01_AnalysisEquilibrium.ipynb and 02_AnalysisPulse.ipynb. These consist of Python scripts for producing all figures included in Landwehrs et al. (2020a) and its Supplement from the model output files included in this data package. When all required python packages are installed this should work out of the box. Python v3.7.3 was originally used. The figures produced with these notebooks are stored in plots/plot_pdf_files/

- **coral_data/** contains files required to produce Fig. 3 and Fig. 4 which include information on coral reef occurrences. ReefLocations_Kopie.csv is a database of modern coral reef occurences, downloaded from reefbase.org. Modern sea surface temperatures were calculated from woa18_decav_t00_01.nc which is from the World Ocean Atlas 2018 (Locarnini et al. 2018). The files fossilworks_scleractinia_Norian_reef.csv and fossilworks_scleractinia_Rhaetian_reef.csv include fossil stony coral reef occurrences from the Norian and Rhaetian which were retrieved via fossilworks.org.

- **misc/** includes i.a. tools_plot.py and tools_analysis.py which are used in 01_AnalysisEquilibrium.ipynb and 02_AnalysisPulse.ipynb for analysing and plotting the model output data.

- the climber/ directory also contains continental_mask.pickle and depth_adj_225Ma.dat. In continental_mask.pickle (which can be generated from one of the mentioned Jupyter notebooks), a continental mask for plotting the end-Triassic continental contours is stored. Similarly, continental contours for the Norian in Fig. 3f,g,h are plotted based on the Climber3alpha ocean depth levels stored in depth_adj_225Ma.dat, which were generated from the paleogeographic reconstruction of Scotese (2014) for 225Ma.

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