

TargetBC ESM experiments: description and access to results

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As part of the [TargetBC project](#), a set of ESM experiments have been designed, perturbing emissions of black carbon (BC) and sulfur dioxide (SO₂) in different latitude bands and geographical regions.

This document describes the experiment setup and output. This document also contains directions for accessing, using, and acknowledging the data (Section 4).

In addition to a year 2014 control simulation, simulations where emissions are perturbed individually in 4 broad latitude bands and 4 geographical regions are performed. An additional experiment perturbing global shipping emissions is requested. Table 1 summarizes the experiments. Simulations have been performed with 5 models: GISS-E2.1, NorESM2.0.6, UKESM1.1, CanESM5.1-PAM, and CESM2. A brief overview of these models is provided in Appendix 1, including information about their treatment of aerosols and deposition of BC on snow.

1 Experimental details:

- Participating models are used in their CMIP6 configuration and all emissions and forcing data are as per CMIP6
- For the control and latitude band perturbations, both fixed SST (free running AMIP style) and ocean coupled simulations are requested
- for the geographical region perturbations only fixed SST simulations are requested
- Fixed SST simulations are run for between 30 and 45 years, using the last 20 for the estimation of ERF
- Coupled simulations are run for 100 years, discarding as spin-up a model dependent number of years (see Table 2)
- For all experiments, one realization/ensemble member is run
- Models use their own default prescribed sea surface temperature or fSST runs (either year 2014 or climatology – see individual model details in Table 2)
- Models do not use a common restart file

2 Emission perturbations are implemented as follows:

- All perturbations are 10x year 2014¹ CMIP6 emissions of BC and SO₂, respectively, keeping everything else fixed in the control simulation configuration.
- For black carbon:

¹ Due to a scaling factor within the model being applied to CMIP6 configuration, the UKESM simulations are actually x20 biomass burning (emissions data should reflect this).

- Latitude bands: all experiments are performed with the perturbation applied to land anthropogenic (i.e. no international shipping or aviation) plus biomass burning emissions² AND with the perturbation applied to land anthropogenic emissions only.
- Geographical regions: the perturbation applied to only land anthropogenic
- For sulfur dioxide:
 - Latitude bands: perturbation applied to land anthropogenic emissions only.
 - Geographical regions: perturbation applied to land anthropogenic emissions only
- The definition of the geographical regions follows those used in the HTAP3-OPNS experiments. The region mask file is available from <https://zenodo.org/records/15669165>

Table 1: Summary of requested experiments. Experiment short names for output file naming (see Section 3) where *glb*=global, *arc*=Arctic (65-90N), *nhm*=northern hemisphere midlatitudes (15-65N), *trp*=tropics (15S-15N) and *she*=Southern Hemisphere (15-90S). *Ant*=anthropogenic land-based emissions; *Ind*=anthropogenic land based + biomass burning emissions; *shp*= shipping emissions; *Isa*=land anthropogenic + shipping; *all*= land anthropogenic + biomass burning + shipping.

Experiment full name	Experiment short name	Region of perturbation	Emissions perturbed	fSST and coupled
2014 control	2014CTRL	n/a	n/a	Y
Black carbon				
Global Anth 10xBC	glbBCant	Global	Land anthropogenic	Y
Global Anth+BB 10xBC	glbBCInd	Global	Land anthropogenic + biomass burning (BB)	Y
Ocean 10xBC	glbBCshp	Global	Shipping	Y
Arctic Anth+BB 10xBC	arcBCInd	65N - 90N	Land anthropogenic + BB	Y
NH mid-lat Anth+BB 10xBC	nhmBCInd	15N - 65N	Land anthropogenic + BB	Y
Tropics Anth+BB 10xBC	trpBCInd	15S - 15N	Land anthropogenic + BB	Y
SH Anth+BB 10xBC	sheBCInd	15S - 90S	Land anthropogenic + BB	Y
Arctic Anth 10xBC	arcBCant	65N - 90N	Land anthropogenic	fSST only
NH mid-lat Anth 10xBC	nhmBCant	15N - 65N	Land anthropogenic	fSST only
Tropics Anth 10xBC	trpBCant	15S - 15N	Land anthropogenic	fSST only
SH Anth 10xBC	sheBCant	15S - 90S	Land anthropogenic	fSST only
East Asia Anth 10xBC	easBCant	HTAP EAS	Land anthropogenic	fSST only
South Asia Anth 10xBC	sasBCant	HTAP SAS	Land anthropogenic	fSST only

² One model (GISS-E2.1) used a climatological mean of the biomass burning emissions as the basis for the 10x perturbation, the rest perturbed single year emissions. A preliminary analysis showed that 2014 did not stand out as an extreme biomass burning year, at least globally.

North America Anth 10xBC	namBCant	HTAP NAM	Land anthropogenic	fSST only
Europe Anth 10xBC	eurBCant	HTAP EMEP_West	Land anthropogenic	fSST only
Sulfur dioxide				
Global Anth 10xSO2	glbSO2ant	Global	Land anthropogenic	Y
Global Anth + ship 10xSO2	glbSO2lsa	Global	Land anthropogenic + shipping	Y
Ocean 10xSO2	glbSO2shp	Global	Shipping	Y
Global Anth+BB 10xSO2	glbSO2all	Global	Land anthropogenic + BB +shipping	fSST only
Arctic 10xSO2	arcSN2ant	65N - 90N	Land anthropogenic	Y
NH mid lat 10xSO2	nhmSO2ant	15N - 65N	Land anthropogenic	Y
Tropics Anth 10xSO2	trpSO2ant	15S - 15N	Land anthropogenic	Y
SH 10xSO2	sheSO2ant	15S - 90S	Land anthropogenic	Y
East Asia 10xSO2	easSO2ant	HTAP EAS	Land anthropogenic	fSST only
South Asia 10xSO2	sasSO2ant	HTAP SAS	Land anthropogenic	fSST only
North America 10xSO2	namSO2ant	HTAP NAM	Land anthropogenic	fSST only
Europe 10xSO2	eurSO2ant	HTAP EMEP_West	Land anthropogenic	fSST only

Table 2: model-specific information about runs

Model Name	SST information – 2014 or climatology	fSST run total length and spin-up	Coupled run total length and spin-up
NorESM2.0.6	2014	BC: 30 years, 10 years spin-up SO2: 45 years, 15 years spin-up	100 years for SO ₂ , 200 years for BC. (nc files contain all years; data prior to equilibration of global surface air temperature should be considered spin up (number of years depend on experiment)).
GISS-E2.1	2014	45 years, 15 years spin-up	100 years (71 years spin up)
UKESM1.1	2014	45 years, 15 years spin-up	100 years (70 years spin up)
CanESM5.1-PAM	2014	45 years, 15 years spin-up (nc files contain only the last 30 years)	100-120 years (depending on the perturbation), 70-90 years spin-up (nc files contain only the last 31 years)
CESM2	2014	45 years, 15 years spin-up	tbc

3 Model output request and file naming convention:

The models are requested to output standard CMIP6 monthly mean variables. A complete list of requested variables is given in Appendix 2.

For models who can do this, selected additional variables at daily resolution are requested:

ta, trefht, prect, psl, fluxes (rsut, rsdt, rlut, rsds, rsus, rlds, rlus), concbc, od550aer, abs550aer, cl, clt

The naming of output files roughly follows the CMIP6 convention:

**<variable>_<timeres>_<modelname>_<experimentname>_<experiment_type>
[optional: _<realization>_<model_grid>_<time_period>].nc**

variable = CMIP6 name. *timeres* = mon or day. experiment: experiment short name from Table 1, experiment type: *atm* for fSST runs, *cpl* for coupled ocean runs.

4 Data access and further use:

Model output is stored in part on the Electronic Research Data Archive at Aarhus University (ERDA, <https://erda.au.dk/>), with additional variables available from individual institutions storage facilities. Data will be made openly available once documented but is at present available for further analysis upon request. If using one or more data sets in a publication, we ask that you offer co-authorship to the people who designed and carried out the simulations. Contact points and people to include in further publications are for each model:

- CanESM5.1-PAM: Cynthia Whaley, Cynthia.Whaley@ec.gc.ca
- GISS-E2.1: Ulas Im, ulas@envs.au.dk
- NorESM2: Marianne T. Lund, m.t.lund@cicero.oslo.no, Maura Dewey maura.dewey@cicero.oslo.no
- UKESM1.1: Steven Turnock, steven.turnock@metoffice.gov.uk
- CESM2: Zhihong Zhuo, zhuo.zhihong@uqam.ca

For questions related to ERDA: Ulas Im, ulas@envs.au.dk.

In any use of the data, we request that you also acknowledge the *TargetBC* project: “This dataset was produced as part of the Clean Air Fund (CAF) project *TargetBC*”.

Appendix 1: Information about participating models

Model	Type	Horizontal grid	Vertical grid	Aerosol Scheme	Treatment of BC on snow
GISS-E2.1	ESM	2° × 2.5° lat/lon grid	40 levels, up to 0.1 hPa	MATRIX (Bauer et al. 2008), which is a microphysical aerosol model, is used, which can track the mixing state of several aerosol populations. DMS, sea-salt, mineral dust, and biogenic emissions are calculated online.	Hansen and Nazarenko (1994)
NorESM2.0.6	ESM	1.9° × 2.5° lat/lon grid	32 levels, lid ~3 hPa, hybrid sigma-pressure	CAM6-Nor (based on CAM6) (Danabasoglu et al. 2020) with OsloAero aerosol scheme (Kirkevåg et al. 2018). Modal scheme simulating aerosol mass and number.	SNICAR (Snow, Ice, and Aerosol Radiative model) (Flanner et al. 2007)
UKESM1.1	ESM	145 × 192 (1.875° × 1.25° lat/lon grid)	85 (hybrid height terrain following grid) levels, up to ~0.01 hPa	Aerosol scheme is GLOMAP-Mode (Modal scheme, simulating aerosol mass and number). Separate mass-based bin scheme used for minerals dust. SO ₄ , BC, OM, sea salt in 5 log-normal modes (nucleation to coarse) and dust in 6 size segregated bins. Online emissions of DMS, sea-salt and dust aerosols, as well as emissions of primary marine organics and biogenic organic compounds. Archibald et al., (2020), Mulcahy et al., (2020), Mulcahy et al., (2023)	Currently no representation of BC deposition on snow.
CanESM5.1-PAM	ESM	128x64, T63 (~2.8° × 2.8°)	49 vertical hybrid levels extending up to 1 hPa	Piecewise lognormal approximation Aerosol Model (PAM) (von Salzen et al, 2013)	Namazi et al (2015)
CESM2	ESM	0.9° lat x 1.25° lon	70 vertical hybrid levels extending up to ~6 × 10 ⁻⁶ hPa	Modal Aerosol Model version 4 (MAM4) (Liu et al. 2016)	SNICAR (Snow, Ice, and Aerosol Radiative model), (Flanner et al. 2007)

Appendix 2: List of output variables

Table/dimensions	Name	Description	Units	Note
Core variables				
Amon				
(month,lat, lon)				
	rsdt	TOA Incident Shortwave Radiation	W m-2	
	rsut	TOA Outgoing Shortwave Radiation	W m-2	
	rlut	TOA Outgoing Longwave Radiation	W m-2	
	Rsutcs	TOA Outgoing Clear-Sky Shortwave Radiation	W m-2	
	Rlutcs	TOA Outgoing Clear-Sky Longwave Radiation	W m-2	
	Hfls	Surface Upward Latent Heat Flux	W m-2	
	Hfss	Surface Upward Sensible Heat Flux	W m-2	
	Rlds	Surface Downwelling Shortwave Radiation	W m-2	
	Rsus	Surface Upwelling Shortwave Radiation	W m-2	
	Rlds	Surface Downwelling Longwave Radiation	W m-2	
	Rlus	Surface Upwelling Longwave Radiation	W m-2	
	Rsdscs	Surface Downwelling Clear-Sky Shortwave Radiation	W m-2	
	Rsuscs	Surface Upwelling Clear-Sky Shortwave Radiation	W m-2	
	Rldscs	Surface Downwelling Clear-Sky Longwave Radiation	W m-2	
	Tas	Near-Surface Air Temperature	K	

	Ts	Surface Temperature	K	
	Cl _t	Total Cloud Cover Percentage	%	
	P _{sl}	Sea Level Pressure	Pa	
(month, lev, lat, lon)				
	P _{full}	Pressure at Model Full-Levels	Pa	
Limon				
(month,lat, lon)				
	S _{nc}	Snow Area Percentage	%	
	S _{nd}	Snow Depth	m	
AERmon				
(month,lat, lon)				
	dry _{bc}	Dry Deposition Rate of Black Carbon Aerosol Mass	kg m ⁻² s ⁻¹	
	dry _{so2}	Dry Deposition Rate of SO ₂	kg m ⁻² s ⁻¹	
	wet _{bc}	Wet Deposition Rate of Black Carbon Aerosol Mass	kg m ⁻² s ⁻¹	
	wet _{so2}	Wet Deposition Rate of SO ₂	kg m ⁻² s ⁻¹	
	em _{bc}	Total Emission Rate of Black Carbon Aerosol Mass	kg m ⁻² s ⁻¹	
	em _{so2}	Total Emission Rate of SO ₂	kg m ⁻² s ⁻¹	
(month, lev, lat, lon)				
	mm _{rbc}	Elemental Carbon Mass Mixing Ratio	kg kg ⁻¹	
	so ₂	SO ₂ Volume Mixing Ratio	mol mol ⁻¹	

	airmass	Vertically Integrated Mass Content of Air in Layer	kg m ⁻²	
	mmrso4	Aerosol Sulfate Mass Mixing Ratio	kg kg ⁻¹	
Additional variables requested				
Amon				
(month,lat, lon)				
	pr	Precipitation rate	m/s	
	ps	Surface pressure	Pa	
	rsdt	TOA Incident Shortwave Radiation, double call	W m ⁻²	For IRF calculations, i.e. a call to the radiation scheme without aerosols present. Incident would be the same.
	rsutaf	TOA Outgoing Shortwave Radiation, double call	W m ⁻²	For IRF calculations, i.e. a call to the radiation scheme without aerosols present
	rlutaf	TOA Outgoing Longwave Radiation, double call	W m ⁻²	For IRF calculations, i.e. a call to the radiation scheme without aerosols present
(month, lev, lat, lon)				
	hus	Specific humidity	kg/kg	
	ua	Zonal wind	m/s	
	va	Meridional wind	m/s	
	wap	Omega (Vertical air pressure tendency)	Pa s ⁻¹	
	pfull	Pressure	Pa	
	zg	Geopotential height	m	

	ta	Air temperature	K	
AERmon				
(month,lat, lon)				
	aod550abs	Absorbtion AOD	Unitless	
	aod550	AOD	Unitless	
day				
(lon,lat,day)				
	tas	Surface temperature	K	
	tasmax	Maximum surface temperature	K	
	tasmin	Minimum surface temperature	K	
	pr	Precipitation rate	m/s	

References:

- Archibald et al. 2020 <https://doi.org/10.5194/gmd-13-1223-2020>
- Bauer et al. 2008 <https://doi.org/10.5194/acp-8-6003-2008>
- Danabasoglu et al, 2020 <https://doi.org/10.1029/2019MS001916>
- Flanner et al. 2007 <https://doi.org/10.1029/2006JD008003>
- Hansen and Nazarenko 1994 <https://doi.org/10.1073/pnas.2237157100>
- Kirkevåg et al. 2018 <https://doi.org/10.5194/gmd-11-3945-2018>
- Liu et al. 2016 <https://doi.org/10.5194/gmd-9-505-2016>
- Mulcahy et al. 2020 <https://doi.org/10.5194/gmd-13-6383-2020>
- Mulcahy et al. 2023 <https://doi.org/10.5194/gmd-16-1569-2023>
- Namazi et al. (2015) <https://doi.org/10.5194/acp-15-10887-2015>
- von Salzen et al. 2013 <https://doi.org/10.1080/07055900.2012.755610>