The Black Carbon Experiment Protocol
V0.2 30.07.2018

Scientific Rationale

Direct radiative forcing due to anthropogenic black carbon (BC) is highly uncertain but best estimates suggest a large positive effect (+0.71 [+0.08, +1.27] W m-2). The uncertainty in the total forcing is due to large uncertainties in the atmospheric burden of BC and its radiative properties. The uncertainty in the burden is in-turn due to the uncertainty in emissions (7500 [2000, 29000] Gg yr-1) and lifetime (removal rates). In comparison with the available observations GCMs tend to under-predict absorption near source (e.g. at Aeronet stations), and over-predict concentrations in remote regions (e.g. as measured by HIPPO). By exploring the uncertainties in the dominant emission and removal processes, and in the key radiative property (the imaginary part of the refractive index) and comparing with a variety of observations we hope to better constrain the radiative forcing.

We aim to address the uncertainty in direct radiative forcing in a unique way by developing a new approach to tackle two dominant sources of model uncertainty: structural uncertainty and parametric uncertainty. We will do this via a multi-model perturbed parameter ensemble (MMPPE).

Experiment description:

Each participating model will run a 3-parameter perturbed parameter ensemble (PPE). This will consist of 39 pre-defined simulations that will be run for the years 2008 and 1850 + any required spin-up time. The 2008 simulations will be the priority but 1850 simulations are required to calculate the radiative forcing. This is a total of 78 years of simulation + spin-up. The pre-defined simulations will allow statistical modelling to be carried out for defined diagnostics producing sensitivity analyses that will be used to compare individual models following Lee, et al. 2011 and Carslaw et al. 2013. Participants are also requested to submit the results of the one-at-a-time high/low tests used to test the implementation of the perturbation for initial comparisons.

Model set-up

Emissions:

We will not specify harmonised emissions but we recommend participants use the latest CMIP6 emissions. Please confirm the emissions used in signup sheet.

Nudging:

We will not specify specific nudging requirements but participants will need to diagnose radiation effects in the single year simulations. We anticipate models will require nudged winds but not temperature (see Regayre, et al. 2018) where the model was nudged to horizontal winds at and above level 17 (around 2150m) to diagnose rapid adjustments and ERF). Free-running simulations will be too noisy to carry out the necessary statistics. Please confirm the model nudging carried out on signup sheet.

Chemistry:

Models will use offline chemistry where possible but models should not be used in CTM mode. Please confirm the chemistry set-up in the signup sheet.

Model perturbations

We request perturbations are made from the latest AeroCom baseline run.

1. Targeted process: aerosol number

Perturbation parameter – scale mass flux of BC carbonaceous emission

We will scale the number flux by scaling the BC mass flux at emission with fixed radius. All sources of BC are to be scaled. OC is not scaled.

Size distribution and mixing will be defined as in the AeroCom baseline experiment. Participants are asked to report the hydrophilic/hydrophobic fractions of BC at emission and how ageing between the two is handled in the signup sheet.

Perturbation range: BC mass emissions (X) will be scaled between X*½ and X*2. Implementation tests should be run at X*½ and X*2.

2. Targeted process: Wet deposition/nucleation+impaction scavenging

Perturbation parameter – scale removal tendencies/change in droplet number in the wet deposition scheme for all species

We will scale the removal of aerosol through in-cloud and below-cloud scavenging including large/dynamic and small/convective precipitation, further including ice and snow. In some models this may be referred to as nucleation and impaction scavenging. We allow the scheme to complete the calculation of the change in droplet number from all precipitation and scale this.

Perturbation range: Scale the change in droplet number (Y) between Y*1/3 and Y*3. Implementation tests should be run at Y*1/3 and Y*3.

3. Targeted process: BC optical properties

Perturbation parameter: the imaginary part of the refractive index for all SW wavelengths contributing to the forcing calculation

We will perturb the imaginary part of the refractive index (IRI) for all SW wavelengths. This will be implemented by perturbing the refractive index at 550nm within an absolute range based on Bond & Bergstrom (2006) and scaling all other SW wavelengths by the same amount. The scaling for all other SW wavelengths is calculated as $IRI_{550nm,baseline}/IRI_{550nm,perturbation}$.

The real part of the imaginary index is not perturbed.

When the IRIs are available as a table within the code the implementation should be reasonably simple. When look-up tables are used we have previously calculated the individual look up tables externally and implemented the perturbation as a change in the filename for the look-up table (Regayre, et al. 2018). Please contact us for further information on this method if required.

Perturbation range: We will perturb the IRI at 550nm (Z) between 0.2 and 0.8. Implementation tests should be run at Z=0.2 and Z=0.8. A further implementation test with Z=0 is requested in order to calculate a BC semi-direct effect following Ghan, 2013.

Model simulations

All perturbations should be made from the model's base run. This will match the model's default values considered to give the best simulation – ideally it will match the AeroCom baseline run but please specify if this is not what you consider to be your model's best run and how it differs from the AeroCom baseline run.

Implementation tests:

We suggest one-at-a-time tests to test the implementation of the parameter perturbations within participant's code. We have suggested 7 particular OAT tests that test the ranges of our perturbations. If you are happy to share, the results of these can be placed on google drive https://docs.google.com/spreadsheets/d/1dVOIrhKoUp_lJIp9RD37h7ujpEJQbh6PZ8NL7eTtP_8/edit?usp=sharing putting different models under different tabs. Feel free to add any relevant columns for model output you have checked. Please specify what time period you have looked at.

We anticipate running the same tests will help us to diagnose any differences between models and the effect of the ranges specified for perturbation. If any concerns are raised or interesting features are found from these tests please get in touch.

Implementation Test		
1. Aerosol number	**2. Wet deposition**	**3. Optical properties**
BC mass emissions * ½	**Change in droplet number * 1/3**	**IRI_550nm = 0**
BC mass emissions * 2	**Change in droplet number * 3**	**IRI_550nm = 0.2**
		IRI_550nm = 0.8

The ensemble simulations that you should carry out are pre-defined according to a Latin hypercube sampling strategy. The design is available in both .csv and .dat format on google drive <link>.

Collected diagnostics

We will use the AeroCom repository to store the data, https://wiki.met.no/aerocom/data_submission.

Please submit a single netcdf per variable. Please name files according to the AeroCom standard:

aerocom3_<ModelName>_<ExperimentName>_<VariableName>_<VerticalCoordinateType>_<Period>_<Frequency>.nc

where experiment name contains 'bcmmppe' and the simulation number.

For the control experiment <ExperimentName>='bcmmppe',

otherwise <ExperimentName>='bcmmppe-<simulationnumber>', i.e. 'bcmmppe-01', 'bcmmppe-02',…,'bcmmppe-39'.

Defined points are available from Duncan Watson-Parris inline with his separate AeroCom experiment: duncan.watson-parris@physics.ox.ac.uk.

Diagnostic	**Domain**	**Structure**	**Time scale**	**Observation source**	**Which simulations?**
N50	Flight track simulator	Defined points	3hrly	GASSP database	All
N50	Global	3d field	Monthly	GASSP database	All
N3	Flight track simulator	Defined points	3hrly	GASSP database	All
N3	Global	3d field	Monthly	GASSP database	All
TOA fluxes	Global	2d field	Monthly		All

Instaneous forcing (double radiation call)*[see below table]	Global	2d field - speciated if available	Monthly		All
AOD (440 and 870nm)	Station	Station	3hr	Aeronet	All
AOD (550nm)	Global	2d field	Monthly	MODIS	All
AAOD	Station	Station	3hr	Aeronet	All
BC mass mixing ratio	Flight track simulator	Defined points	3hrly	GASSP + CLARIFY database	All
BC mass mixing ratio	Global	3d field	Monthly	GASSP database	All
BC dry deposition flux	Global	2d field	Monthly		All
BC wet deposition flux	Global	2d field	Monthly		All
BC burden	Global	2d field	Monthly		All
BC emissions flux	Global	3d field	Monthly		All
All species (except BC) emission flux	Global	3d field	Monthly		Control run only (to be defined)
Mass of component (in each mode), including water	Global	3d field	Monthly		All
Aerosol number (in each mode)	Global	3d field	Monthly		All

* Sometimes this is called a 'double call', but all models do two calls:

1. All sky, prognostic

2. Remove all cloud condensate and re-run the radiation code for 'clear sky' fields

A third call is:

3. Aerosols removed from the All Sky call. The difference between 1 and 3 is the direct effect, and it can be used to generate 'clean sky' indirect effects.

This follows Ghan, 2013.

References:

Bond, T. C., & Bergstrom, R. W. (2006). Light Absorption by Carbonaceous Particles: An Investigative Review. *Aerosol Science and Technology*, *40*(1), 27–67. http://doi.org/10.1080/02786820500421521

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Ghan, S.J., X. Liu, R.C. Easter, R. Zaveri, P.J. Rasch, J. Yoon, and B. Eaton, 2012: Toward a Minimal Representation of Aerosols in Climate Models: Comparative Decomposition of Aerosol Direct, Semidirect, and Indirect Radiative Forcing. J. Climate, 25, 6461–6476, https://doi.org/10.1175/JCLI-D-11-00650.1

Ghan, S. J.: Technical Note: Estimating aerosol effects on cloud radiative forcing, Atmos. Chem. Phys., 13, 9971–9974, https://doi.org/10.5194/acp-13-9971-2013, 2013.

Lee LA; Carslaw KS; Pringle KJ; Mann GW; Spracklen DV (2011) Emulation of a complex global aerosol model to quantify sensitivity to uncertain parameters, ATMOSPHERIC CHEMISTRY AND PHYSICS, 11, pp.12253-12273.

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