<u>The Cloud Experiment Protocol</u>
<u>V0.3 30.07.2018</u>

Scientific Rationale

The goal is to understand what factors affect the magnitude of the aerosol-cloud interactions in several different model systems. The indirect radiative effect of aerosols on clouds (ACI, or ERF_ACI according to the IPCC) is the largest uncertainty in climate forcing over the historical record. Sophisticated earth system models typically treat aerosols cloud interactions as a series of processes starting with aerosols and total Cloud Condensation Nuclei (CCN), to activation of aerosols as cloud droplets (Activation) to the loss process for cloud water, often through precipitation (Autoconversion). This experiment will test several different processes to see how ACI are sensitive to the process representations, and in what combination.

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 experiment (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.

<u>Model set-up</u>

Emissions:

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

Model perturbations

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

1. Targeted process: CCN concentration

Perturbation parameter – scale emissions of DMS

We will scale the emission of DMS as a natural source of sulphuric CCN.

Perturbation range: DMS emission (X) will be scaled between X*1/2 and X*2. Implementation tests should be run at X*1/2 and X*2.

2. Targeted process: Activation

Perturbation parameter – scale the number of activated particles following execution of the activation scheme

We will scale the activated particle number after implementation of the activation scheme. This removes the dependence on the activation scheme used.

Perturbation range: The activated number (Y) will be perturbed by Y*1/3 and Y*3. Implementation tests should be run at Y*1/3 and Y*3.

Important: If you have a minimum drop number limiter in your model, please turn it off. This is important for building emulators, otherwise we will get discontinuous behavior on the low end of the parameter range.

3. Targeted process: Autoconversion

Perturbation parameter: the exponent in the autoconversion scheme

We will perturb the exponent on the cloud droplet number concentration in the autoconversion scheme to perturb the sensitivity of autoconversion to the aerosol concentration. We begin under the assumption that models are using the Khairoutdinov and Kogan (2010) (KK) scheme that uses the default value of -1.79.

Perturbation range: The exponent in the autoconversion scheme (Z) is perturbed between [-2,-1]. When the KK scheme is not used we will use offline calculations and the implementation tests to perturb the autoconversion similarly.

Implementation tests should be run at Z = -2 and Z = -1.

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 6 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/1-HGYd4HJiZ8g2e9857UyZGZzlOiJoojtcAxCwF9lGt0/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 from these tests please get in touch.

Implementation Test		
1. CCN number	**2. Activation**	**3. Autoconversion**
DMS emissions * ½	**Activated number * 1/3**	**KK CDNC component = -1**
DMS emissions * 2	**Activated number * 3**	**KK CDNC component = -2**

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 cdat format on google drive https://drive.google.com/open?id=1g_vd2yk2fJ3yZngB8pU1ZF5dDLfnB5r-

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 'cloudmmppe' and the simulation number.

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

otherwise <ExperimentName>='cloudmmppe-<simulationnumber>', i.e. 'cloudmmppe-01', 'cloudmmppe-02',…,'cloudmmppe-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, surface	3d field	Monthly	GASSP database	All
N3	Flight track simulator	Defined points	3hrly	GASSP database	All
N3	Global, surface	3d field	Monthly	GASSP database	All
TOA fluxes	Global	2d field	Monthly		All
Instaneous forcing (double radiation call)*[see below table]	Global	2d field	Monthly		All
AOD (550nm)	Global	2d field	Monthly	MODIS	All
Mass of component (in each mode), including water	Global	3d field	Monthly		All
Aerosol number (in each mode)	Global	3d field	Monthly		All

Drop size/effective radius	Global	3d field	Monthly		All
CCN	Global	3d field	Monthly		All
LWP (liquid)	Global	2d field	Daily	Ed G	All
CDNC (liquid)	Global	2d field - cloud top	Daily	Ed G	All
Cloud fraction (liquid)	Global	2d field	Daily	Ed G	All
Surface fluxes of sensible and latent heat	Global	2d field	Monthly		All
Precipitation rate (kg/kg/s or mm/day)	Global	2d field	Monthly		All
Rain water path	Global	2d field	6-hourly instantaneous		All
Snow water path	Global	2d field	6-hourly instantaneous		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.

COSP/CFODD diagnostics

Additionally, we invite participants to submit COSP diagnostics for CFODDs as discussed by Johannes Muelmenstaedt along with Kenta Suzuki and Jing Xianwen. They have prepared information on how all modelling groups could participate in this analysis with different levels of sophistication. To participate in the most sophisticated analysis the full COSP diagnostics are requested for the two OAT tests in which autoconversion is perturbed. To help understand uncertainty on observational constraints a 'lightweight' set of diagnostics can be used. More precise details can be found on the AeroCom wiki: https://wiki.met.no/aerocom/warm-rain-diagnostics

Please contact Johannes for further details regarding COSP and CFODD: Johannes Muelmenstaedt johannes.muelmenstaedt@gmail.com.

References:

Carslaw KS; Lee LA; Reddington CL; Pringle KJ; Rap A; Forster PM; Mann GW; Spracklen DV; Woodhouse MT; Regayre LA; Pierce JR (2013) Large contribution of natural aerosols to uncertainty in indirect forcing, Nature, 503, pp.67-71.

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. doi: 10.5194/acp-11-12253-2011

Regayre, L. A., Johnson, J. S., Yoshioka, M., Pringle, K. J., Sexton, D. M. H., Booth, B. B. B., Lee, L. A., Bellouin, N., and Carslaw, K. S.: Aerosol and physical atmosphere model parameters are both important sources of uncertainty in aerosol ERF, Atmos. Chem. Phys., 18, 9975-10006, https://doi.org/10.5194/acp-18-9975-2018, 2018.

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.