CMIP6 Model Documentation

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Documentation Contents

1 Key Properties

Key properties of the aerosol model

1.1.1 Top level properties

Key properties of the aerosol model

1.1.1.1 Name *

Name of aerosol model code

Coupled Large-scale Aerosol Simulator for Studies In Climate (CLASSIC)

1.1.1.2 Keywords *

Keywords associated with aerosol model code

CLASSIC

1.1.1.3 Overview *

Overview of aerosol model.

The aerosol scheme used is the Coupled Large-scale Aerosol Simulator for Studies In Climate (CLASSIC) (Bellouin et al. 2011). The model includes interactive schemes for sulphate, sea salt, black carbon from fossil-fuel emissions, organic carbon from fossil-fuel emissions, mineral dust, and biomass-burning aerosols. The model also includes a fixed monthly climatology of mass-mixing ratios of secondary organic aerosols from terpene emissions (biogenic aerosols).

1.1.1.4 Scheme Scope *

Atmospheric domains covered by the aerosol model

- ☐ Troposphere
- ☐ Stratosphere
- ☐ Mesosphere
- ☒ Whole atmosphere
- ☐ Other - please specify:

1.1.1.5 Basic Approximations *

Basic approximations made in the aerosol model

Enter TEXT:

1.1.1.6 Prognostic Variables Form *

Prognostic variables in the aerosol model

- ☒ 3D mass/volume ratio for aerosols
- ☐ 3D number concentration for aerosols

☐ Other - please specify:

1.1.1.7 Number Of Tracers *

Number of tracers in the aerosol model

21

1.1.1.8 Family Approach *

Are aerosol calculations generalized into families of species?

☐ True ☒ False

1.2.1 Software Properties

Software properties of aerosol code

1.2.1.1 Repository

Location of code for this component.

Private repository, available upon request

1.2.1.2 Code Version

Code version identifier.

UM7.3

1.2.1.3 Code Languages

Code language(s).

Fortran90

1.3.1 Timestep Framework

Physical properties of seawater in ocean

1.3.1.1 Method *

Mathematical method deployed to solve the time evolution of the prognostic variables

Select SINGLE option:

☐ Uses atmospheric chemistry time stepping

☐ Specific timestepping (operator splitting)

☐ Specific timestepping (integrated)

☐ Other - please specify:

1.3.1.2 Split Operator Advection Timestep

Timestep for aerosol advection (in seconds)

Enter INTEGER value:

1.3.1.3 Split Operator Physical Timestep

Timestep for aerosol physics (in seconds).

Enter INTEGER value:

1.3.1.4 Integrated Timestep *

Timestep for the aerosol model (in seconds)

Enter INTEGER value:

1.3.1.5 Integrated Scheme Type *

Specify the type of timestep scheme

Select SINGLE option:

- [ ] Explicit
- [ ] Implicit
- [ ] Semi-implicit
- [ ] Semi-analytic
- [ ] Impact solver
- [ ] Back Euler
- [ ] Newton Raphson
- [ ] Rosenbrock
- [ ] Other - please specify:

1.4.1 Meteorological Forcings

1.4.1.1 Variables 3D

Three dimensional forcing variables, e.g. U, V, W, T, Q, P, conventive mass flux

Enter COMMA SEPARATED list:

1.4.1.2 Variables 2D

Two dimensional forcing variables, e.g. land-sea mask definition

Enter COMMA SEPARATED list:

1.4.1.3 Frequency

Frequency with which meteorological forcings are applied (in seconds).

Enter INTEGER value:

1.5.1 Resolution

Resolution in the aerosol model grid

1.5.1.1 Name *

This is a string usually used by the modelling group to describe the resolution of this grid, e.g. ORCA025, N512L180, T512L70 etc.

Enter TEXT:

1.5.1.2 Canonical Horizontal Resolution

Expression quoted for gross comparisons of resolution, eg. 50km or 0.1 degrees etc.

Enter TEXT:

1.5.1.3 Number Of Horizontal Gridpoints

Total number of horizontal (XY) points (or degrees of freedom) on computational grid.

Enter INTEGER value:

1.5.1.4 Number Of Vertical Levels

Number of vertical levels resolved on computational grid.

Enter INTEGER value:

1.5.1.5 Is Adaptive Grid *

Set to true if the grid resolution changes during execution.

Select either TRUE or FALSE:

☐ True ☐ False

1.6.1 Tuning Applied

Tuning methodology for aerosol model

1.6.1.1 Description *

General overview description of tuning: explain and motivate the main targets and metrics retained. Document the relative weight given to climate performance metrics versus process oriented metrics, and on the possible conflicts with parameterization level tuning. In particular describe any struggle with a parameter value that required pushing it to its limits to solve a particular model deficiency.

Enter TEXT:

1.6.1.2 Global Mean Metrics Used

List of metrics of the global mean state used in tuning model/component

Enter COMMA SEPARATED list:

1.6.1.3 Regional Metrics Used

List of metrics of regional mean state used in tuning model/component

Enter COMMA SEPARATED list:

1.6.1.4 Trend Metrics Used

List observed trend metrics used in tuning model/component

Enter COMMA SEPARATED list:

2 Grid

Aerosol grid

2.1.1 Top level properties

Aerosol grid

2.1.1.1 Name

Name of grid in aerosol model.

Same as atmospheric model

2.1.1.2 Overview

Overview of grid in aerosol model.

The grid used for the aerosols model is the same as for the atmosphere model.

2.1.1.3 Matches Atmosphere Grid *

Does the atmospheric aerosol grid match the atmosphere grid?

☒ True ☐ False

2.2.1 Resolution

Resolution in the atmospheric aerosol grid

2.2.1.1 Name *

This is a string usually used by the modelling group to describe the resolution of this grid, e.g. ORCA025, N512L180, T512L70 etc.

N96L38

2.2.1.2 Canonical Horizontal Resolution

Expression quoted for gross comparisons of resolution, e.g. 50km or 0.1 degrees etc.

1.875 x 1.25

2.2.1.3 Number Of Horizontal Gridpoints

Total number of horizontal (XY) points (or degrees of freedom) on computational grid.

27840

2.2.1.4 Number Of Vertical Levels

Number of vertical levels resolved on computational grid.

38

2.2.1.5 Is Adaptive Grid *

Set to true if grid resolution changes during execution.

Select either TRUE or FALSE:

☐ True ☐ False

3 Transport

Aerosol transport

3.1.1 Top level properties

Aerosol transport

3.1.1.1 Name

Commonly used name for the transport in aerosol model.

HadGEM2-ES tracer advection scheme

3.1.1.2 Overview

Overview of aerosol transport in aerosol model.

Aerosol transport is done by the HadGEM2-ES tracer advection scheme, which includes large-scale advection (Davies et al. 2005), convective transport (Gregory and Rowntree, 1990), and boundary layer mixing (Lock et al., 2000).

3.1.1.3 Scheme *

Method for aerosol transport modelling

- [ ] Uses atmospheric chemistry transport scheme
- [ ] Specific transport scheme (eulerian)
- [x] Specific transport scheme (semi-lagrangian)
- [ ] Specific transport scheme (eulerian and semi-lagrangian)
- [ ] Specific transport scheme (lagrangian)

3.1.1.4 Mass Conservation Scheme *

Methods used to ensure mass conservation.

Select MULTIPLE options:

- [ ] Uses atmospheric chemistry transport scheme
- [ ] Mass adjustment
- [ ] Concentrations positivity
- [ ] Gradients monotonicity
- [ ] Other - please specify:

3.1.1.5 Convention *

Transport by convention

Select MULTIPLE options:

- [ ] Uses atmospheric chemistry transport scheme
- [ ] Convective fluxes connected to tracers
- [ ] Vertical velocities connected to tracers
- [ ] Other - please specify:

4 Emissions

Atmospheric aerosol emissions

4.1.1 Top level properties

Atmospheric aerosol emissions

4.1.1.1 Name

Commonly used name for the emissions in aerosol model.

No name

4.1.1.2 Overview

Overview of atmospheric aerosol emissions in aerosol model.

Emissions for the sulphur cycle include emissions of ammonium sulphate aerosol precursors: sulphur dioxide and dimethylsulphide. For sulphur dioxide, anthropogenic emissions are split into surface and chimney-level emissions. Natural emissions from volcanoes are provided as a 3D field. DMS emissions are provided by the ocean biogeochemistry scheme over the ocean, and provided through a dataset over land surfaces. All sulphur-cycle emissions are expressed in term of mass of sulphur within the model. For black-carbon and organic-carbon aerosols from fossil-fuel and biofuel emissions, emissions are provided at near-surface level. These emissions are expressed in term of mass of carbon. For biomass-burning aerosol, emissions are provided as two fields: surface emissions, and high-level emissions. The latter field is homogeneously distributed across the boundary layer. Biomass emissions are expressed in term of mass of carbon. Emissions for sea-salt and mineral dust aerosols are computed interactively from the modelled meteorology and soil properties by their respective schemes. The climatology of monthly-averaged mass-mixing ratios of secondary organic aerosol from terpene emissions was derived from the chemistry-transport model STOCHEM (Derwent et al., 2003). 2D emissions: All emission fields are provided as monthly means, which are time interpolated by the model every 5 days. Sulphur dioxide emissions are derived from sector-based emissions datasets for IPCC AR5 (Lamarque et al., 2009). Emissions for all sectors are considered surface emissions, except for energy emissions and half of industrial emissions which are considered chimney-level emissions. Emissions for land-based dimethylsulphide are taken from Spiro et al. (1992). Anthropogenic emissions for black carbon and organic carbon are from the sum of all sector-based emissions in the IPCC AR5 dataset. They are emitted in the second level of the model (near-surface emissions). Anthropogenic emissions for biomass-burning aerosol are the sum of IPCC AR5 emissions for black and organic carbon from biomass-burning emissions. Grass fire emissions are assumed to be surface emissions, while forest fire emissions are distributed homogeneously across the boundary layer. Emissions based on interactive schemes: Sea-salt and mineral dust aerosol emissions are computed interactively depending on modelled near-surface wind speeds and soil properties (Jones et al., 2001; Woodward, 2001). The only 3D aerosol-related emissions used in the model are natural emissions of sulphur dioxide from background volcanoes (Andres and Kasgnoc, 1998). Aircraft emissions of aerosol precursors or primary [aerosols] are not included in the model.

4.1.1.3 Method *

Method used to define aerosol species (several methods allowed because the different species may not use the same method).

- ☐ None
- ☐ Prescribed (climatology)
- ☐ Prescribed CMIP6

- [ ] Prescribed above surface
- [x] Interactive
- [ ] Interactive above surface
- [ ] Other - please specify:

4.1.1.4 Sources

Sources of the aerosol species are taken into account in the emissions scheme

- [x] Vegetation
- [x] Volcanos
- [x] Bare ground
- [x] Sea surface
- [ ] Lightning
- [x] Fires
- [ ] Aircraft
- [x] Anthropogenic
- [ ] Other - please specify:

4.1.1.5 Prescribed Climatology

Specify the climatology type for aerosol emissions

- [ ] Constant
- [ ] Interannual
- [ ] Annual
- [x] Monthly
- [ ] Daily

4.1.1.6 Prescribed Climatology Emitted Species

List of aerosol species emitted and prescribed via a climatology

Sulphur dioxide from degassing volcanoes, secondary organic aerosol, ocean-based DMS

4.1.1.7 Prescribed Spatially Uniform Emitted Species

List of aerosol species emitted and prescribed as spatially uniform

Sulphur dioxide, ammonia, fossil-fuel black carbon, fossil-fuel organic carbon, biomass-burning

4.1.1.8 Interactive Emitted Species

List of aerosol species emitted and specified via an interactive method

Mineral dust, sea-salt, ocean-based DMS

4.1.1.9 Other Emitted Species

List of aerosol species emitted and specified via an "other method"

Natural emissions from land surface of DMS and vegetation emissions

4.1.1.10 Other Method Characteristics

Characteristics of the "other method" used for aerosol emissions

Enter TEXT:

5 Concentrations

Atmospheric aerosol concentrations

5.1.1 Top level properties

Atmospheric aerosol concentrations

5.1.1.1 Name

Commonly used name for the concentrations in aerosol model.

No name

5.1.1.2 Overview

Overview of atmospheric aerosol concentrations in aerosol model.

For HadGEM2 the concentrations in the model are unknown with no species listed.

5.1.1.3 Prescribed Lower Boundary

List of species prescribed at the lower boundary.

N/A

5.1.1.4 Prescribed Upper Boundary

List of species prescribed at the upper boundary.

N/A

5.1.1.5 Prescribed Fields Mmr

List of species prescribed as mass mixing ratios.

None

5.1.1.6 Prescribed Fields Aod Plus Ccn

List of species prescribed as AOD plus CCNs.

Enter COMMA SEPARATED list:

6 Optical Radiative Properties

Aerosol optical and radiative properties

6.1.1 Top level properties

Aerosol optical and radiative properties

6.1.1.1 Name

Commonly used name for the optical radiative properties in aerosol model.

Enter TEXT:

6.1.1.2 Overview

Overview of aerosol optical and radiative properties in aerosol model.

Enter TEXT:

6.2.1 Absorption

Absortion properties in aerosol scheme

6.2.1.1 Black Carbon

Absorption mass coefficient of black carbon at 550nm (if non-absorbing enter 0)

Enter FLOAT value:

6.2.1.2 Dust

Absorption mass coefficient of dust at 550nm (if non-absorbing enter 0)

Enter FLOAT value:

6.2.1.3 Organics

Absorption mass coefficient of organics at 550nm (if non-absorbing enter 0)

0

6.3.1 Mixtures

6.3.1.1 External *

Is there external mixing with respect to chemical composition?

Select either TRUE or FALSE:

☐ True ☐ False

6.3.1.2 Internal *

Is there internal mixing with respect to chemical composition?

Select either TRUE or FALSE:

☐ True ☐ False

6.3.1.3 Mixing Rule

If there is internal mixing with respect to chemical composition then indicate the mixing rule

Enter TEXT:

6.4.1 Impact Of H2o

The impact of $H2O$ on aerosols

6.4.1.1 Size *

Does $H2O$ impact size?

Select either TRUE or FALSE:

☐ True ☐ False

6.4.1.2 Internal Mixture *

Does $H2O$ impact aerosol internal mixture?

Select either TRUE or FALSE:

☐ True ☐ False

6.4.1.3 External Mixture *

Does $H2O$ impact aerosol external mixture?

Select either TRUE or FALSE:

☐ True ☐ False

6.5.1 Radiative Scheme

Radiative scheme for aerosol

6.5.1.1 Overview *

Overview of radiative scheme

The radiation code is the solution to the two-stream equations by Edwards and Slingo (1996), with some developments. It includes absorption by CO2, H2O, O3, O2, N2O, CH4 and CFCs. The longwave band from 1200 to 1500 cm-1 has been split at 1330 cm-1 in order to better represent the overlap between CH4 and N2O. Gaseous absorption is based on the updated High-Resolution Transmission (HITRAN) 2000 database (Rothman et al., 2003). The water vapour continuum is version 2.4 of the Clough-Kneizys-Davies (CKD) formulation (Clough et al., 1992) and has been included in the shortwave region. Treatment of the effects of non-spherical ice cloud particles are determined using the parameterization by Kristjansson et al. (2000). The sea surface albedo is based on the functional form of Barker and Li (1995), modified in the light of aircraft data, and the land-surface albedo is described by Essery et al. (2003). The direct (scattering and absorption of radiation) and indirect radiative effects of aerosols is included. The radiation scheme includes the Tripleclouds scheme developed by Shonk et al. (2010) to represent horizontal cloud inhomogeneity.

6.5.1.2 Shortwave Bands *

Number of shortwave bands

6

6.5.1.3 Longwave Bands *

Number of longwave bands

9

6.6.1 Cloud Interactions

Aerosol-cloud interactions

6.6.1.1 Overview *

Overview of aerosol-cloud interactions

Enter TEXT:

6.6.1.2 Twomey *

Is the Twomey effect included?

☒ True ☐ False

6.6.1.3 Twomey Minimum Ccn

If the Twomey effect is included, then what is the minimum CCN number?

0

6.6.1.4 Drizzle *

Does the scheme affect drizzle?

☒ True ☐ False

6.6.1.5 Cloud Lifetime *

Does the scheme affect cloud lifetime?

☒ True ☐ False

6.6.1.6 Longwave Bands *

Number of longwave bands

Enter INTEGER value:

7 Model

Aerosol model

7.1.1 Top level properties

Aerosol model

7.1.1.1 Name

Commonly used name for the model in aerosol model.

Coupled Large-scale Aerosol Simulator for Studies In Climate (CLASSIC)

7.1.1.2 Overview *

Overview of atmospheric aerosol model

The model includes interactive schemes for sulphate, sea salt, black carbon from fossil-fuel emissions, organic carbon from fossil-fuel emissions, mineral dust, and biomass-burning aerosols. The model also includes a fixed monthly climatology of mass-mixing ratios of secondary organic aerosols from terpene emissions (biogenic aerosols). All aerosol species, except sea-salt and biogenic aerosols, are advected using the tracer advection scheme and undergo wet and dry deposition. Wet deposition accounts for re-evaporation of precipitation (Bellouin et al., 2007). All aerosol species exert a direct effect (scattering and absorption of shortwave and longwave radiation) and thereby also a semi-direct effect (impact on atmospheric temperature and cloud profiles of aerosol absorption). All aerosol species, except black carbon and mineral dust, also contribute to both the first and second indirect effects on clouds, modifying cloud albedo and precipitation efficiency, respectively. The version of the sulphur cycle is described in Jones et al. [2001] and Roberts and Jones [2004] with further improvements described hereafter. The sulphate scheme is a modal scheme where the free aerosol is assumed to have a log-normal size distribution in the Aitken and accumulation size ranges, which include particles with a radius less than 0.05 and 0.5 m, respectively. Sulphate aerosol may also be in a dissolved mode where layer clouds are present, thus affecting the cloud droplet size and exerting first and second indirect effects (modification of cloud albedo and precipitation efficiency, respectively). The sulphur cycle also includes improvements described by Bellouin et al. [2007]: condensation of sulphuric acid from dry oxidation of sulphur dioxide and dimethysulphide, and conversion from Aitken to accumulation mode particles by condensation. In addition, the oxidation of SO2 and DMS is now using oxidant concentrations (OH, HO2, H2O2, O3) provided by ancillary files. Emissions of dimethylsulphide from the ocean are calculated from the concentration of DMS in seawater (provided by an ancillary file), surface windspeed and sea-surface temperature. The sea salt scheme is a simple diagnostic scheme depending on wind speed and height above the surface to determine the number concentration of sea salt particles in two size modes (Jones et al., 2001). Schemes for black carbon from fossil-fuel emissions (Roberts and Jones, 2004), biomass-burning, and organic carbon from fossil-fuel emissions (Collins et al, 2008) include modes for freshly emitted particles that gradually age into another, more hygroscopic mode; there is also a mode for aerosols that have become incorporated into cloud droplets. Black carbon is considered to be slightly hygroscopic, only becoming incorporated into cloud droplets by diffusion, whereas organic carbon and biomass-burning aerosols are considered to act as cloud condensation nuclei. The mineral dust scheme is based on Woodward (2001) with revisions described by Bellouin et al. (2007). Emissions are computed interactively and depend on vegetation fraction, soil roughness length and moisture, and near surface wind speeds. The modelled horizontal flux is calculated for nine size bins covering particle radii from 0.0316 to 1000 microns. The vertical flux into the atmosphere is obtained from the horizontal flux and partitioned across six size bins, covering radii from 0.0316 to 31.6 microns. These six size bins are then transported and experience deposition through gravitational settling, turbulent mixing, and below cloud scavenging.

7.1.1.3 Processes *

Processes included in the aerosol model.

- [x] Dry deposition
- [x] Sedimentation
- [x] Wet deposition (impaction scavenging)
- [x] Wet deposition (nucleation scavenging)
- [x] Coagulation
- [x] Oxidation (gas phase)
- [x] Oxidation (in cloud)
- [x] Condensation
- [x] Ageing
- [x] Advection (horizontal)
- [x] Advection (vertical)
- [ ] Heterogeneous chemistry
- [ ] Nucleation

7.1.1.4 Coupling

Other model components coupled to the aerosol model

- [x] Radiation
- [x] Land surface
- [ ] Heterogeneous chemistry
- [x] Clouds
- [x] Ocean
- [ ] Cryosphere
- [ ] Gas phase chemistry
- [ ] Other - please specify:

7.1.1.5 Gas Phase Precursors *

Gas phase aerosol precursors.

- [x] DMS
- [x] SO2
- [ ] Ammonia
- [ ] Iodine
- [ ] Terpene

- [ ] Isoprene
- [ ] VOC
- [ ] NOx
- [ ] Other - please specify:

7.1.1.6 Scheme Type *

Type(s) of aerosol scheme used by the aerosol model (potentially multiple: some species may be covered by one type of aerosol scheme and other species covered by another type).

- [x] Bulk
- [ ] Modal
- [ ] Bin
- [ ] Other - please specify:

7.1.1.7 Bulk Scheme Species *

Species covered by the bulk scheme.

Select MULTIPLE options:

- [ ] Sulphate
- [ ] Nitrate
- [ ] Sea salt
- [ ] Dust
- [ ] Ice
- [ ] Organic
- [ ] Black carbon / soot
- [ ] SOA (secondary organic aerosols)
- [ ] POM (particulate organic matter)
- [ ] Polar stratospheric ice
- [ ] NAT (Nitric acid trihydrate)
- [ ] NAD (Nitric acid dihydrate)
- [ ] STS (supercooled ternary solution aerosol particule)
- [ ] Other - please specify: