CMIP6 Model Documentation

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Documentation Contents

1 Key Properties

Key properties of the model

1.1.1 Top level properties

Key properties of the model

1.1.1.1 Name *

Name of coupled model

GFDL-AM4.0.1, Geophysical Fluid Dynamics Laboratory

1.1.1.2 Keywords *

Keywords associated with coupled model

AMIP, prescribed SST and sea-ice concentration, atmosphere-land-vegetation coupled model

1.1.1.3 Overview *

Top level overview of coupled model

This is the Atmosphere and Land component (AM4.0.1) of GFDL coupled model CM4.0 for use in CMIP6. The Atmospheric component is identifical to the AM4.0 model documented in Zhao et. al (2018a, 2018b). The vegetation, land and glacier models differ from AM4.0 in the following aspects: 1) dynamical vegetation was used instead the static vegetation used in AM4.0. 2) glacier albedo is retuned. 3) other minor tuning in the land model.

1.2.1 Flux Correction

Flux correction properties of the model

1.2.1.1 Details *

Describe if/how flux corrections are applied in the model

Flux corrections are not applicable to the model, since SST is prescribed.

1.3.1 Genealogy

Genealogy and history of the model

1.3.1.1 Year Released *

Year the model was released

2018.0

1.3.1.2 CMIP3 Parent

CMIP3 parent if any

AM2, see GFDL-GAMDT, 2004, Journal of Climate

1.3.1.3 CMIP5 Parent

CMIP5 parent if any

AM3, see Donner et al., 2011, Journal of Climate

1.3.1.4 CMIP5 Differences

Briefly summarize the differences between this model and its CMIP5 parent, if applicable

AM4 contains two versions wth different levels of complexity in atmospheric chemistry. The light chemistry version (AM4.0) is used in CM4 while the full chemistry version (AM4.1) is used in ESM4. AM4.0 differs from AM3 in the following: 1) higher horizontal resolution; 2) reduced chemical gas tracers; 3) prescribed ozone; 4) improved radiative transfer model; 5) improved parameterizations in mountain gravity wave drag, moist convection, aerosol-cloud interactions.

1.3.1.5 Previous Name

Previously known as

N/A

1.4.1 Software Properties

Software properties of model

1.4.1.1 Repository

Location of code for this component.

Https://github.com/NOAA-GFDL/AM4

1.4.1.2 Code Version

Code version identifier.

Warsaw

1.4.1.3 Code Languages

Code language(s).

Fortran, C

1.4.1.4 Components Structure

Describe how model realms are structured into independent software components (coupled via a coupler) and internal software components.

FMS (Flexible Modeling System) coupler exchanges fluxes among various independent components (atmosphere, ocean, sea ice, land) ensuring the conservation of properties (e.g. mass, energy) and numerical stability.

1.4.1.5 Coupler

Overarching coupling framework for model.

- [ ] OASIS - The OASIS coupler - prior to OASIS-MCT
- [ ] OASIS3-MCT - The MCT variant of the OASIS coupler

☐ ESMF - Vanilla Earth System Modelling Framework

☐ NUOPC - National Unified Operational Prediction Capability variant of ESMF

☐ Bespoke - Customised coupler developed for this model

☐ Unknown - It is not known what/if-a coupler is used

☐ None - No coupler is used

☐ Other - please specify:

1.5.1 Coupling

1.5.1.1 Atmosphere Double Flux *

Is the atmosphere passing a double flux to the ocean and sea ice (as opposed to a single one)?

☐ True ☒ False

1.5.1.2 Atmosphere Fluxes Calculation Grid

Where are the air-sea fluxes calculated

☐ Atmosphere grid

☐ Ocean grid

☒ Specific coupler grid

☐ Other - please specify:

1.5.1.3 Atmosphere Relative Winds *

Are relative or absolute winds used to compute the flux? I.e. do ocean surface currents enter the wind stress calculation?

☐ True ☒ False

1.6.1 Tuning Applied

Tuning methodology for model

1.6.1.1 Description *

General overview description of tuning: explain and motivate the main targets and metrics/diagnostics retained. Document the relative weight given to climate performance metrics/diagnostics versus process oriented metrics/diagnostics, 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.

Model simulated present-day global top-of-atmsphere radiative fluxes are tuned towards the observational estimates from CERES (EBAF-Ed2.8). Model development focused on model performance in simulating present-day climatolgy such as precipitation, winds, TOA radiative fluxes.

1.6.1.2 Global Mean Metrics Used

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

Global mean OLR and SW absorption at top-of-atmosphere

1.6.1.3 Regional Metrics Used

List of regional metrics/diagnostics of mean state (e.g THC, AABW, regional means etc) used in tuning model/component

No specific regional metrics/diagnostic of mean state are used in tuning model. However, model development has used global RMSE of precipitation, TOA radiative flux for model evaluation.

1.6.1.4 Trend Metrics Used

List observed trend metrics/diagnostics used in tuning model/component (such as 20th century)

No observed trend metrics/diagnostics are used in tuning model/compoent. However, model Cess sensitivity and aerosol forcings are monitored during model development. This could indirectly affect coupled model simulation of 20th century.

1.6.1.5 Energy Balance *

Describe how energy balance was obtained in the full system: in the various components independently or at the components coupling stage?

Dissipation of kinetic energy due to dynamical core is corrected globally by adding a heating rate to the atmosphere. Energy conserved by dynamical core and physics parameterization are not identifical. More details documented in Zhao et. al (2018).

1.6.1.6 Fresh Water Balance *

Describe how fresh_water balance was obtained in the full system: in the various components independently or at the components coupling stage?

N/A

1.6.2 Heat

Global heat convervation properties of the model

1.6.2.1 Global *

Describe if/how heat is conserved globally

There is no specific enforcement of global heat conservation. But when averaged over multiple years, the global heat flux difference between TOA and surface is typically less than 0.1 W/m2.

1.6.2.2 Atmos Ocean Interface

Describe if/how heat is conserved at the atmosphere/ocean coupling interface

FMS coupler conserves heat across ocean/atmosphere interface

1.6.2.3 Atmos Land Interface *

Describe if/how heat is conserved at the atmosphere/land coupling interface

FMS coupler conserves heat across land/atmosphere interface

1.6.2.4 Atmos Sea-ice Interface

Describe if/how heat is conserved at the atmosphere/sea-ice coupling interface

FMS coupler conserves heat across sea ice/atmosphere interface

1.6.2.5 Ocean Seaice Interface

Describe if/how heat is conserved at the ocean/sea-ice coupling interface

N/A (prescribed SSTs)

1.6.2.6 Land Ocean Interface

Describe if/how heat is conserved at the land/ocean coupling interface

FMS coupler conserves heat across land/ocean interface by passing heat carried by rivers to the ocean.

1.6.3 Fresh Water

Global fresh water convervation properties of the model

1.6.3.1 Global *

Describe if/how fresh_water is conserved globally

N/A (prescribed SSTs)

1.6.3.2 Atmos Ocean Interface

Describe if/how fresh_water is conserved at the atmosphere/ocean coupling interface

N/A (prescribed SSTs)

1.6.3.3 Atmos Land Interface *

Describe if/how fresh water is conserved at the atmosphere/land coupling interface

FMS coupler conserves fresh water across land/atmosphere interface

1.6.3.4 Atmos Sea-ice Interface

Describe if/how fresh water is conserved at the atmosphere/sea-ice coupling interface

N/A (prescribed sea-ice)

1.6.3.5 Ocean Seaice Interface

Describe if/how fresh water is conserved at the ocean/sea-ice coupling interface

N/A (prescribed SSTs and sea-ice)

1.6.3.6 Runoff

Describe how runoff is distributed and conserved

Runoff from land enters into river network, which transports it to the discharge points (river mouths) and passes the fresh water flux to the ocean. River network interacts with the atmopshere through the fluxes from/to open water fractions of the land grid cell.

1.6.3.7 Iceberg Calving

Describe if/how iceberg calving is modeled and conserved

N/A (prescribed SSTs)

1.6.3.8 Endoreic Basins

Describe if/how endoreic basins (no ocean access) are treated

River network carries all runoff to the ocean.

1.6.3.9 Snow Accumulation

Describe how snow accumulation over land and over sea-ice is treated

To avoid long-term unbound accumulation of snow on land, snow accumulated above certain thershold is converted to runoff and put into the river network.

1.6.4 Salt

Global salt convervation properties of the model

1.6.4.1 Ocean Seaice Interface

Describe if/how salt is conserved at the ocean/sea-ice coupling interface

N/A (prescribed SSTs)

1.6.5 Momentum

Global momentum convervation properties of the model

1.6.5.1 Details

Describe if/how momentum is conserved in the model

Enter TEXT:

2 Radiative Forcings

Radiative forcings of the model for historical and scenario (aka Table 12.1 IPCC AR5)

2.1.1 Top level properties

Radiative forcings of the model for historical and scenario (aka Table 12.1 IPCC AR5)

2.1.1.1 Name

Commonly used name for the radiative forcings in toplevel model.

CMIP6 radiative forcings

2.1.1.2 Overview

Overview of radiative forcings of the model for historical and scenario (aka table 12.1 ipcc ar5) in toplevel model.

Radiative forcings include time series of GHG concentrations, aerosols and aerosols precursor emissions, ozone concentrations, optical properties for stratospheric vocanic aerosols, and annual land use change.

2.1.2 CO2

Carbon dioxide forcing

2.1.2.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.2.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Meinshausen et al. 2017

2.1.3 CH4

Methane forcing

2.1.3.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.3.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Meinshausen et al. 2017

2.1.4 N2O

Nitrous oxide forcing

2.1.4.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.4.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Meinshausen et al. 2017

2.1.5 Tropospheric O3

Troposheric ozone forcing

2.1.5.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.5.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Checa-Garcia et al (2019)

2.1.6 Stratospheric O3

Stratospheric ozone forcing

2.1.6.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.6.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Checa-Garcia et al (2019)

2.1.7 CFC

Ozone-depleting and non-ozone-depleting fluorinated gases forcing

2.1.7.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.7.2 Equivalence Concentration *

Details of any equivalence concentrations used

☐ N/A - Not applicabale (CFCs not included or emissions and concentrations determined by the model state)

☐ Option 1 - CFCs, including CFC-12, are provided as actual concentrations

☐ Option 2 - CFC-12 is provided as actual concentrations and any other gases are provided as an equivalence concentration of CFC-11

☐ Option 3 - Ozone depleting gases, including CFC-12, are provided as an equivalence concentration of CFC-12 and all other fluorinated gases are provided as an equivalence concentration of HFC-134a

☐ Other - please specify:

2.1.7.3 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Meinshausen et al. 2017

2.1.8 SO4

SO4 aerosol forcing

2.1.8.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.8.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Hoesly et al (2018) and van Marle et al (2017)

2.1.9 Black Carbon

Black carbon aerosol forcing

2.1.9.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.9.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Hoesly et al (2018) and van Marle et al (2017)

2.1.10 Organic Carbon

Organic carbon aerosol forcing

2.1.10.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.10.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Hoesly et al (2018) and van Marle et al (2017)

2.1.11 Nitrate

Nitrate forcing

2.1.11.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.11.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Enter TEXT:

2.1.12 Cloud Albedo Effect

Cloud albedo effect forcing (RFaci)

2.1.12.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.12.2 Aerosol Effect On Ice Clouds *

Radiative effects of aerosols on ice clouds are represented?

☐ True ☒ False

2.1.12.3 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Donner et. al 2011

2.1.13 Cloud Lifetime Effect

Cloud lifetime effect forcing (ERFaci)

2.1.13.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.13.2 Aerosol Effect On Ice Clouds *

Radiative effects of aerosols on ice clouds are represented?

☐ True ☒ False

2.1.13.3 RFaci From Sulfate Only *

Radiative forcing from aerosol cloud interactions from sulfate aerosol only?

☐ True ☒ False

2.1.13.4 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

All prognostic aerosols (sulfate, organic and black carbon, sea-salt, and dust) affect cloud droplet number concentration. See Donner et. al 2011 for details.

2.1.14 Dust

Dust forcing

2.1.14.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.14.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Ginoux et al. 2001

2.1.15 Tropospheric Volcanic

Tropospheric volcanic forcing

2.1.15.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.15.2 Historical Explosive Volcanic Aerosol Implementation *

How explosive volcanic aerosol is implemented in historical simulations

☐ Type A - Explosive volcanic aerosol returns rapidly to zero (or near-zero) background.

☐ Type B - Explosive volcanic aerosol returns rapidly to constant (average volcano)

☐ Type C - Explosive volcanic aerosol returns slowly (over several decades) to constant (average volcano) background.

☐ Type D - Explosive volcanic aerosol set to zero

☐ Type E - Explosive volcanic aerosol set to constant (average volcano) background

☐ Other - please specify:

2.1.15.3 Future Explosive Volcanic Aerosol Implementation *

How explosive volcanic aerosol is implemented in future simulations

☐ Type A - Explosive volcanic aerosol returns rapidly to zero (or near-zero) background.

☐ Type B - Explosive volcanic aerosol returns rapidly to constant (average volcano)

☐ Type C - Explosive volcanic aerosol returns slowly (over several decades) to constant (average volcano) background.

☐ Type D - Explosive volcanic aerosol set to zero

☐ Type E - Explosive volcanic aerosol set to constant (average volcano) background

☐ Other - please specify:

2.1.15.4 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

The contribution to tropospheric SO2 from continuously degassing and explosive volcanoes is treated in the same way as in AM3 (Donner et al., 2011).

2.1.16 Stratospheric Volcanic

Stratospheric volcanic forcing

2.1.16.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.16.2 Historical Explosive Volcanic Aerosol Implementation *

How explosive volcanic aerosol is implemented in historical simulations

☐ Type A - Explosive volcanic aerosol returns rapidly to zero (or near-zero) background.

☐ Type B - Explosive volcanic aerosol returns rapidly to constant (average volcano)

☐ Type C - Explosive volcanic aerosol returns slowly (over several decades) to constant (average volcano) background.

☐ Type D - Explosive volcanic aerosol set to zero

☐ Type E - Explosive volcanic aerosol set to constant (average volcano) background

☐ Other - please specify:

2.1.16.3 Future Explosive Volcanic Aerosol Implementation *

How explosive volcanic aerosol is implemented in future simulations

☐ Type A - Explosive volcanic aerosol returns rapidly to zero (or near-zero) background.

☐ Type B - Explosive volcanic aerosol returns rapidly to constant (average volcano)

☐ Type C - Explosive volcanic aerosol returns slowly (over several decades) to constant (average volcano) background.

☐ Type D - Explosive volcanic aerosol set to zero

☐ Type E - Explosive volcanic aerosol set to constant (average volcano) background

☐ Other - please specify:

2.1.16.4 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

CMIP6 prescribed Volcanic dataset is used (ftp://iacftp.ethz.ch/pub_read/luo/CMIP6/GFDL/), interpolated onto pressure levels and GFDL radiation bands.

2.1.17 Sea Salt

Sea salt forcing

2.1.17.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.17.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Monahan et al. 1986; Martensson et al. 2003

2.1.18 Land Use

Land use forcing

2.1.18.1 Provision *

How this forcing agent is provided (e.g. via concentrations, emission precursors, prognostically derived, etc.)

☐ N/A - Not applicable - forcing agent is not included

☐ M - Emissions and concentrations determined by the model state rather than externally prescribed

☐ Y - Prescribed concentrations, distributions or time series data

☐ E - Concentrations calculated interactively driven by prescribed emissions or precursor emissions

☐ ES - Surface emissions (and 3-D concentrations away from the surface) derived via the model from the prescribed surface concentration

☐ C - Fixed prescribed climatology of concentrations with no year-to-year variability

☐ Other - please specify:

2.1.18.2 Crop Change Only *

Land use change represented via crop change only?

☐ True ☒ False

2.1.18.3 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Land use transitions from LUH2 forcing data set are imposed on the vegetation anually; the land use types employed by the model are primary (natural, undisturbed), croplands, pastures, and secondary (disturbed but recovering) vegetation. Croplands and pastures are harvested, indirectly influencing all surface properties, including albedo.

2.1.19 Solar

Solar forcing

2.1.19.1 Provision *

How solar forcing is provided

☐ N/A - Not applicable - solar forcing is not included

☒ Irradiance - Solar irradiance forcing

☐ Proton - Proton pathway to solar forcing

☐ Electron - Electron pathway to solar forcing

☐ Cosmic ray - Cosmic ray pathway to solar forcing

☐ Other - please specify:

2.1.19.2 Additional Information

Additional information relating to the provision and implementation of this forcing agent (e.g. citations, use of non-standard datasets, explaining how multiple provisions are used, etc.).

Mathes et al. (2017)