Essential Model Documentation (EMD)

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Version	**0.992**
Date	12 May 2025
DOI	10.5281/zenodo.15439552
Citation	Hassel, D., Levavasseur, G., Pascoe, C., Taylor, K., Crawford, A., Durack, P., Ellis, D., Goddard, C., Horanya, A., Lawrence B., and Stockhause M. (2025). Essential Model Documentation (EMD). DOI: 10.5281/zenodo.15439552

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1. Introduction

The Essential Model Documentation (EMD) is a high-level description of an earth system model.

It is intended to contain information about model configuration that may be helpful to the communities who expect to make use of the model output, whilst not imposing burdensome requirements on those providing the data.

It is not intended to contain all information about a model. More detailed model documentation than that provided by the EMD should be found in the references cited as part of the EMD, or from other external sources.

The EMD is collected for the model as a whole (section 2. Top-level model) and for each of the model's components (section 3. Model components).

This document is intended to be a human-readable specification with preliminary, but not complete or finalised, controlled vocabularies. It does not place any constraint on the tools and file-serialisation that will be required to create, store, and access EMD content. In particular, it is expected that the controlled vocabularies will evolve to meet the needs of the models being described.

1.1. Application to CMIP7

The EMD has been designed to be applicable to any earth system model, nonetheless some guidance has been included in this version for its use within the CMIP7 project (Dunne et al., 2024), for which EMD was originally developed. This is indicated in the specification as "***for CMIP7***", and these particular notes and instructions may be ignored when using EMD within other projects.

The EMD will be considered especially valuable if it is provided by all models. To ensure this, it has been agreed that the EMD will be a mandatory requirement for CMIP7 participation, and the registration of a CMIP7 model will not be possible unless its EMD has been provided.

An on-line creation tool will be used for CMIP7 model registration, and this tool will collect the content that will be recorded in the EMD. The EMD will be reviewed, and when it is accepted the model registration can be completed. The on-line tool will also enable those documenting a model to import documentation from earlier registered models, which can then be edited, if required.

1.2. History

EMD was developed by the CMIP7 Documentation Task Team from December 2023 to May 2025. During this period it was improved by suggestions arising from community reviews provided by:

- the WCRP Working Group on Coupled Modelling (WGCM) CMIP and WIP Panels,
- the CMIP7 Fresh Eyes on CMIP and MIP Controlled Vocabularies Task Teams,

- the CMIP Model Intercomparison Projects (MIPs),
- the climate modelling centres taking part in CMIP7,
- climate service providers acting as stakeholders for the archive of CMIP model outputs.

2. Top-level model

The following properties provide a top-level description of the model as whole.

In the property examples, *underlined and italicised* values are taken from section 7. Controlled vocabularies.

- **name**
  - The name of the top-level model.
  - ***For CMIP7***, this name will be registered as the model's *source_id.*
  - The name may include an indication of the top-level model's family (given by the model **family** property), and should also specify a particular version of the top-level model.
  - E.g. *HadGEM3-GC31-HH*
- **family**
  - The top-level model's "family" name. A family of models share much of their code bases, but may be configured in different ways (e.g. different resolutions, parameter choices, or the inclusion or not of particular model components). See Masson and Knutti (2011) for an example of how the family can be used to inform model genealogies.
  - A family name may be the first part of its full name, as given by the top-level model's **name** property.
  - Use a value of "*none*" to indicate that there is no such family for the top-level model.
  - E.g. *HadCM2*
  - E.g. *HadGEM3*
  - E.g. *CCSM*
  - E.g. *none*
- **dynamic_components**
  - The model components that are dynamically simulated within the top-level model.
  - Taken from a standardised list: 7.1 component CV.
  - These components must be further described by the model component properties, as discussed in section 3. Model components.
  - E.g. *atmosphere*, *land_ice*, *land_surface*
- **prescribed_components**
  - The components that are represented in the top-level model with prescribed values.
  - Taken from a standardised list: 7.1 component CV.
  - These components are typically represented by constant or time varying values or fields that are provided as input to the top-level model.
  - E.g. *atmospheric_chemistry*, *ocean*, *sea_ice*
- **omitted_components**
  - The components that are wholly omitted from the top-level model.

  - Taken from a standardised list: 7.1 component CV.
  - E.g. *aerosol*, *ocean_biogeochemistry*
- **description**
  - A brief, free-text scientific overview of the top-level model.
  - The description should include a brief mention of all the components listed in the 7.1 component CV, whether dynamically simulated, prescribed, or omitted.
  - Dynamically simulated components (i.e. those listed by the **dynamic_components** property) are described elsewhere, as discussed in section 3. Model components, so only a very short, high-level overview is required in this description. For instance "*The model includes a global process-based model of the land surface and the terrestrial biosphere that calculates water, energy, and carbon fluxes between the surface and the atmosphere*", and this description should also include the component's name, if appropriate.
  - Prescribed components (i.e. those listed by the **prescribed_components** property) are not described elsewhere, so information on how they are treated should be included the description. For instance "*The model requires that a monthly mean, zonally averaged ozone field be prescribed because the model does not include an interactive atmospheric chemistry component*".
  - Components that are wholly omitted (i.e. those listed by the **omitted_components** property) must be noted as such. For instance, "*The model has no treatment of atmospheric chemistry*").
- **calendar**
  - The calendar, or calendars, that define which dates are permitted in the top-level model.
  - Taken from a standardised list: 7.2 calendar CV.
  - ***For CMIP7***, only the set of calendars that are adopted in CMIP7 simulations should be provided, identifying which calendar is most commonly used by setting that calendar as the first in the list. For instance, "*standard*" might apply for historical and future simulations, and "*365_day*" for paleo-experiments.
  - E.g. *360_day*
  - E.g. *standard*, *365_day*
- **release_year**
  - The year in which the top-level model being documented was released, or first used for published simulations.
  - E.g. *2016*
- **references**
  - One or more references to published work for the top-level model as a whole.
  - Each reference must include the properties described in section 5. References.

3. Model components

Properties that provide a description of an individual model component of the top-level model.

Eight model components are defined that somewhat independently account for different sets of interactive processes: aerosol, atmosphere, atmospheric chemistry, land surface, land ice, ocean, ocean biogeochemistry, and sea ice. The interactive processes covered by each component are described in section 7.1 component CV.

Each component is characterized as "dynamic", "prescribed", or "omitted" (see 2. Top-level model), but only model components that dynamically simulate their processes are described in this section of the EMD. Relationships among dynamically simulated components are indicated by specifying that they are "embedded in" or "coupled with" other components (see 3.1. Embedded and coupled components).

Note for CMIP7: *The component types in the 7.1 component CV have similar names and definitions to the CMIP "realms" given by the CMIP6_realm.json file (Durack et al., 2025), but the context in which they are used is different. An EMD component type defines a set of physical processes that are simulated by one model component; whereas as one or more CMIP realms are assigned to an individual output variable according to which sets of processes the variable is physically related to, rather than which model component created it. The CMIP realms for an output variable often include the EMD component type that created it, but this is not always the case.*

In the property examples, *underlined and italicised* values are taken from section 7. Controlled vocabularies.

- **component**
  - The type of the model component.
  - Taken from a standardised list: 7.1 component CV.
  - E.g. *aerosol*
- **name**
  - The name of the model component.
  - If the component is embedded in a host component and has no commonly recognised name, then a name can be constructed by combining the host component's **name** with this component's **component** type, separated by a hyphen.
  - E.g. *BISICLES-UKESM-ISMIP6*
  - E.g. *MOSES2*
  - E.g. *HadAM3-aerosol*
- **family**
  - The model component's "family" name. For a component, its family members should all share much of their code bases, but the members may be configured in different ways (e.g. different resolutions, parameter choices, or the inclusion

or not of particular sub-process). See Masson and Knutti (2011) for an example of how the family can be used to inform model genealogies.
    - Use a value of "*none*" to indicate that there is no such family for the model component.
    - E.g. *BISICLES*
    - E.g. *CLM*
    - E.g. *none*
- **description**
    - A scientific overview of the model component.
    - The description should summarise the key processes simulated by the model component.
    - ***For CMIP7***, easy-to-answer MIP-relevant questions may be posed, which should be addressed using free text. For instance "*Are aerosols driven by emissions or concentration?*" or "*What is the aerosol activation scheme?*".
- **references**
    - One or more references to published work for the model component.
    - Each reference must include the properties described in section 5. References.
- **code_base**
    - A URL (preferably for a DOI) for the source code for the model component.
    - If the source code is in a versioncontrolled repository (e.g. a git or svn repository) then the URL must identify a specific point in the repository's history.
    - Set to "*private*" if not publicly available.
- **embedded_in**
    - The host model component (identified by its **component** property) in which this component is "embedded".
    - See section 3.1. Embedded and coupled model components for a definition of an embedded component. Note that a component must be either embedded in a another component or else coupled with other components, but can not be both.
    - Taken from a standardised list: 7.1 component CV.
    - Omit when this component is coupled with other components (see the **coupled_with** property).
    - E.g. in some cases, for an aerosol model component: *atmosphere*
- **coupled_with**
    - The model components (identified by their **component** properties) with which this component is "coupled".
    - See section 3.1. Embedded and coupled model components for a definition of a coupled component. Note that a component must be either embedded in a another component or else coupled with other components, but can not be both.
    - Taken from a standardised list: 7.1 component CV.
    - Omit when this component is embedded in another component (see the **embedded_in** property).

  - E.g. In some cases for a land ice component: *atmosphere*, *land_surface*, *ocean*
- **native_horizontal_grid**
  - A standardised description of the model component's horizontal grid.
  - The grid is described by defining the properties listed in section 4.1. Horizontal grid.
- **native_vertical_grid**
  - A standardised description of the model component's vertical grid.
  - The grid is described by defining the properties listed in section 4.2. Vertical grid.

3.1. Embedded and coupled model components

All dynamically simulated components within a model interact with each other either directly or indirectly. The EMD only describes direct interactions between components, characterising them as either "embedded" or "coupled", and recording this using the **embedded_in** and **coupled_with** model component properties respectively.

Note: *Beyond the characterisation of "embedded" or "coupled", the EMD does not include further information about the nature of component interactions (e.g. it does not state which physical quantities are exchanged between components, nor how frequently these exchanges occur).*

The following characteristics can be used to help determine whether a component is "embedded in" or "coupled with" another component:

An "embedded" model component typically:

- shares the same horizontal grid as the host component;
- is constructed such that the code representing the component would be exceedingly difficult to extract and transfer to another top-level model;
- is coded such that within a single time-step, interactions between it and its host might involve exchanges of information affecting both;
- cannot be easily "driven" independently of its host (e.g. it cannot be run by itself in stand-alone "offline" mode with prescribed external conditions imposed);
- may not have a recognisable name or version number (other than those of the host component).

A "coupled" model component typically:

- is identified using a recognisable name, and often a version number (e.g. "MOM5", the fifth version of the Modular Ocean Model);
- interacts at regular intervals with other components by exchanging the collection of quantities needed by each to advance a simulation (such as mass, momentum, energy, etc.), either via a coupler (i.e. code specially adapted to represent the exchanges between the various components) or by other means;

- is coded such that it is relatively isolated from other parts of a top-level model code and (by design) might be extracted to be adopted in another top-level model.

Note: *A component must be either embedded in another component or else coupled with other components, but can not be both.*

Note: *The distinction between these two types may not always be obvious, and in some cases a somewhat arbitrary choice may have to be made. For instance, this could be the case when a component satisfies characteristics from both interaction types (e.g. it is possible for a component with a recognisable name and version number to be embedded in a host, rather than coupled).*

An embedded component has a single host component, and can not be coupled with any other components. Multiple components can be embedded in the same host. When there is more than one candidate for the host component, it should be chosen as the one that most directly influences the other components' processes. For instance, the ocean biogeochemistry, sea ice, and ocean components of a top-level model might be treated together in the model's code, but both sea ice and ocean biogeochemistry are considered to be embedded in the host ocean because, although there may be direct interactions and exchanges between the ocean biogeochemistry and sea ice, both of these components are more strongly influenced by properties primarily determined by the ocean component (e.g. the sea water temperature and salinity).

A non-embedded model component must be coupled with one or more other model components. Coupling (unlike embedding) is symmetrical, in that if model component A is coupled with model component B, then model component B must also be coupled with model component A, and this would be recorded in the **coupled_with** properties of both model components. For instance, an ocean model component might commonly be coupled with atmosphere, sea ice, and ocean biogeochemistry model components, but it could also be coupled with the land surface model component (if river water discharge into the ocean were explicitly calculated by the land model and "seen" by the ocean) and the land ice component (if the melting of an ice shelf contributed mass to the ocean or if heat or momentum fluxes were exchanged at the base of the ice shelf).

4. Model component grids

Properties that provide a description of the grids of a model component defined in section 3. Model components.

Documentation of the native grid of each model component, i.e. the grid on which the component is integrated, is split into separate horizontal and vertical parts. Each part is described with a standardised specification that is based on selections from controlled vocabularies or the provision of numerical values. A free-text description is also available for cases where information outside of the standardised specification is useful.

There are many properties in the grid descriptions, but only a subset will apply to any given grid. For instance a regular latitude-longitude grid does not need to provide any of the spectral grid truncation properties.

Note: *A model component may output variables on non-native grids (such as data on constant pressure levels from a model component with a terrain-following native vertical grid), or its output variables may be post-processed to non-native grids for storage in archived datasets (such as data interpolated to a regular 1 degree grid from a model component with a variable resolution native horizontal grid). However, it is always the native grid on which the model component is integrated that is described in the EMD.*

In the property examples, *underlined and italicised* values are taken from section 7. Controlled vocabularies.

4.1. Horizontal grid

The model component's horizontal grid is described by a subset of the following properties:

- **grid**
  - The horizontal grid type, i.e. the method of distributing grid points over the sphere.
  - Taken from a standardised list: 7.3 grid CV.
  - If there is no horizontal grid, then the value "*none*" must be selected, and no other properties should be set.
  - E.g. *regular_latitude_longitude*
  - E.g. *tripolar*
  - E.g. *none*
- **description**
  - A free-text description of the grid.
  - A description is only required if there is information that is not covered by any of the other properties.
  - Omit if not needed.
- **grid_mapping**

  - The name of the coordinate reference system of the horizontal coordinates.
  - Taken from a standardised list: 7.4 grid_mapping CV.
  - E.g. *latitude_longitude*
  - E.g. *lambert_conformal_conic*
- **region**
  - The geographical region, or regions, over which the component is simulated.
  - A region is a contiguous part of the Earth's surface, and may include areas for which no calculations are made (such as ocean areas for a land surface component).
  - Taken from a standardised list: 7.5 region CV.
  - E.g. *global*
  - E.g. *antarctica*, *greenland*
  - E.g. *limited_area*
- **temporal_refinement**
  - The grid temporal refinement, indicating how the distribution of grid cells varies with time.
  - Taken from a standardised list: 7.6 temporal_refinement CV.
  - E.g. *static*
- **arrangement**
  - A characterisation of the relative positions on the grid of mass-, velocity- or flux-related fields.
  - Taken from a standardised list: 7.7 arrangement CV.
  - E.g. *arakawa_b*
- **resolution_x**
  - The size of grid cells in the "X" direction.
  - The X direction for a grid defined by spherical polar coordinates is longitude.
  - The value's physical units are given by the **horizontal_units** property.
  - Report only when cell sizes are identical or else reasonably uniform (in their given units). When cells sizes are not identical, a representative value should be provided and this fact noted in the **description** property, but only if the cell sizes vary by less than 25%.
  - Omit when not applicable.
  - E.g. *3.75*
- **resolution_y**
  - The size of grid cells in the "Y" direction.
  - The Y direction for a grid defined by spherical polar coordinates is latitude.
  - The value's physical units are given by the **horizontal_units** property.
  - Report only when cell sizes are identical or else reasonably uniform (in their given units). When cells sizes are not identical, a representative value should be provided and this fact noted in the **description** property, but only if the cell sizes vary by less than 25%.
  - Omit when not applicable.
  - E.g. *2.5*

- **horizontal_units**
  - The physical units of the **resolution_x** and **resolution_y** property values.
  - Taken from a standardised list: 7.8 horizontal_units CV.
  - Omit when not applicable.
  - E.g. *km*
  - E.g. *degree*
- **n_cells**
  - The total number of cells in the horizontal grid.
  - If the horizontal grid is unstructured and the component utilises primal and dual meshes (i.e. when each vertex of a primal mesh cell is uniquely associated with the "centre" of a dual mesh cell, and vice versa), then the number of cells for the primal mesh should be provided.
  - Omit when not applicable or not constant.
  - E.g. *265160*
- **n_sides**
  - For unstructured horizontal grids only, the total number of unique cell sides.
  - When the component utilises primal and dual meshes (i.e. when each vertex of a primal mesh cell is uniquely associated with the "centre" of a dual mesh cell, and vice versa), the number of sides for the primal mesh should be provided.
  - Omit when not applicable or not constant.
  - E.g. *714274*
- **n_vertices**
  - For unstructured horizontal grids only, the number of unique cell vertices.
  - When the component utilises primal and dual meshes (i.e. when each vertex of a primal mesh cell is uniquely associated with the "centre" of a dual mesh cell, and vice versa), the number for the primal mesh should be provided.
  - Omit when not applicable or not constant.
  - E.g. *567145*
- **truncation_method**
  - The method for truncating the spherical harmonic representation of a spectral model.
  - Taken from a standardised list: 7.9 truncation_method CV.
  - Omit when not applicable.
  - E.g. *triangular*
- **truncation_number**
  - The zonal (east-west) wave number at which a spectral model is truncated.
  - Omit when not applicable.
  - E.g. *63*
- **resolution_range_km**
  - The minimum and maximum resolution (in km) of cells of the horizontal grid.
  - Calculate as described in this documented Python code, which can be used to obtain the maximum, minimum and mean resolution.
  - E.g. *57.0, 290*

- **mean_resolution_km**
  - The mean resolution (in km) of cells of the horizontal grid.
  - Calculate as described in this documented Python code, which can be used to obtain the maximum, minimum, and mean resolution.
  - E.g. *234.8*
- **nominal_resolution**
  - The nominal resolution characterises the approximate resolution of a horizontal grid.
  - The nominal resolution is obtained from the **mean_resolution_km** property by looking it up in the table at 7.10 nominal_resolution CV.
  - E.g. *A grid with mean resolution of 82 will have a nominal resolution of 100 km*

4.2. Vertical grid

The model component's vertical grid is described by a subset of the following properties:

- **coordinate**
  - The coordinate type of the vertical grid.
  - Taken from a standardised list: 7.11 coordinate CV.
  - If there is no vertical grid, then the value "*none*" must be selected, and no other properties should be set.
  - E.g. *height*
  - E.g. *none*
- **description**
  - A free-text description of the vertical grid.
  - A description is only required if there is information that is not covered by any of the other properties.
  - Omit if not needed.
- **n_z**
  - The number of layers (i.e. grid cells) in the Z direction.
  - Omit when not applicable or not constant.
  - If the number of layers varies in time or across the horizontal grid, then the **n_z_range** property may be used instead.
  - E.g. *70*
- **n_z_range**
  - The minimum and maximum number of layers for vertical grids with a time- or space-varying number of layers.
  - Omit if not applicable, or if the **n_z** property has been set.
  - E.g. *5, 15*
- **bottom_layer_thickness**
  - The thickness of the bottom model layer (i.e. the layer closest to the centre of the Earth).

  - The value should be reported as a dimensional (as opposed to parametric) quantity.
  - If the value varies in time or across the horizontal grid, then provide a nominal or typical value.
  - The value's physical units are given by the **vertical_units** property.
  - Omit when not applicable.
  - E.g. *10*
- **top_layer_thickness**
  - The thickness of the top model layer (i.e. the layer furthest away from the centre of the Earth).
  - The value should be reported as a dimensional (as opposed to parametric) quantity.
  - If the value varies in time or across the horizontal grid, then provide a nominal or typical value.
  - The value's physical units are given by the **vertical_units** property.
  - Omit when not applicable.
  - E.g. *10*
- **top_of_model**
  - The upper boundary of the top model layer (i.e. the upper boundary of the layer that is furthest away from the centre of the Earth).
  - The value should be relative to the lower boundary of the bottom layer of the model, or an appropriate datum (such as mean sea level).
  - The value should be reported as a dimensional (as opposed to parametric) quantity.
  - The value's physical units are given by the **vertical_units** property.
  - Omit when not applicable or not constant.
  - E.g. *85003.5*
- **vertical_units**
  - The physical units of the **bottom_layer_thickness**, **top_layer_thickness**, and **top_of_model** property values.
  - Taken from a standardised list: 7.12 vertical_units CV.
  - Omit when not applicable.
  - E.g. *m*

5. References

An academic reference to published work for the top-level model or one its model components is defined by the following properties:

- **citation**
    - A human-readable citation for the work.
    - E.g. *Smith, R. S., Mathiot, P., Siahaan, A., Lee, V., Cornford, S. L., Gregory, J. M., et al. (2021). Coupling the U.K. Earth System model to dynamic models of the Greenland and Antarctic ice sheets. Journal of Advances in Modeling Earth Systems, 13, e2021MS002520. https://doi.org/10.1029/2021MS002520, 2023*
- **doi**
    - The persistent identifier (DOI) used to identify the work.
    - A DOI is required for all references. A reference that does not already have a DOI (as could be the case for some technical reports, for instance) must be given one (e.g. with a service like Zenodo).
    - E.g. *https://doi.org/10.1029/2021MS002520*

6. Examples

Here are a limited number of model component examples, and grid-only examples, that are based on some CMIP6 models.

In these examples, *underlined and italicised* values are taken from section 7. Controlled vocabularies.

***Note**: These examples are for illustrative purposes only, and should not be considered as definitive descriptions of these model components.*

6.1. Land Surface component

- **component**: *land_surface*
- **name**: CLM4
- **family**: CLM
- **description**: The model represents several aspects of the land surface including surface heterogeneity and consists of components or submodels related to land biogeophysics, the hydrologic cycle, biogeochemistry, human dimensions, and ecosystem dynamics. Spatial land surface heterogeneity in CLM is represented as a nested subgrid hierarchy in which grid cells are composed of multiple landunits, snow/soil columns, and PFTs. Each grid cell can have a different number of landunits, each landunit can have a different number of columns, and each column can have multiple PFTs. Biogeophysical processes are simulated for each subgrid landunit, column, and PFT independently and each subgrid unit maintains its own prognostic variables. The same atmospheric forcing is used to force all subgrid units within a grid cell. The surface variables and fluxes required by the atmosphere are obtained by averaging the subgrid quantities weighted by their fractional areas.
- **references**
  - **citation**: Ke, Y., Leung, L. R., Huang, M., Coleman, A. M., Li, H., and Wigmosta, M. S.: Development of high resolution land surface parameters for the Community Land Model, Geosci. Model Dev., 5, 1341–1362, https://doi.org/10.5194/gmd-5-1341-2012, 2012.
  - **doi**: https://doi.org/10.5194/gmd-5-1341-2012, 2012
- **embedded_in:** *atmosphere*
- **native_horizontal_grid**
  - **grid**: *regular_latitude_longitude*
  - **grid_mapping**: *latitude_longitude*
  - **region**: *global*
  - **arrangement**: *arakawa_c*
  - **temporal_refinement**: *static*
  - **resolution_x**: 1.25

- **resolution_y**: 0.9
- **horizontal_units**: *degree*
- **n_cells:** 55296
- **resolution_range_km**: 100.0, 170.1
- **mean_resolution_km**: 139.5
- **nominal_resolution**: *100 km*

– **native_vertical_grid**
  - **description**: Vegetated, wetland, and glacier landunits have 15 vertical layers. Lakes have 10 layers. Snow can have up to 5 layers.
  - **coordinate**: *depth*

6.2. Land Ice component

– **component**: *land_ice*
– **name**: BISICLES-UKESM-ISMIP6-1.0
– **family**: BISICLES
– **description**: UniCiCles (Unified Model-CISM-BISICLES) is a package combining BISICLES with an interface that obtains boundary conditions from Unified Model or JULES data, using code derived from the Glint interface of the Glimmer-CISM ISM. BISICLES uses the adaptive-mesh Chombo libraries. All cells in the mesh are rectangles that may be recursively refined by subdivision into four smaller cells with the same aspect ratio. The configuration of BISICLES approximates the momentum equations using the "shelfy-stream" approximation with simplified vertical shear strains included in the effective viscosity, often referred to as SSA*. Basal traction is set to zero beneath floating ice and modelled using power laws beneath grounded ice. Greenland ice sheet uses a linear drag law everywhere while AIS uses a cubic law far upstream from the grounding line, which tends to a Coulomb friction law near the grounding line.
– **references**
  - **citation**: Smith, R. S., Mathiot, P., Siahaan, A., Lee, V., Cornford, S. L., Gregory, J. M., et al. (2021). Coupling the U.K. Earth System model to dynamic models of the Greenland and Antarctic ice sheets. Journal of Advances in Modeling Earth Systems, 13, e2021MS002520. https://doi.org/10.1029/2021MS002520, 2023
  - **doi**: https://doi.org/10.1029/2021MS002520

– **coupled_with**: *atmosphere*, *land_surface*, *ocean*
– **native_horizontal_grid**
  - **description**: Greenland ice sheet (GrIS) is modelled with 9.6 km square base cells that may subdivide to 1.2 km and Antarctic ice sheet (AIS) with 8 km that may subdivide to 2 km. The meshes are updated every 8 timesteps for GrIS and 4 for AIS allowing the resolution to evolve with the ice dynamics.
  - **grid**: *plane_projection_grid*
  - **grid_mapping:** *polar_stereographic*
  - **region**: *greenland*, *antarctica*
  - **arrangement**: *arakawa_a*

    - **temporal_refinement**: *adaptive*
    - **resolution_range_km**: 1.7, 13.6
    - **mean_resolution_km**: 3.67
    - **nominal_resolution:** *5 km*
- **native_vertical_grid**
    - **coordinate**: *land_ice_sigma_coordinate*
    - **n_z**: 10

6.3. Grid: Regular latitude-longitude/ atmosphere_hybrid_height_coordinate

- **native_horizontal_grid**
    - **grid**: *regular_latitude_longitude*
    - **grid_mapping**: *latitude_longitude*
    - **region**: *global*
    - **arrangement**: *arakawa_c*
    - **temporal_refinement:** *static*
    - **resolution_x**: *0.833*
    - **resolution_y**: *0.556*
    - **horizontal_units**: *degree*
    - **n_ cells:** 139968
    - **resolution_range_km**: 75, 140
    - **mean_resolution_km**: 95.8
    - **nominal_resolution**: *100 km*
- **native_vertical_grid**
    - **coordinate**: *atmosphere_hybrid_height_coordinate*
    - **n_z**: 85
    - **top_of_model**: 84763.34
    - **vertical_units**: *m*

6.4. Grid: Tripolar ocean

- **native_horizontal_grid**
    - **description**: *eORCA025*
    - **grid**: *tripolar*
    - **grid_mapping**: *latitude_longitude*
    - **region**: *global*
    - **arrangement**: *arakawa_c*
    - **temporal refinement**: *static*
    - **n_cells**: 1725200
    - **resolution_range_km**: 15, 60
    - **mean_resolution_km**: 32.4
    - **nominal_resolution**: *25 km*

- **native_vertical_grid**
  - **coordinate**: *ocean_s_coordinate*
  - **n_z**: 75
  - **top_layer_thickness**: 1.5
  - **vertical_units**: *m*

6.5. Grid: Reduced Gaussian

- **native_horizontal_grid**
  - **description**: T127. Gaussian Reduced with 256 grid points per latitude circle between 30 degrees north and 30 degrees south, reducing to 20 grid points per latitude circle at 88.9 degrees north and 88.9 degrees south.
  - **grid**: *reduced_gaussian*
  - **grid_mapping**: *latitude_longitude*
  - **region**: *global*
  - **arrangement**: *arakawa_b*
  - **temporal_refinement**: *static*
  - **resolution_y**: *1.40625*
  - **horizontal_units**: *degree*
  - **n_cells**: 24572
  - **truncation_method**: *triangular*
  - **truncation_number**: 127
  - **resolution_range_km**: 34, 140
  - **mean_resolution_km**: 123
  - **nominal_resolution:** *100 km*
- **native_vertical_grid**
  - **coordinate**: *atmosphere_hybrid_sigma_pressure_coordinate*
  - **n_z**: 91
  - **top_of_model**: 1500
  - **vertical_units**: *Pa*

6.6. *Grid: Unstructured grid*

- **native_horizontal_grid**
  - **description**: *oEC60to30*. Unstructured mesh created using Spherical Centroidal Voronoi Tessellations.
  - **grid**: *unstructured_polygon*
  - **grid_mapping**: *latitude_longitude*
  - **region**: *global*
  - **arrangement**: *arakawa_c*
  - **temporal_refinement**: *static*
  - **n_cells**: 235160
  - **n_ sides**: 714274

- **resolution_range_km**: 30, 60
- **mean_resolution_km**: 45.7
- **nominal_resolution**: *50 km*

7. Controlled vocabularies

Many EMD property values are restricted to selections from controlled vocabularies, i.e. standardised lists which contain all possible values.

Note*: It is known that some of these controlled vocabularies are not complete, because it is not known in advance what is required for every model.*

For CMIP7, the EMD on-line creation tool will provide the ability to request a new controlled vocabulary entry, which will be subsequently finalised on a GitHub issue. Once accepted, the new entry will be available for general use.

7.1. **component** CV

Component types. A component type describes a set of interactive processes that are simulated by single model component. See sections 2. Top-level model and 3. Model components.

Options for the top-level model **dynamic_components**, **prescribed_components**, and **omitted_components** properties; and the model component **component**, **embedded_in**, and **coupled_with** properties:

- **aerosol**
    - *The behaviour and evolution of aerosols suspended in the atmosphere.*
- **atmosphere**
    - *Dynamical, thermodynamical, and physical processes in the atmosphere.*
- **atmospheric_chemistry**
    - *The behaviour and evolution of the chemical composition of the atmosphere.*
- **land_surface**
    - *Water, energy, and mass fluxes between the surface and the atmosphere.*
- **land_ice**
    - *Frozen freshwater in glaciers, ice-caps, ice-sheets, and ice-shelves.*
- **ocean**
    - *Dynamical, thermodynamical, and physical processes in the ocean.*
- **ocean_biogeochemistry**
    - *Biological, geological, and chemical processes in the ocean.*
- **sea_ice**
    - *Frozen seawater that floats on the ocean surface.*

7.2. **calendar** CV

Calendar types. A calendar defines the set of valid dates and times that are allowed. The calendar names are a subset of the allowed CF calendar names, with the same definitions. See section 2. Top-level model.

Note that explicitly defined CF calendars could be added to this CV, if required. For instance, a paleoclimate simulation might require a calendar of "*126 kyr BP*".

Options for the model **calendar** property:

- **standard**
    - *A mixed Gregorian/Julian calendar which is Gregorian after 1582-10-15, and Julian before.*
- **proleptic_gregorian**
    - *A calendar with the Gregorian rules for leap-years extended to dates before 1582-10-15.*
- **julian**
    - *The Julian calendar, in which a year is a leap year if it is divisible by 4, even if it is also divisible by 100.*
- **360_day**
    - *A calendar in which all years are 360 days, and divided into 30 day months.*
- **365_day**
    - *A calendar with no leap years, i.e. all years are 365 days long.*
- **366_day**
    - *A calendar in which every year is a leap year, i.e. all years are 366 days long.*
- **none**
    - *No calendar.*

7.3. **grid** CV

Horizontal grid types. A grid type describes the method for distributing grid points over the sphere. See section 4.1 Horizontal grid.

Options for the horizontal grid **grid** property:

- **regular_latitude_longitude**
    - *A rectilinear latitude-longitude grid with evenly spaced latitude points and evenly spaced longitude points.*
- **regular_gaussian**
    - *A Gaussian grid for which the number of longitudinal points is constant for each latitude.*
- **reduced_gaussian**
    - *A Gaussian grid for which the number of longitudinal points is reduced as the poles are approached.*
- **spectral_gaussian**
    - *A grid based on the transformation from spectral space to a reduced or non-reduced Gaussian grid.*
- **spectral_reduced_gaussian**
    - *A grid based on the transformation from spectral space to a reduced Gaussian grid.*

- **linear_spectral_gaussian**
    - *A spectral Gaussian grid for which the smallest spectral wavelength is represented by 2 grid points.*
- **quadratic_spectral_gaussian**
    - *A spectral Gaussian grid for which the smallest spectral wavelength is represented by 3 grid points.*
- **cubic_octahedral_spectral_reduced_gaussian**
    - *A spectral reduced Gaussian grid for which the smallest spectral wavelength is represented by 4 grid points, and which uses an octahedron-based method to reduce the number of grid points towards the poles.*
- **rotated_pole**
    - *A regular latitude-longitude grid that is rotated to define a different north pole location.*
- **stretched**
    - *A grid with higher resolution concentrated over an area of interest, at the expense of lower resolution elsewhere.*
- **displaced_pole**
    - *An ocean grid whose poles are not antipodean, typically with the northern pole displaced to lie over land.*
- **tripolar**
    - *A global curvilinear ocean grid with a southern pole and two northern poles all placed over land.*
- **cubed_sphere**
    - *The spherical surface is defined as six coupled "logically square" regions.*
- **icosahedral_geodesic**
    - *A grid that uses triangular tiles based on the subdivision of an icosahedron.*
- **icosahedral_geodesic_dual**
    - *A grid that uses hexagonal and pentagonal tiles and is the dual of an icosahedral_geodesic grid.*
- **yin_yang**
    - *Two overlapping grid patches.*
- **unstructured_triangular**
    - *An unstructured mesh consisting solely of triangles.*
- **unstructured_polygonal**
    - *An unstructured mesh consisting of arbitrary polygons.*
- **plane_projection**
    - *Any transformation employed to represent the spherical surface of the globe on a plane.*
- **none**
    - *There is no horizontal grid.*

7.4. **grid_mapping** CV

Horizontal grid mappings. A grid mapping describes the horizontal coordinate reference system. The grid mappings are all CF grid mapping names with the same definitions. See section 4.1 Horizontal grid.

Options for the horizontal grid **grid_mapping** property:

- **albers_conical_equal_area**
- **azimuthal_equidistant**
- **geostationary**
- **lambert_azimuthal_equal_area**
- **lambert_conformal_conic**
- **lambert_cylindrical_equal_area**
- **latitude_longitude**
- **orthographic**
- **polar_stereographic**
- **rotated_latitude_longitude**
- **sinusoidal**
- **stereographic**
- **transverse_mercator**
- **vertical_perspective**

7.5. **region** CV

Horizontal grid regions. A region is a contiguous part of the Earth's surface over which a model component is simulated. See section 4.1 Horizontal grid.

Options for the horizontal grid **region** property:

- **antarctica**
  - *The geographical region of Antarctica, as defined by the CF standardised regions.*
- **global**
  - *The geographical region of the whole of the Earth's surface, as defined by the CF standardised regions.*
- **greenland**
  - *The geographical region of Greenland, as defined by the CF standardised regions.*
- **limited_area**
  - *Any contiguous subregion of the Earth's surface, used to indicate a limited area model that may be placed over different geographical regions independently of the model formulation.*

7.6. **temporal_refinement** CV

Horizontal grid temporal refinement types. A temporal refinement type describes how the distribution of grid cells varies with time. See section 4.1 Horizontal grid.

Options for the horizontal grid **temporal_refinement** property:

- **static**
  - *The total number of grid points stays constant during the model run and there is no grid refinement, i.e. the grid is held fixed.*
- **dynamically_stretched**
  - *The total number of grid points stays constant, but grid points can be dynamically relocated.*
- **adaptive**
  - *The total number of grid points varies during the model run. The grid is refined locally when important physical processes occur that need additional grid resolution, and coarsened when the additional resolution is no longer needed.*

7.7. **arrangement** CV

Horizontal grid arrangement types. A grid arrangement describes the relative locations of mass- and velocity-related quantities on the computed grid (Collins et al. (2013), for example). See section 4.1 Horizontal grid.

Options for the horizontal grid **arrangement** property:

- **arakawa_a**
  - *The Arakawa A grid places mass- and velocity-related quantities at the same location on each grid cell.*
- **arakawa_b**
  - *The Arakawa B grid places velocity-related quantities at the corners of mass cells.*
- **arakawa_c**
  - *The Arakawa C grid places velocity-related quantities at the centres of mass cell edges, such that each component is perpendicular to its edge.*
- **arakawa_d**
  - *The Arakawa D grid places velocity-related quantities at the centres of mass cell edges, such that each component is tangential to its edge.*
- **arakawa_e**
  - *The Arakawa E grid places mass-related quantities at the centres of velocity cell edges.*

7.8. **horizontal_units** CV

Physical units of the horizontal grid **resolution_x** and **resolution_y** property values. See section 4.1 Horizontal grid.

Options for the horizontal grid **horizontal_units** property:

- **km**
  - *kilometre (unit for length).*
- **degree**
  - *degrees (unit for angular measure).*

7.9. **truncation_method** CV

Horizontal grid truncation method. A truncation method describes the technique used to truncate the spherical harmonic representation of a spectral model. See section 4.1 Horizontal grid.

Options for the horizontal grid **truncation_method** property:

- **triangular**
  - *Triangular truncation.*
- **rhomboidal**
  - *Rhomboidal truncation.*

7.10. **nominal_resolution** CV

Horizontal grid nominal resolutions. A nominal resolution (in km) characterizes the resolution of the grid as a function of the value of the **mean_resolution_km** property. See section 4.1 Horizontal grid.

Options for the horizontal grid **nominal_resolution** property:

mean_resolution_km, R	nominal_resolution
$0.036 \le R < 0.072$	**0.05 km**
$0.072 \le R < 0.16$	**0.1 km**
$0.16 \le R < 0.36$	**0.25 km**
$0.36 \le R < 0.72$	**0.5 km**
$0.72 \le R < 1.6$	**1 km**
$1.6 \le R < 3.6$	**2.5 km**
$3.6 \le R < 7.2$	**5 km**

7.2 ≤ R < 16	**10 km**
16 ≤ R < 36	**25 km**
36 ≤ R < 72	**50 km**
72 ≤ R < 160	**100 km**
160 ≤ R < 360	**250 km**
360 ≤ R < 720	**500 km**
720 ≤ R < 1600	**1000 km**
1600 ≤ R < 3600	**2500 km**
3600 ≤ R < 7200	**5000 km**
7200 ≤ R < 16000	**10000 km**

7.11. **coordinate** CV

Vertical grid coordinate types. A coordinate type describes the vertical coordinate reference system. The coordinate types are all CF standard names (except where indicated) with the same definitions. See section 4.2 Vertical grid.

Options for the vertical grid **coordinate** property:

- **none**
  - *(Not a standard name) There is no vertical dimension.*
- **height**
  - *Height is the vertical distance above the earth's surface.*
- **geopotential_height**
  - *Geopotential height is the geopotential divided by the standard acceleration due to gravity.*
- **air_pressure**
  - *Air pressure is the pressure that exists in the medium of air.*
- **air_potential_temperature**
  - *Air potential temperature is the temperature a parcel of air would have if moved dry adiabatically to a standard pressure.*
- **atmosphere_ln_pressure_coordinate**
  - *Parametric atmosphere natural log pressure coordinate.*
- **atmosphere_sigma_coordinate**
  - *Parametric atmosphere sigma coordinate.*
- **atmosphere_hybrid_sigma_pressure_coordinate**
  - *Parametric atmosphere hybrid sigma pressure coordinate.*
- **atmosphere_hybrid_height_coordinate**
  - *Parametric atmosphere hybrid height coordinate.*
- **atmosphere_sleve_coordinate**

- *Parametric atmosphere smooth vertical level coordinate.*
- **depth**
  - *Depth is the vertical distance below the earth's surface.*
- **sea_water_pressure**
  - *Sea water pressure is the pressure that exists in the medium of sea water.*
- **sea_water_potential_temperature**
  - *Sea water potential temperature is the temperature a parcel of sea water would have if moved adiabatically to sea level pressure.*
- **ocean_sigma_coordinate**
  - *Parametric ocean sigma coordinate.*
- **ocean_s_coordinate**
  - *Parametric ocean s-coordinate.*
- **ocean_s_coordinate_g1**
  - *Parametric ocean s-coordinate, generic form 1.*
- **ocean_s_coordinate_g2**
  - *Parametric ocean s-coordinate, generic form 2.*
- **ocean_sigma_z_coordinate**
  - *Parametric ocean sigma over z coordinate.*
- **ocean_double_sigma_coordinate**
  - *Parametric ocean double sigma coordinate.*
- **land_ice_sigma_coordinate**
  - *Land ice (glaciers, ice-caps and ice-sheets resting on bedrock and also includes ice-shelves) sigma coordinate.*
- **z***
  - *(Not a standard name) The z* coordinate of Adcroft and Campin (2004).*

7.12. **vertical_units** CV

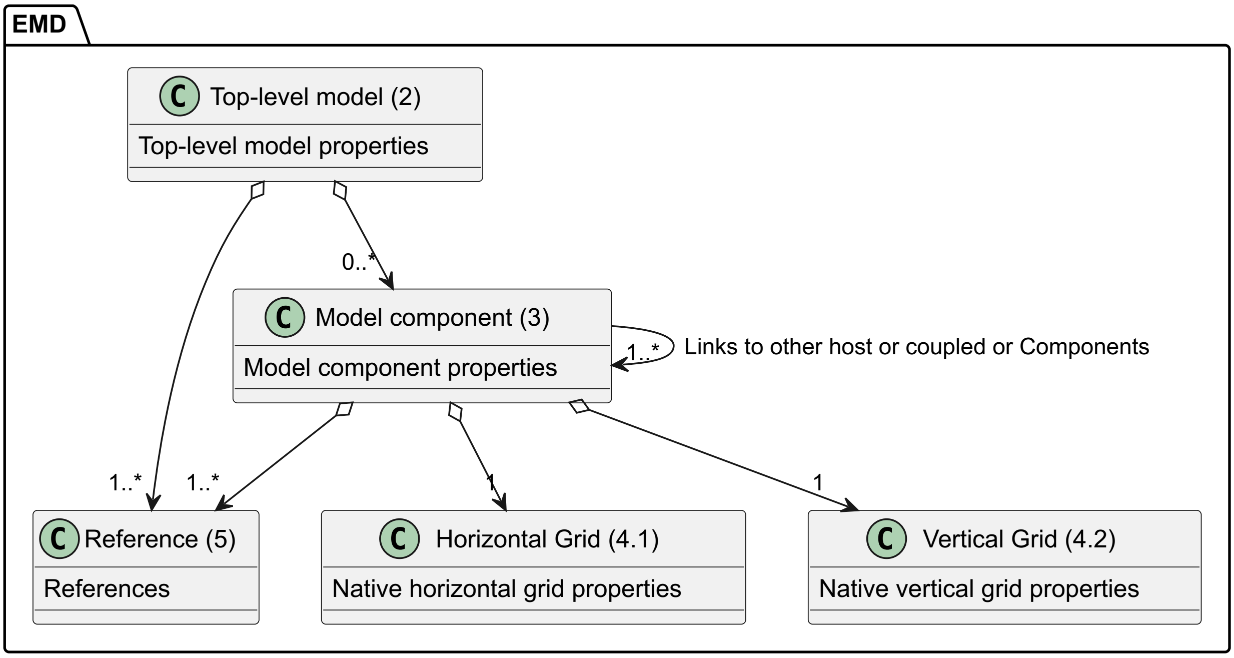
Physical units of the vertical grid **bottom_layer_thickness**, **top_layer_thickness**, and **top_of_model** property values. See section 4.2 Vertical grid.

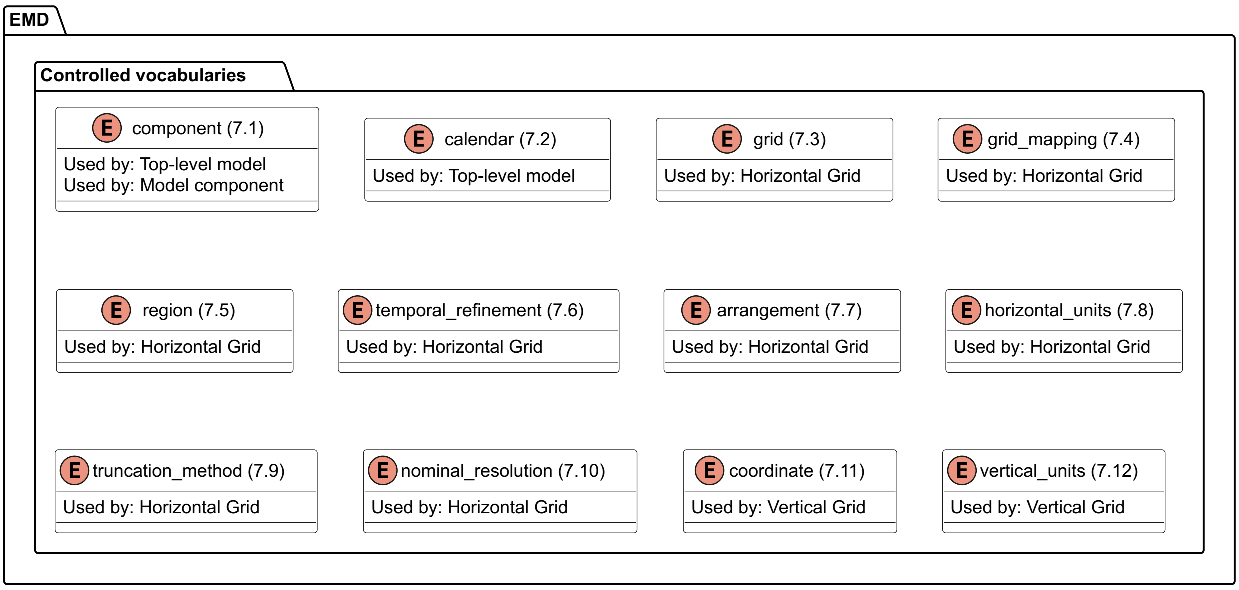
Options for the vertical grid **vertical_units** property:

- **m**
  - *metre (unit for length).*
- **Pa**
  - *pascal (unit for pressure).*
- **K**
  - *kelvin (unit for temperature).*

8. EMD data model

The EMD may be represented by the following class diagram:





The numbers in brackets refer to the sections of this document where the class (C) or enumeration (E) is fully defined, and each enumeration also specifies which classes make use of it.

Bibliography

Adcroft, Alistair & Campin, Jean-Michel. (2004). **Rescaled height coordinates for accurate representation of free-surface flows in ocean circulation models**. Ocean Modelling. Volume 7, Issues 3–4, Pages 269-284. https://doi.org/10.1016/j.ocemod.2003.09.003

Balaji, V. & Liang, Zhi. (2007). **Gridspec: A standard for the description of grids used in Earth System models**. https://www.researchgate.net/publication/228641121

S. N. Collins, R. S. James, P. Ray, K. Chen, A. Lassman, and J. Brownlee (2013): **Grids in Numerical Weather and Climate Models', Climate Change and Regional/Local Responses**. InTech, May 22, 2013. doi: http://dx.doi.org/10.5772/55922

Dunne, J. P., Hewitt, H. T., Arblaster, J., Bonou, F., Boucher, O., Cavazos, T., Durack, P. J., Hassler, B., Juckes, M., Miyakawa, T., Mizielinski, M., Naik, V., Nicholls, Z., O'Rourke, E., Pincus, R., Sanderson, B. M., Simpson, I. R., and Taylor, K. E. (2024): **An evolving Coupled Model Intercomparison Project phase 7 (CMIP7) and Fast Track in support of future climate assessment**, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3874

Durack, P. J., Taylor, K. E., Mizielinski, M., Doutriaux, C., Nadeau, D., & Juckes, M. (2025). **CMIP6 Controlled Vocabularies (CVs) (6.2.58.76)**. Zenodo. https://doi.org/10.5281/zenodo.14657960

Eaton, B., Gregory, J., Drach, B., Taylor, K., Hankin, S., Caron, J., Signell, R., Bentley, P., Rappa, G., Höck, H., Pamment, A., Juckes, M., Raspaud, M., Blower, J., Horne, R., Whiteaker, T., Blodgett, D., Zender, C., Lee, D., … Bartholomew, S. L. (2024). **NetCDF Climate and Forecast (CF) Metadata Conventions**. CF Community. https://doi.org/10.5281/zenodo.14274886

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E. (2016). **Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization**, Geosci. Model Dev., 9, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016

Lawrence, B. N., Balaji, V., Bentley, P., Callaghan, S., DeLuca, C., Denvil, S., Devine, G., Elkington, M., Ford, R. W., Guilyardi, E., Lautenschlager, M., Morgan, M., Moine, M.-P., Murphy, S., Pascoe, C., Ramthun, H., Slavin, P., Steenman-Clark, L., Toussaint, F., Treshansky, A., and Valcke, S. (2012). **Describing Earth system simulations with the Metafor CIM**. Geosci. Model Dev., 5, 1493–1500, https://doi.org/10.5194/gmd-5-1493-2012

Masson, D., and R. Knutti (2011). **Climate model genealogy**. *Geophys. Res. Lett.*, 38, L08703, https://doi.org/10.1029/2011GL046864

Taylor, K. E., Gleckler, P. J., Stouffer, R. J., Meehl, G. A., AchutaRao, K., Covey, C. C., Fiorino, M., Latif, M., McAvaney, B., Mitchell, J., Phillips, T. J., & Sperber, K. R. (2009). **CMIP3 Model Standard Output. In Program for Climate Model Diagnosis and Intercomparison**. Zenodo. https://doi.org/10.5281/zenodo.12765216

Taylor, K. E., Balaji, V., Hankin, S., Juckes, M., Lawrence, B., & Pascoe, S. (2012). **CMIP5 Data Reference Syntax (DRS) and Controlled Vocabularies (CVs). In Program for Climate Model Diagnosis and Intercomparison**. Zenodo. https://doi.org/10.5281/zenodo.12764404

Taylor, K. E., Juckes, M., Balaji, V., Cinquini, L., Denvil, S., Durack, P. J., Elkington, M., Guilyardi, E., Kharin, S., Lautenschlager, M., Lawrence, B., Nadeau, D., & Stockhause, M. (2018). **CMIP6 Model Output Metadata**

Requirements, Data Reference Syntax (DRS) and Controlled Vocabularies (CVs). In Program for Climate Model Diagnosis and Intercomparison. Zenodo. https://doi.org/10.5281/zenodo.12768887

CF standard name table: http://cfconventions.org/Data/cf-standard-names/current/build/cf-standard-name-table.html

Python code for calculating the representative resolution: https://pcmdi.github.io/nominal_resolution/html/index.html