CMIP6 Model Documentation

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Documentation Contents

1 Key Properties

Atmosphere key properties

1.1.1 Top level properties

Atmosphere key properties

1.1.1.1 Name *

Name of atmos model code

ARPEGE-Climat Version 6.3

1.1.1.2 Keywords *

Keywords associated with atmos model code

ARPEGE-Climat, dynamical core, cloud parameterization, turbulence parameterization, convection parameterization, gravity wave parameterization

1.1.1.3 Overview *

Overview of atmos model.

ARPEGE-Climat Version 6.3 is the atmospheric component of the CNRM climate and Earth System models (CNRM-CM6-1 and CNRM-ESM2-1). It is based on the cycle 37 of the ARPEGE/IFS model (declared in 2010), developed under a collaboration between Mto-France and ECMWF. ARPEGE-Climat shares a large part of its physics and dynamics with its NWP counterpart ARPEGE used operationnally at Mto-France. In comparison to ARPEGE-Climat Version 5.1 used for the CMIP5 exercice in CNRM-CM5.1, most of the atmospheric physics has been updated or revisited (Roehrig et al. 2019, Voldoire et al. 2019). For the surface, it is coupled to the SURFEX platform (Decharme et al. 2019).

1.1.1.4 Model Family *

Type of atmospheric model.

☐ AGCM - Atmospheric General Circulation Model

☐ ARCM - Atmospheric Regional Climate Model

☐ Other - please specify:

1.1.1.5 Basic Approximations *

Basic approximations made in the atmosphere.

☒ Primitive equations

☐ Non-hydrostatic

☐ Anelastic

☒ Boussinesq

☒ Hydrostatic

☐ Quasi-hydrostatic

☐ Other - please specify:

1.2.1 Resolution

Characteristics of the model resolution

1.2.1.1 Horizontal Resolution Name *

This is a string usually used by the modelling group to describe the resolution of the model grid, e.g. T42, N48.

T127

1.2.1.2 Canonical Horizontal Resolution *

Expression quoted for gross comparisons of resolution, e.g. 2.5 x 3.75 degrees lat-lon.

Roughly 150x150 km (1.4x1.4 degrees lat-lon at the equator)

1.2.1.3 Range Horizontal Resolution *

Range of horizontal resolution with spatial details, eg. 1 deg (Equator) - 0.5 deg

Roughly 150 km (reduced gaussian grid)

1.2.1.4 Number Of Vertical Levels *

Number of vertical levels resolved on the computational grid.

91

1.2.1.5 High Top *

Does the atmosphere have a high-top? High-Top atmospheres have a fully resolved stratosphere with a model top above the stratopause.

☐ True ☐ False

1.3.1 Timestepping

Characteristics of the atmosphere model time stepping

1.3.1.1 Timestep Dynamics *

Timestep for the dynamics in seconds

900

1.3.1.2 Timestep Shortwave Radiative Transfer

Timestep for the shortwave radiative transfer in seconds.

3600

1.3.1.3 Timestep Longwave Radiative Transfer

Timestep for the longwave radiative transfer in seconds.

3600

1.4.1 Orography

Characteristics of the model orography

1.4.1.1 Type *

Type of orographic representation.

- [ ] Fixed: present day
- [ ] Fixed: modified - Provide details of modification below
- [ ] Other - please specify:

1.4.1.2 Modified

If the orography type is modified describe the adaptation.

Select MULTIPLE options:

- [ ] Related to ice sheets
- [ ] Related to tectonics
- [ ] Modified mean
- [ ] Modified variance if taken into account in model (cf gravity waves)
- [ ] Other - please specify:

1.4.1.3 Time-varying

Describe any time varying orographic change

Enter TEXT:

1.5.1 Tuning Applied

Tuning methodology for atmospheric component

1.5.1.1 Description *

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

A significant part of the parameterization internal parameters, especially for the moist physics, were first guessed using single-column simulations of a few case studies (mostly shallow and deep convection). Then other relevant parameters (especially those regarding cloud microphysics and cloud radiative properties) were further tuned to achieve reasonable present-day top-of-atmosphere and surface radiative fluxes, using CERES data as an observational target. A specific attention

was also given to precipitation (e.g., seasonal climatologies, daily distribution over several regions - references: GPCP/TRMM), clouds (climatologies of cloud radiative effects, cloud amount - references: CERES, CloudSat/CALIPSO), low- and upper-level large-scale circulations (seasonal climatologies - reference: ERA-Interim), and some aspects of the variability (e.g., QBO).

1.5.1.2 Global Mean Metrics Used

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

Shortwave and longwave radiative fluxes at the top of the atmosphere and at the surface of the ocean, shortwave and longwave cloud radiative effects

1.5.1.3 Regional Metrics Used

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

Seasonal climatologies of precipitation, seasonal climatologies of the large-scale circulation (wind at 850 and 200hPa, mean sea level pressure), annual climatology of cloud amount and cloud radiative effect, daily precipitation distribution over tropical land and tropical ocean and several continental areas of the midlatitudes.

1.5.1.4 Trend Metrics Used

List observed trend metrics used in tuning model/component

Enter COMMA SEPARATED list:

2 Grid

Atmosphere grid

2.1.1 Top level properties

Atmosphere grid

2.1.1.1 Name

Name of grid in atmos model.

T127 triangular trunction and equivalent gaussian grid

2.1.1.2 Overview

Overview of grid in atmos model.

ARPEGE-Climat uses a reduced T127 gaussian grid and the equivalent spectral T127 triangular trunction, depending on the computations (Hortal and Simmons, 1991).

2.1.2 Horizontal

Atmosphere discretisation in the horizontal

2.1.2.1 Scheme Type *

Horizontal discretisation type

- ☒ Spectral
- ☒ Fixed grid
- ☐ Other - please specify:

2.1.2.2 Scheme Method *

Horizontal discretisation method

Select SINGLE option:

- ☐ Finite elements
- ☐ Finite volumes
- ☐ Finite difference
- ☐ Centered finite difference

2.1.2.3 Scheme Order *

Horizontal discretisation function order

- ☐ Second
- ☐ Third

- [ ] Fourth
- [ ] Other - please specify:

2.1.2.4 Horizontal Pole

Horizontal discretisation pole singularity treatment

- [ ] Filter
- [ ] Pole rotation
- [ ] Artificial island
- [ ] Other - please specify:

2.1.2.5 Grid Type *

Horizontal grid type

- [x] Gaussian
- [ ] Latitude-Longitude
- [ ] Cubed-Sphere
- [ ] Icosahedral
- [ ] Other - please specify:

2.1.3 Vertical

Atmosphere discretisation in the vertical

2.1.3.1 Coordinate Type *

Type of vertical coordinate system

Select MULTIPLE options:

- [ ] Isobaric - Vertical coordinate on pressure levels
- [ ] Sigma - Allows vertical coordinate to follow model terrain
- [ ] Hybrid sigma-pressure - Sigma system near terrain and isobaric above
- [ ] Hybrid pressure
- [ ] Vertically lagrangian
- [ ] Other - please specify:

3 Dynamical Core

Characteristics of the dynamical core

3.1.1 Top level properties

Characteristics of the dynamical core

3.1.1.1 Name

Commonly used name for the dynamical core in atmos model.

Two-time-level semi-lagrangian semi-implicit scheme

3.1.1.2 Overview

Overview of characteristics of the dynamical core in atmos model.

The time discretization is based on a two-time-level semi-Lagrangian semi-implicit numerical integration scheme (e.g., Ct and Staniforth, 1988). The non-linear terms appearing in the right-hand side of the primitive equations are averaged along the trajectory using their interpolation at the trajectory mid- and departure points. The scheme uses 32-point quasi-cubic interpolations (linear interpolation along the edges of the stencil, fully cubic in the interior see Ritchie et al., 1995). Interpolation are also quasi-monotone for all model advected variables (Bermejo and Staniforth, 1992), except the vertical interpolations involved in the momentum and thermodynamic equations. The semi-Lagrangian dynamical core is not fully conservative (e.g., Lucarini and Ragone, 2011). A local mass fixer algorithm based on Bermejo and Conde (2002) is applied to specific humidity and microphysical species (Diamantakis and Flemming, 2014). A global and uniform conservation procedure for the model atmosphere dry mass (additive correction on the surface pressure) and total water content (multiplicative correction on the surface precipitation flux) is also applied every time step.

3.1.1.3 Timestepping Type *

Timestepping framework type

- ☐ Adams-Bashforth
- ☐ Explicit
- ☐ Implicit
- ☒ Semi-implicit
- ☐ Leap frog
- ☐ Multi-step
- ☐ Runge Kutta fifth order
- ☐ Runge Kutta second order
- ☐ Runge Kutta third order
- ☐ Other - please specify:

3.1.1.4 Prognostic Variables *

List of the model prognostic variables

Select MULTIPLE options:

- ☐ Surface pressure
- ☐ Wind components
- ☐ Divergence/curl
- ☐ Temperature
- ☐ Potential temperature
- ☐ Total water
- ☐ Water vapour
- ☐ Water liquid
- ☐ Water ice
- ☐ Total water moments
- ☐ Clouds
- ☐ Radiation
- ☐ Other - please specify:

3.2.1 Top Boundary

Type of boundary layer at the top of the model

3.2.1.1 Top Boundary Condition *

Top boundary condition

Select SINGLE option:

- ☐ Sponge layer
- ☐ Radiation boundary condition
- ☐ Other - please specify:

3.2.1.2 Top Heat *

Top boundary heat treatment

Enter TEXT:

3.2.1.3 Top Wind *

Top boundary wind treatment

Enter TEXT:

3.3.1 Lateral Boundary

Type of lateral boundary condition (if the model is a regional model)

3.3.1.1 Condition

Type of lateral boundary condition

Select SINGLE option:

- [ ] Sponge layer
- [ ] Radiation boundary condition
- [ ] Other - please specify:

3.4.1 Diffusion Horizontal

Horizontal diffusion scheme

3.4.1.1 Scheme Name

Horizontal diffusion scheme name

Enter TEXT:

3.4.1.2 Scheme Method *

Horizontal diffusion scheme method

Select SINGLE option:

- [ ] Iterated Laplacian
- [ ] Bi-harmonic
- [ ] Other - please specify:

3.4.2 Tracers

Tracer advection scheme

3.4.2.1 Scheme Name

Tracer advection scheme name

Select SINGLE option:

- [ ] Heun

- [ ] Roe and VanLeer
- [ ] Roe and Superbee
- [ ] Prather
- [ ] UTOPIA
- [ ] Other - please specify:

3.4.2.2 Scheme Characteristics *

Tracer advection scheme characteristics

Select MULTIPLE options:

- [ ] Eulerian
- [ ] Modified Euler
- [ ] Lagrangian
- [ ] Semi-Lagrangian
- [ ] Cubic semi-Lagrangian
- [ ] Quintic semi-Lagrangian
- [ ] Mass-conserving
- [ ] Finite volume
- [ ] Flux-corrected
- [ ] Linear
- [ ] Quadratic
- [ ] Quartic
- [ ] Other - please specify:

3.4.2.3 Conserved Quantities *

Tracer advection scheme conserved quantities

Select MULTIPLE options:

- [ ] Dry mass
- [ ] Tracer mass
- [ ] Other - please specify:

3.4.2.4 Conservation Method *

Tracer advection scheme conservation method

Select SINGLE option:

- ☐ Conservation fixer
- ☐ Priestley algorithm
- ☐ Other - please specify:

3.4.3 Momentum

Momentum advection scheme

3.4.3.1 Scheme Name

Momentum advection schemes name

Select SINGLE option:

- ☐ VanLeer
- ☐ Janjic
- ☐ SUPG (Streamline Upwind Petrov-Galerkin)
- ☐ Other - please specify:

3.4.3.2 Scheme Characteristics *

Momentum advection scheme characteristics

Select MULTIPLE options:

- ☐ 2nd order
- ☐ 4th order
- ☐ Cell-centred
- ☐ Staggered grid
- ☐ Semi-staggered grid
- ☐ Other - please specify:

3.4.3.3 Scheme Staggering Type *

Momentum advection scheme staggering type

Select SINGLE option:

- ☐ Arakawa B-grid
- ☐ Arakawa C-grid
- ☐ Arakawa D-grid
- ☐ Arakawa E-grid

☐ Other - please specify:

3.4.3.4 Conserved Quantities *

Momentum advection scheme conserved quantities

Select MULTIPLE options:

☐ Angular momentum

☐ Horizontal momentum

☐ Enstrophy

☐ Mass

☐ Total energy

☐ Vorticity

☐ Other - please specify:

3.4.3.5 Conservation Method *

Momentum advection scheme conservation method

Select SINGLE option:

☐ Conservation fixer

☐ Other - please specify:

4 Radiation

Characteristics of the atmosphere radiation process

4.1.1 Top level properties

Characteristics of the atmosphere radiation process

4.1.1.1 Name

Commonly used name for the radiation in atmos model.

RRTMG for the longwave and Fouquart-Morcrette for the shortwave

4.1.1.2 Overview

Overview of characteristics of the atmosphere radiation process in atmos model.

The longwave radiation scheme is based on the version of the Rapid Radiation Transfer Model (RRTM, Mlawer et al. 1997) optimized for GCM, and included in the cycle 37 of the ARPEGE/IFS system (very close to that in the cycle 32, Morcrette et al. The RRTM scheme follows the two-stream approach and computes upward and downward radiative fluxes in 16 spectral bands encompassing the 10-3000 cm-1 range. The parameterization uses the correlated-k approach with 140 g-points (the number per spectral band depends on the absorption coefficient variations within this band and on the spectral band contribution to the total flux). It includes line absorption by H2O, CO2 , O3 , CH4 , N2O, CFC-11, CFC-12 and CCl4 based on the HITRAN 1996 spectrocospic data base (Rothman et al., 1998) and on the CKD 2.2 water vapor continuum model (Clough et al. 1989). The shortwave radiation scheme, originally developed by Fouquart and Bonnel (1980) and which further evolved in the IFS system until its cycle 32r2 (Morcrette et al., 2008), integrates the fluxes over the whole shortwave spectrum between 200 and 4000 nm. The scheme includes Rayleigh scattering, absorption by water vapor and ozone, both varying in space and time, and by CO2, N2O, CO, CH4 and O2, which are treated as uniformly mixed gases. The parameterization resolved the radiative transfer equations in 6 spectral bands, three bands being in the UV and visible spectral range (185-250, 250-440 and 440-690 nm) and three bands covering the near infrared range (690-1190, 1190-2380 and 2380-4000 nm).

4.1.1.3 Aerosols *

Aerosols whose radiative effect is taken into account in the atmosphere model

- [x] Sulphate
- [ ] Nitrate
- [x] Sea salt
- [x] Dust
- [ ] Ice
- [x] Organic
- [ ] BC - 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 particle
- [ ] Other - please specify:

4.2.1 Shortwave Radiation

Properties of the shortwave radiation scheme

4.2.1.1 Name

Commonly used name for the shortwave radiation scheme

Fouquart-Morcrette (IFS cycle 32r2)

4.2.1.2 Spectral Integration *

Shortwave radiation scheme spectral integration

- [x] Wide-band model
- [ ] Correlated-k
- [ ] Exponential sum fitting
- [ ] Other - please specify:

4.2.1.3 Transport Calculation *

Shortwave radiation transport calculation methods

- [x] Two-stream
- [ ] Layer interaction
- [ ] Bulk - Highly parameterised methods that use bulk expressions
- [ ] Adaptive - Exploits spatial and temporal correlations in optical characteristics
- [ ] Multi-stream
- [ ] Other - please specify:

4.2.1.4 Spectral Intervals *

Shortwave radiation scheme number of spectral intervals

6

4.2.1.5 General Interactions *

General radiative interactions e.g. with aerosols, cloud ice and cloud water

- [x] Emission/absorption,

☒ Scattering

☐ Other - please specify:

4.3.1 Shortwave GHG

Representation of greenhouse gases in the shortwave radiation scheme

4.3.1.1 Greenhouse Gas Complexity *

Complexity of greenhouse gases whose shortwave radiative effects are taken into account in the atmosphere model

☐ CO2 - Carbon Dioxide

☐ CH4 - Methane

☐ N2O - Nitrous Oxide

☐ CFC-11 eq - Summarize the effect of non CO2, CH4, N2O and CFC-12 gases with an equivalence concentration of CFC-11

☐ CFC-12 eq - Summarize the radiative effect of the Ozone Depleating Substances, ODSs, with a CFC-12 equivalence concentration

☐ HFC-134a eq - Summarize the radiative effect of other fluorinated gases with a HFC-134a equivalence concentration

☐ Explicit ODSs - Explicit representation of Ozone Depleting Substances e.g. CFCs, HCFCs and Halons

☐ Explicit other fluorinated gases - Explicit representation of other fluorinated gases e.g. HFCs and PFCs

☒ O3

☒ H2O

☐ Other - please specify:

4.3.1.2 ODS

Ozone depleting substances whose shortwave radiative effects are explicitly taken into account in the atmosphere model

Select MULTIPLE options:

☐ CFC-12 - CFC

☐ CFC-11 - CFC

☐ CFC-113 - CFC

☐ CFC-114 - CFC

☐ CFC-115 - CFC

☐ HCFC-22 - HCFC

☐ HCFC-141b - HCFC

- [ ] HCFC-142b - HCFC
- [ ] Halon-1211 - Halon
- [ ] Halon-1301 - Halon
- [ ] Halon-2402 - Halon
- [ ] Methyl chloroform - CH3CCl3
- [ ] Carbon tetrachloride - CCl4
- [ ] Methyl chloride - CH3Cl
- [ ] Methylene chloride - CH2Cl2
- [ ] Chloroform - CHCl3
- [ ] Methyl bromide - Ch3Br
- [ ] Other - please specify:

4.3.1.3 Other Flourinated Gases

Other flourinated gases whose shortwave radiative effects are explicitly taken into account in the atmosphere model

Select MULTIPLE options:

- [ ] HFC-134a - HFC
- [ ] HFC-23 - HFC
- [ ] HFC-32 - HFC
- [ ] HFC-125 - HFC
- [ ] HFC-143a - HFC
- [ ] HFC-152a - HFC
- [ ] HFC-227ea - HFC
- [ ] HFC-236fa - HFC
- [ ] HFC-245fa - HFC
- [ ] HFC-365mfc - HFC
- [ ] HFC-43-10mee - HFC
- [ ] CF4 - PFC
- [ ] C2F6 - PFC
- [ ] C3F8 - PFC
- [ ] C4F10 - PFC
- [ ] C5F12 - PFC

☐ C6F14 - PFC

☐ C7F16 - PFC

☐ C8F18 - PFC

☐ C-C4F8 - PFC

☐ NF3

☐ SF6

☐ SO2F2

☐ Other - please specify:

4.4.1 Shortwave Cloud Ice

Shortwave radiative properties of ice crystals in clouds

4.4.1.1 Physical Representation *

Physical representation of cloud ice crystals in the shortwave radiation scheme

☐ Bi-modal size distribution - Small mode diameters: a few tens of microns, large mode diameters: typically hundreds of microns

☐ Ensemble of ice crystals - Complex shapes represented with an ensemble of symmetric shapes

☐ Mean projected area - Randomly oriented irregular ice crystals present a greater mean projected area than spheres

☐ Ice water path - Integrated ice water path through the cloud kg m-2

☐ Crystal asymmetry

☐ Crystal aspect ratio

☒ Effective crystal radius

☐ Other - please specify:

4.4.1.2 Optical Methods *

Optical methods applicable to cloud ice crystals in the shortwave radiation scheme

☐ T-matrix - For non-spherical particles

☐ Geometric optics - For non-spherical particles

☐ Finite difference time domain (FDTD) - For non-spherical particles

☐ Mie theory - For spherical particles

☐ Anomalous diffraction approximation

☐ Other - please specify:

4.5.1 Shortwave Cloud Liquid

Shortwave radiative properties of liquid droplets in clouds

4.5.1.1 Physical Representation *

Physical representation of cloud liquid droplets in the shortwave radiation scheme

- [ ] Cloud droplet number concentration - CDNC
- [x] Effective cloud droplet radii
- [ ] Droplet size distribution
- [ ] Liquid water path - Integrated liquid water path through the cloud kg m-2
- [ ] Other - please specify:

4.5.1.2 Optical Methods *

Optical methods applicable to cloud liquid droplets in the shortwave radiation scheme

- [ ] Geometric optics - For non-spherical particles
- [ ] Mie theory - For spherical particles
- [ ] Other - please specify:

4.6.1 Shortwave Cloud Inhomogeneity

Cloud inhomogeneity in the shortwave radiation scheme

4.6.1.1 Cloud Inhomogeneity *

Method for taking into account horizontal cloud inhomogeneity

- [ ] Monte Carlo Independent Column Approximation - McICA
- [ ] Triplecloud - Regions of clear sky, optically thin cloud and optically thick cloud, Shonk et al 2010
- [x] Analytic
- [ ] Other - please specify:

4.7.1 Shortwave Aerosols

Shortwave radiative properties of aerosols

4.7.1.1 Physical Representation *

Physical representation of aerosols in the shortwave radiation scheme

- [ ] Number concentration
- [ ] Effective radii

- [x] Size distribution
- [x] Asymmetry
- [ ] Aspect ratio
- [ ] Mixing state - For shortwave radiative interaction
- [ ] Other - please specify:

4.7.1.2 Optical Methods *

Optical methods applicable to aerosols in the shortwave radiation scheme

- [ ] T-matrix - For non-spherical particles
- [ ] Geometric optics - For non-spherical particles
- [ ] Finite difference time domain (FDTD) - For non-spherical particles
- [ ] Mie theory - For spherical particles
- [ ] Anomalous diffraction approximation
- [ ] Other - please specify:

4.8.1 Longwave Radiation

Properties of the longwave radiation scheme

4.8.1.1 Name

Commonly used name for the longwave radiation scheme.

RRTMG

4.8.1.2 Spectral Integration *

Longwave radiation scheme spectral integration

- [ ] Wide-band model
- [x] Correlated-k
- [ ] Exponential sum fitting
- [ ] Other - please specify:

4.8.1.3 Transport Calculation *

Longwave radiation transport calculation methods

- [x] Two-stream
- [ ] Layer interaction
- [ ] Bulk - Highly parameterised methods that use bulk expressions

☐ Adaptive - Exploits spatial and temporal correlations in optical characteristics

☐ Multi-stream

☐ Other - please specify:

4.8.1.4 Spectral Intervals *

Longwave radiation scheme number of spectral intervals

16

4.8.1.5 General Interactions *

General radiative interactions e.g. with aerosols, cloud ice and cloud water

☒ Emission/absorption,

☒ Scattering

☐ Other - please specify:

4.9.1 Longwave GHG

Representation of greenhouse gases in the longwave radiation scheme

4.9.1.1 Greenhouse Gas Complexity *

Complexity of greenhouse gases whose longwave radiative effects are taken into account in the atmosphere model

☐ CO2 - Carbon Dioxide

☐ CH4 - Methane

☐ N2O - Nitrous Oxide

☐ CFC-11 eq - Summarize the effect of non CO2, CH4, N2O and CFC-12 gases with an equivalence concentration of CFC-11

☐ CFC-12 eq - Summarize the radiative effect of the Ozone Depleating Substances, ODSs, with a CFC-12 equivalence concentration

☐ HFC-134a eq - Summarize the radiative effect of other fluorinated gases with a HFC-134a equivalence concentration

☐ Explicit ODSs - Explicit representation of Ozone Depleting Substances e.g. CFCs, HCFCs and Halons

☐ Explicit other fluorinated gases - Explicit representation of other fluorinated gases e.g. HFCs and PFCs

☒ O3

☒ H2O

☐ Other - please specify:

4.9.1.2 ODS

Ozone depleting substances whose longwave radiative effects are explicitly taken into account in the atmosphere model

Select MULTIPLE options:

- ☐ CFC-12 - CFC
- ☐ CFC-11 - CFC
- ☐ CFC-113 - CFC
- ☐ CFC-114 - CFC
- ☐ CFC-115 - CFC
- ☐ HCFC-22 - HCFC
- ☐ HCFC-141b - HCFC
- ☐ HCFC-142b - HCFC
- ☐ Halon-1211 - Halon
- ☐ Halon-1301 - Halon
- ☐ Halon-2402 - Halon
- ☐ Methyl chloroform - CH3CCl3
- ☐ Carbon tetrachloride - CCl4
- ☐ Methyl chloride - CH3Cl
- ☐ Methylene chloride - CH2Cl2
- ☐ Chloroform - CHCl3
- ☐ Methyl bromide - Ch3Br
- ☐ Other - please specify:

4.9.1.3 Other Flourinated Gases

Other flourinated gases whose longwave radiative effects are explicitly taken into account in the atmosphere model

Select MULTIPLE options:

- ☐ HFC-134a - HFC
- ☐ HFC-23 - HFC
- ☐ HFC-32 - HFC
- ☐ HFC-125 - HFC
- ☐ HFC-143a - HFC
- ☐ HFC-152a - HFC

- [ ] HFC-227ea - HFC
- [ ] HFC-236fa - HFC
- [ ] HFC-245fa - HFC
- [ ] HFC-365mfc - HFC
- [ ] HFC-43-10mee - HFC
- [ ] CF4 - PFC
- [ ] C2F6 - PFC
- [ ] C3F8 - PFC
- [ ] C4F10 - PFC
- [ ] C5F12 - PFC
- [ ] C6F14 - PFC
- [ ] C7F16 - PFC
- [ ] C8F18 - PFC
- [ ] C-C4F8 - PFC
- [ ] NF3
- [ ] SF6
- [ ] SO2F2
- [ ] Other - please specify:

4.10.1 Longwave Cloud Ice

Longwave radiative properties of ice crystals in clouds

4.10.1.1 Physical Reprenstation *

Physical representation of cloud ice crystals in the longwave radiation scheme

- [ ] Bi-modal size distribution - Small mode diameters: a few tens of microns, large mode diameters: typically hundreds of microns
- [ ] Ensemble of ice crystals - Complex shapes represented with an ensemble of symmetric shapes
- [ ] Mean projected area - Randomly oriented irregular ice crystals present a greater mean projected area than spheres
- [ ] Ice water path - Integrated ice water path through the cloud kg m-2
- [ ] Crystal asymmetry
- [ ] Crystal aspect ratio
- [x] Effective crystal radius

☐ Other - please specify:

4.10.1.2 Optical Methods *

Optical methods applicable to cloud ice crystals in the longwave radiation scheme

☐ T-matrix - For non-spherical particles

☐ Geometric optics - For non-spherical particles

☐ Finite difference time domain (FDTD) - For non-spherical particles

☐ Mie theory - For spherical particles

☐ Anomalous diffraction approximation

☐ Other - please specify:

4.11.1 Longwave Cloud Liquid

Longwave radiative properties of liquid droplets in clouds

4.11.1.1 Physical Representation *

Physical representation of cloud liquid droplets in the longwave radiation scheme

☐ Cloud droplet number concentration - CDNC

☒ Effective cloud droplet radii

☐ Droplet size distribution

☐ Liquid water path - Integrated liquid water path through the cloud kg m-2

☐ Other - please specify:

4.11.1.2 Optical Methods *

Optical methods applicable to cloud liquid droplets in the longwave radiation scheme

☐ Geometric optics - For non-spherical particles

☐ Mie theory - For spherical particles

☐ Other - please specify:

4.12.1 Longwave Cloud Inhomogeneity

Cloud inhomogeneity in the longwave radiation scheme

4.12.1.1 Cloud Inhomogeneity *

Method for taking into account horizontal cloud inhomogeneity

☐ Monte Carlo Independent Column Approximation - McICA

- [ ] Triplecloud - Regions of clear sky, optically thin cloud and optically thick cloud, Shonk et al 2010
- [x] Analytic
- [ ] Other - please specify:

4.13.1 Longwave Aerosols

Longwave radiative properties of aerosols

4.13.1.1 Physical Representation *

Physical representation of aerosols in the longwave radiation scheme

- [ ] Number concentration
- [ ] Effective radii
- [x] Size distribution
- [ ] Asymmetry
- [ ] Aspect ratio
- [ ] Mixing state - For shortwave radiative interaction
- [ ] Other - please specify:

4.13.1.2 Optical Methods *

Optical methods applicable to aerosols in the longwave radiation scheme

Select MULTIPLE options:

- [ ] T-matrix - For non-spherical particles
- [ ] Geometric optics - For non-spherical particles
- [ ] Finite difference time domain (FDTD) - For non-spherical particles
- [ ] Mie theory - For spherical particles
- [ ] Anomalous diffraction approximation
- [ ] Other - please specify:

5 Turbulence Convection

Atmosphere Convective Turbulence and Clouds

5.1.1 Top level properties

Atmosphere Convective Turbulence and Clouds

5.1.1.1 Name

Commonly used name for the turbulence convection in atmos model.

PCMT for convection and CBR for turbulence

5.1.1.2 Overview

Overview of atmosphere convective turbulence and clouds in atmos model.

The turbulence scheme mainly follows the approach of Cuxart et al. (2000), considering additional effect of condensation. The mixing-length is non-local based on the work of Bougeault and Lacarrere (1989). Dry, moist and precipitating convection are represented with a unified mass-flux framework, based on the work of Piriou, Gueremy, and Bouteloup (2018). It follows the ideas of Gueremy (2011) for the convective profile and those of Piriou et al. (2007) which proposed to explicitly separate the convective vertical transport from the convective mi- crophysical processes.

5.2.1 Boundary Layer Turbulence

Properties of the boundary layer turbulence scheme

5.2.1.1 Scheme Name

Boundary layer turbulence scheme name

- [x] Mellor-Yamada
- [ ] Holtslag-Boville
- [ ] EDMF - Combined Eddy Diffusivity Mass-Flux
- [ ] Other - please specify:

5.2.1.2 Scheme Type *

Boundary layer turbulence scheme type

- [x] TKE prognostic
- [ ] TKE diagnostic
- [x] TKE coupled with water
- [ ] Vertical profile of Kz
- [x] Non-local diffusion
- [x] Monin-Obukhov similarity

- [ ] Coastal Buddy Scheme - Separate components for coastal near surface winds over ocean and land
- [x] Coupled with convection
- [ ] Coupled with gravity waves
- [ ] Depth capped at cloud base - Boundary layer capped at cloud base when convection is diagnosed
- [ ] Other - please specify:

5.2.1.3 Closure Order *

Boundary layer turbulence scheme closure order

2

5.2.1.4 Counter Gradient *

Uses boundary layer turbulence scheme counter gradient

- [ ] True
- [ ] False

5.3.1 Deep Convection

Properties of the deep convection scheme

5.3.1.1 Scheme Name

Deep convection scheme name

PCMT (Prognostic Condensate Microphysics and Transport)

5.3.1.2 Scheme Type *

Deep convection scheme type

- [x] Mass-flux
- [ ] Adjustment
- [ ] Plume ensemble - Zhang-McFarlane
- [ ] Other - please specify:

5.3.1.3 Scheme Method *

Deep convection scheme method

- [ ] CAPE - Mass flux determined by CAPE, convectively available potential energy.
- [ ] Bulk - A bulk mass flux scheme is used
- [ ] Ensemble - Summation over an ensemble of convective clouds with differing characteristics
- [ ] CAPE/WFN based - CAPE-Cloud Work Function: Based on the quasi-equilibrium of the free troposphere

- [ ] TKE/CIN based - TKE-Convective Inhibition: Based on the quasi-equilibrium of the boundary layer
- [ ] Other - please specify:

5.3.1.4 Processes *

Physical processes taken into account in the parameterisation of deep convection

- [ ] Vertical momentum transport
- [x] Convective momentum transport
- [x] Entrainment
- [x] Detrainment
- [x] Penetrative convection
- [x] Updrafts
- [x] Downdrafts
- [ ] Radiative effect of anvils
- [x] Re-evaporation of convective precipitation
- [ ] Other - please specify:

5.3.1.5 Microphysics

Microphysics scheme for deep convection. Microphysical processes directly control the amount of detrainment of cloud hydrometeor and water vapor from updrafts

- [ ] Tuning parameter based
- [x] Single moment
- [ ] Two moment
- [ ] Other - please specify:

5.4.1 Shallow Convection

Properties of the shallow convection scheme

5.4.1.1 Scheme Name

Shallow convection scheme name

PCMT

5.4.1.2 Scheme Type *

Shallow convection scheme type

- [x] Mass-flux

☐ Cumulus-capped boundary layer

☐ Other - please specify:

5.4.1.3 Scheme Method *

Shallow convection scheme method

☒ Same as deep (unified)

☐ Included in boundary layer turbulence

☐ Separate diagnosis - Deep and Shallow convection schemes use different thermodynamic closure criteria

☐ Other - please specify:

5.4.1.4 Processes *

Physical processes taken into account in the parameterisation of shallow convection

☐ Convective momentum transport

☐ Entrainment

☐ Detrainment

☐ Penetrative convection

☐ Re-evaporation of convective precipitation

☐ Other - please specify:

5.4.1.5 Microphysics

Microphysics scheme for shallow convection

Select MULTIPLE options:

☐ Tuning parameter based

☐ Single moment

☐ Two moment

☐ Other - please specify:

6 Microphysics Precipitation

Large Scale Cloud Microphysics and Precipitation

6.1.1 Top level properties

Large Scale Cloud Microphysics and Precipitation

6.1.1.1 Name

Commonly used name for the microphysics precipitation in atmos model.

Lopez (2002) scheme

6.1.1.2 Overview

Overview of large scale cloud microphysics and precipitation in atmos model.

The microphysical scheme used in ARPEGE-Climat 6.3 was first developed by Lopez (2002). It mainly follows the approach proposed in Fowler et al. (1996), but with a reduced complexity. A prognostic treatment of the specific mass of four microphysical species (cloud liquid water, cloud ice, rain and snow) is adopted, with two main arguments for using prognostic equations to describe precipitating condensates: (i) given the relatively short time step of the model (15 min), it provides a finer description of the time evolution of the precipitation vertical distribution and associated processes (especially for snow) and (ii) it will allows a more direct approach for future data assimilation of precipitation data in the ARPEGE numerical weather prediction version, so that its use in climate application contributes to the seamless approach seeked at M to-France (Bouteloup et al. 2011).

6.2.1 Large Scale Precipitation

Properties of the large scale precipitation scheme

6.2.1.1 Scheme Name

Commonly used name of the large scale precipitation parameterisation scheme

Lopez (2002) scheme

6.2.1.2 Hydrometeors *

Precipitating hydrometeors taken into account in the large scale precipitation scheme

- [x] Liquid rain
- [x] Snow
- [ ] Hail
- [ ] Graupel
- [ ] Other - please specify:

6.3.1 Large Scale Cloud Microphysics

Properties of the large scale cloud microphysics scheme

6.3.1.1 Scheme Name

Commonly used name of the microphysics parameterisation scheme used for large scale clouds.

Lopez (2002) scheme

6.3.1.2 Processes *

Large scale cloud microphysics processes

Select MULTIPLE options:

- [ ] Mixed phase
- [ ] Cloud droplets
- [ ] Cloud ice
- [ ] Ice nucleation
- [ ] Water vapour deposition
- [ ] Effect of raindrops
- [ ] Effect of snow
- [ ] Effect of graupel
- [ ] Other - please specify:

7 Cloud Scheme

Characteristics of the cloud scheme

7.1.1 Top level properties

Characteristics of the cloud scheme

7.1.1.1 Name

Commonly used name for the cloud scheme in atmos model.

Bougeault (1981)

7.1.1.2 Overview

Overview of characteristics of the cloud scheme in atmos model.

The cloud scheme is based on a statistical joint distribution of qt and thetal following Sommeria and Deardorff (1977), Bougeault (1981) and Ricard and Royer (1993). It is coupled to the turbulence scheme to compute the second-order moment of qt and thetal.

7.1.1.3 Scheme Type *

Describes the type(s) of cloud scheme: prognostic, diagnostic, other.

☐ Prognostic

☒ Diagnostic

☐ Other - please specify:

7.1.1.4 Uses Separate Treatment *

Description for when different cloud schemes are used for different types of clouds e.g. convective, stratiform and boundary layer)

Yes

7.1.1.5 Processes *

Processes included in the cloud scheme

☐ Entrainment

☐ Detrainment

☒ Bulk cloud

☐ Other - please specify:

7.1.1.6 Prognostic Variables

List the prognostic variables used by the cloud scheme, if applicable.

☐ Cloud amount

- [x] Liquid
- [x] Ice
- [ ] Rain
- [ ] Snow
- [ ] Cloud droplet number concentration - To document the use of two-moment cloud microphysics schemes
- [ ] Ice crystal number concentration - To document the use of two-moment cloud microphysics schemes
- [ ] Other - please specify:

7.1.1.7 Atmos Coupling

Atmosphere components that are linked to the cloud scheme

- [x] Atmosphere_radiation
- [x] Atmosphere_microphysics_precipitation
- [x] Atmosphere_turbulence_convection
- [ ] Atmosphere_gravity_waves
- [ ] Atmosphere_natural_forcing
- [x] Atmosphere_observation_simulation

7.2.1 Optical Cloud Properties

Optical cloud properties

7.2.1.1 Cloud Overlap Method

Method for taking into account overlapping of cloud layers

- [ ] Random
- [ ] Maximum
- [ ] Maximum-random - Combination of maximum and random overlap between clouds
- [ ] Exponential
- [ ] Other - please specify:

7.2.1.2 Cloud Inhomogeneity

Method for taking into account cloud inhomogeneity

Constant cloud inhomogeneity parameter

7.3.1 Sub Grid Scale Water Distribution

Sub-grid scale water distribution

7.3.1.1 Type *

Sub-grid scale water distribution type

- ☐ Prognostic
- ☒ Diagnostic

7.3.1.2 Function Name *

Sub-grid scale water distribution function name

Bougeault (1981)

7.3.1.3 Function Order *

Sub-grid scale water distribution function type

2

7.3.1.4 Convection Coupling *

Sub-grid scale water distribution coupling with convection

- ☐ Coupled with deep
- ☐ Coupled with shallow
- ☒ Not coupled with convection

7.4.1 Sub Grid Scale Ice Distribution

Sub-grid scale ice distribution

7.4.1.1 Type *

Sub-grid scale ice distribution type

- ☐ Prognostic
- ☒ Diagnostic

7.4.1.2 Function Name *

Sub-grid scale ice distribution function name

Bougeault (1981)

7.4.1.3 Function Order *

Sub-grid scale ice distribution function type

2

7.4.1.4 Convection Coupling *

Sub-grid scale ice distribution coupling with convection

Select MULTIPLE options:

☐ Coupled with deep

☐ Coupled with shallow

☐ Not coupled with convection

8 Observation Simulation

Characteristics of observation simulation

8.1.1 Top level properties

Characteristics of observation simulation

8.1.1.1 Name

Commonly used name for the observation simulation in atmos model.

COSP: CFMIP Observation Simulator Package

8.1.1.2 Overview

Overview of characteristics of observation simulation in atmos model.

COSP version 1.4.1 was used inline for all CMIP6 experiments

8.2.1 Isscp Attributes

ISSCP Characteristics

8.2.1.1 Top Height Estimation Method

Cloud simulator ISSCP top height estimation methodUo

- ☐ No adjustment
- ☒ IR brightness
- ☒ Visible optical depth
- ☐ Other - please specify:

8.2.1.2 Top Height Direction

Cloud simulator ISSCP top height direction

- ☐ Lowest altitude level
- ☒ Highest altitude level
- ☐ Other - please specify:

8.3.1 Cosp Attributes

CFMIP Observational Simulator Package attributes

8.3.1.1 Run Configuration

Cloud simulator COSP run configuration

☒ Inline

☐ Offline

☐ Other - please specify:

8.3.1.2 Number Of Grid Points

Cloud simulator COSP number of grid points

Enter INTEGER value:

8.3.1.3 Number Of Sub Columns

Cloud simulator COSP number of sub-cloumns used to simulate sub-grid variability

20

8.3.1.4 Number Of Levels

Cloud simulator COSP number of levels

40

8.4.1 Radar Inputs

Characteristics of the cloud radar simulator

8.4.1.1 Frequency

Cloud simulator radar frequency (Hz)

94

8.4.1.2 Type

Cloud simulator radar type

☐ Surface

☒ Space borne

☐ Other - please specify:

8.4.1.3 Gas Absorption

Cloud simulator radar uses gas absorption

☐ True ☐ False

8.4.1.4 Effective Radius

Cloud simulator radar uses effective radius

☐ True ☐ False

8.5.1 Lidar Inputs

Characteristics of the cloud lidar simulator

8.5.1.1 Ice Types

Cloud simulator lidar ice type

☒ Ice spheres

☐ Ice non-spherical

☐ Other - please specify:

8.5.1.2 Overlap

Cloud simulator lidar overlap

Select MULTIPLE options:

☐ Max

☐ Random

☐ Other - please specify:

9 Gravity Waves

Characteristics of the parameterised gravity waves in the atmosphere, whether from orography or other sources

9.1.1 Top level properties

Characteristics of the parameterised gravity waves in the atmosphere, whether from orography or other sources

9.1.1.1 Name

Commonly used name for the gravity waves in atmos model.

Geleyn scheme for orographic GW, Lott scheme for non-orographic GW

9.1.1.2 Overview

Overview of characteristics of the parameterised gravity waves in the atmosphere, whether from orography or other sources in atmos model.

The orographic gravity wave drag parameterization used in ARPEGE-Climat 6.3 is described in Dqu et al. (1994) and Geleyn et al. (1994), with a few updates introduced by Catry et al. (2008). Parameterization of non-orographic gravity waves follows the works of Lott et al (2012), Lott and Guez (2013) and de la Camara et al (2013).

9.1.1.3 Sponge Layer *

Sponge layer in the upper levels in order to avoid gravity wave reflection at the top.

- [x] Rayleigh friction
- [ ] Diffusive sponge layer
- [ ] Other - please specify:

9.1.1.4 Background *

Background wave distribution

- [ ] Continuous spectrum
- [x] Discrete spectrum
- [ ] Other - please specify:

9.1.1.5 Subgrid Scale Orography *

Subgrid scale orography effects taken into account.

- [x] Effect on drag
- [x] Effect on lifting
- [ ] Enhanced topography - To enhance the generation of long waves in the atmosphere

- [ ] Other - please specify:

9.2.1 Orographic Gravity Waves

Gravity waves generated due to the presence of orography

9.2.1.1 Name

Commonly used name for the orographic gravity wave scheme

Geleyn scheme

9.2.1.2 Source Mechanisms *

Orographic gravity wave source mechanisms

- [x] Linear mountain waves
- [ ] Hydraulic jump
- [ ] Envelope orography
- [x] Low level flow blocking
- [x] Statistical sub-grid scale variance
- [ ] Other - please specify:

9.2.1.3 Calculation Method *

Orographic gravity wave calculation method

- [x] Non-linear calculation
- [ ] More than two cardinal directions
- [ ] Other - please specify:

9.2.1.4 Propagation Scheme *

Orographic gravity wave propogation scheme

- [ ] Linear theory
- [x] Non-linear theory
- [ ] Includes boundary layer ducting
- [ ] Other - please specify:

9.2.1.5 Dissipation Scheme *

Orographic gravity wave dissipation scheme

- [ ] Total wave

- [ ] Single wave
- [ ] Spectral
- [ ] Linear
- [x] Wave saturation vs Richardson number
- [ ] Other - please specify:

9.3.1 Non Orographic Gravity Waves

Gravity waves generated by non-orographic processes.

9.3.1.1 Name

Commonly used name for the non-orographic gravity wave scheme

Lott scheme

9.3.1.2 Source Mechanisms *

Non-orographic gravity wave source mechanisms

- [x] Convection
- [ ] Precipitation
- [ ] Background spectrum
- [ ] Other - please specify:

9.3.1.3 Calculation Method *

Non-orographic gravity wave calculation method

- [x] Spatially dependent
- [x] Temporally dependent

9.3.1.4 Propagation Scheme *

Non-orographic gravity wave propogation scheme

- [x] Linear theory
- [ ] Non-linear theory
- [ ] Other - please specify:

9.3.1.5 Dissipation Scheme *

Non-orographic gravity wave dissipation scheme

Select SINGLE option:

- ☐ Total wave
- ☐ Single wave
- ☐ Spectral
- ☐ Linear
- ☐ Wave saturation vs Richardson number
- ☐ Other - please specify:

10 Natural Forcing

Natural forcing: solar and volcanic.

10.1.1 Top level properties

Natural forcing: solar and volcanic.

10.1.1.1 Name

Commonly used name for the natural forcing in atmos model.

CMIP6

10.1.1.2 Overview

Overview of natural forcing: solar and volcanic. in atmos model.

The CMIP6 specification were used for the natural forcings of ARPEGE-Climat 6.3

10.2.1 Solar Pathways

Pathways for solar forcing of the atmosphere

10.2.1.1 Pathways *

Pathways for the solar forcing of the atmosphere model domain

☐ SW radiation - Shortwave solar spectral irradiance.

☐ Precipitating energetic particles - Precipitating energetic particles from the sun (predominantly protons) and the magnetosphere (predominantly electrons) affect the ionization levels in the polar middle and upper atmosphere, leading to significant changes of the chemical composition

☐ Cosmic rays - Cosmic rays are the main source of ionization in the troposphere and lower stratosphere.

☐ Other - please specify:

10.3.1 Solar Constant

Solar constant and top of atmosphere insolation characteristics

10.3.1.1 Type *

Time adaptation of the solar constant.

☐ Fixed

☒ Transient

10.3.1.2 Fixed Value

If the solar constant is fixed, enter the value of the solar constant (W m-2).

Enter FLOAT value:

10.3.1.3 Transient Characteristics

Solar constant transient characteristics (W m-2)

Monthly average of the bulk solar constant, following CMIP6 specification.

10.4.1 Orbital Parameters

Orbital parameters and top of atmosphere insolation characteristics

10.4.1.1 Type *

Type of orbital parameter

☐ Fixed

☒ Transient

10.4.1.2 Fixed Reference Date

Reference date for fixed orbital parameters (yyyy)

Enter INTEGER value:

10.4.1.3 Transient Method

Description of transient orbital parameters

Enter TEXT:

10.4.1.4 Computation Method

Method used for computing orbital parameters.

Select SINGLE option:

☐ Berger 1978

☐ Laskar 2004

☐ Other - please specify:

10.5.1 Insolation Ozone

Impact of solar insolation on stratospheric ozone

10.5.1.1 Solar Ozone Impact *

Does top of atmosphere insolation impact on stratospheric ozone?

☐ True ☐ False

10.6.1 Volcanoes Treatment

Characteristics and treatment of volcanic forcing in the atmosphere

10.6.1.1 Volcanoes Characteristics *

Description of how the volcanic forcing is taken into account in the atmosphere.

ARPEGE-Climat uses the volcanoe aerosol optical depth following the CMIP6 specifications (monthly average). The mass of aerosol is then redistributed along the vertical with a profile constant in time and space. It is considered as a class of stratospheric aerosols.

10.6.1.2 Volcanoes Implementation *

How volcanic effects are modeled in the atmosphere.

Select SINGLE option:

☐ High frequency solar constant anomaly

☐ Stratospheric aerosols optical thickness

☐ Other - please specify: