

ANS – Numerical Applications and Scenarios Division

INGV-CMCC Carbon (ICC): A Carbon Cycle Earth System Model

Fogli, P.G. (1), E. Manzini (1,2), M. Vichi (1,2), A. Alessandri (1), L. Patara (1), S. Gualdi (1,2), E. Scoccimarro (2), S. Masina (1,2), and A. Navarra (1,2)

*(1) Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC),
ANS Division, Bologna, Italy*

(2) Istituto Nazionale di Geofisica e Vulcanologia (INGV), Bologna, Italy

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Summary

This document describes the CMCC Earth System Model (ESM) for the representation of the carbon cycle in the atmosphere, land, and ocean system. The structure of the report follows the software architecture of the full system. It is intended to give a technical description of the numerical models at the base of the ESM, and how they are coupled with each other.

Keywords: Climate models, atmosphere, ocean, sea ice, vegetation, biogeochemistry.

Address for correspondence:

Pier Giuseppe Fogli

Centro Euro-Mediterraneo per i Cambiamenti Climatici

Viale Aldo Moro, 44. 40127 Bologna, Italy.

E-mail: fogli@bo.ingv.it

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1. Introduction

The INGV-CMCC Carbon Earth System Model (ICC-ESM) is designed to simulate the carbon cycle for climate change research. The ESM consists of two main components: the atmosphere, land and vegetation (ECHAM5/SILVA) model and the ocean, sea ice, and biogeochemistry (OPA8.2/LIM/PELAGOS) model. Each of these two main components respectively consisting of two sub-components, for the representation of physical processes (atmosphere: ECHAM5; ocean and sea ice: OPA8.2/LIM) and processes related to the biological and geochemical parts of the carbon cycle (land and vegetation: SILVA; ocean biogeochemistry: PELAGOS). See Figure 1 for the ESM structure summary.

The focus of the report is on documenting the development carried out to couple the various components, while we point to the relevant literature for the description of the models themselves. This report is aimed at technical experts and scientists, familiar with numerical general circulation models and their software codes, therefore specific introduction to the terminology used is avoided, to keep the report compact. The programming languages used for the models are FORTRAN and C.

The structure of the report follows the software architecture of the full system, consisting of three main aggregations of software codes: (1) the coupler, (2) the atmosphere, land and vegetation model, and (3) the ocean, sea ice and biogeochemistry model. Each aggregation of codes is separately compiled and produces its own executable file. The coupler executable file drives and manages the run carried out with the ESM.

The coupler, the newly developed biophysical interface, the ESM components and their internal coupling are reported in Section 2. The files with the initial and boundary conditions for the different model components together with their output and restart files are listed in Section 3.

2. ICC-ESM: Technical Description

2.1. Atmosphere-ocean interface

This part describes the exchange of energy, water, momentum and carbon between the atmosphere and the ocean, as implemented in the ECHAM5/SILVA and OPA8.2/LIM/PELAGOS models and carried out by the OASIS3 coupler, and as used in the ENSEMBLES scenario experiments.

To implement the exchange of information (variables, etc) for the biophysical coupling, the source codes of each model have been modified by means of pre-processor macros (Table 2 and Table), as detailed in the respective sections thereafter.

The boundary variables exchanged between the atmosphere and the ocean are the following (Figure 2):

Ocean-sea ice to atmosphere: (1) sea surface temperature; (2) sea ice concentration (also named sea ice cover and sea ice fraction); (3) sea ice thickness; (4) snow thickness over sea ice; and (5) CO₂ flux.

Atmosphere to ocean-sea ice: (1) solar heat flux; (2) non solar heat flux; (3) atmospheric water flux; (4) runoff; (5) snow fall; (6) horizontal wind stresses; (7) CO₂ partial pressure; and (8) 10 m wind speed modulus.

The coupling time step between the atmosphere and the ocean is currently one day.

Not used (therefore only mentioned here) but implemented and technically tested additional coupling features include the exchange of ocean currents (activated with the pre-processor macros number 9 of Table 1 and number 7 of Table 2), to provide a non zero bottom boundary condition for the vertical diffusion in the atmosphere, and an alternative coupling between the sea ice and the atmosphere, for which the sea ice albedo and temperature are passed to the atmosphere instead of the sea ice and snow thicknesses (macros number 10 of Table 1 and number 9 of Table 2).

2.1.1. Coupler

The tasks of the software named “coupler” consist of a number of operations related to the management of a simulation with two or more interacting models. Here, the models are the ECHAM5/SILVA model and the OPA8.2/LIM/PELAGOS model. The coupler software used is OASIS3 (Valcke, 2006). In the CMCC ESM, the software system for running such a simulation consists of three executable files, respectively coming from: ECHAM5/SILVA, OPA8.2/LIM/PELAGOS, and OASIS3. There is no direct communication between the two models, all communications occurring through the OASIS3 coupler.

To start the simulation, only the OASIS3 executable is launched through the `mpirun` command (UNIX) within the job-script (a shell script). Thereafter, OASIS3 launches the two models through the dynamic process management feature of the MPI2 library (routine `MPI Spawn`).

The OASIS3 coupler controls the run depending on information stored in the configuration file *namcouple*. Communication between the two models and the OASIS3 coupler is enabled by a set of library routines (the PSMILe library, part of OASIS3) based on the MPI2 library. The source codes of each model have been modified in order to include these routines. The compilation of these modifications is activated by pre-processor macros number 1 in Table 2 and number 2 in Table .

The OASIS3 configuration file *namcouple* specifies:

- How many models (executables) participate in the coupled run (2 for the ESM)
- How many processes (UNIX sense, virtual executables) have to be started for every model (1 for OPA8.2/LIM/PELAGOS, one or more depending on the platform for ECHAM5/SILVA)
- Run characteristics: run length, coupling time step, necessary files, communication method (MPI2), type of calendar in use (Gregorian, with leap years)

- Variables to be exchanged and the operations to be performed on them

Variables (boundary conditions) between the models are exchanged through OASIS3 at the coupling time step (synchronization point) during the simulation. The variables to be exchanged are accumulated over the coupling time step in their respective model and thereafter sent to OASIS3 at the coupling time step. The OASIS3 coupler performs a number of calculations on the received variables related to and including their interpolations between the respective surface grids of the models. To interpolate, OASIS3 uses the routines of the SCRIP library (Jones 1998). Thereafter, the coupler returns the manipulated variables to the target model.

2.1.2. Interface

Sea surface temperature

The sea surface temperature is computed by the OPA8.2 model. In the coupler, the sea surface temperature is interpolated using a distance-weighted interpolation and is converted from degree Celsius (used in OPA8.2) to Kelvin (used in ECHAM5). The field is extrapolated over continental area before the interpolation.

Sea-ice concentration

The sea ice concentration (adimensional cell fraction) is computed by the LIM model. In the coupler, the sea ice concentration is interpolated using a first-order conservative remapping (Jones 1999) that ensure the conservation of the total sea ice area.

Sea ice thickness and snow thickness over sea ice

The sea ice thickness (m) and snow thickness (m) over sea ice are calculated by the LIM model. In the coupler, the sea ice thickness and the snow thickness over sea ice are interpolated using a bilinear interpolation. The snow thickness (in meter) is converted in water equivalent (in meter, but using the snow / water density ratio) of snow over sea ice, as required by ECHAM5. Both fields are extrapolated over continental area before the interpolation.

Solar and non-solar heat fluxes

Net heat fluxes for sea ice and ocean (sea ice-free or open water) surfaces are computed by the ECHAM5 model:

$$F_H^k = F_{SW}^k + F_{LW}^k + F_{LH}^k + F_{SH}^k \quad (1)$$

where k is either i for sea ice or o for ocean, F_H is the total heat flux at the air-sea interface, F_{SW} is the net surface shortwave radiation, F_{LW} is the net surface longwave radiation, F_{LH} is the latent heat flux and F_{SH} is the sensible heat flux. Fluxes are in W m^{-2} . Positive values mean downward fluxes (i.e. from the atmosphere to the ocean/sea ice).

The OPA8.2/LIM model does not distinguish between longwave, latent and sensible heat fluxes. As a consequence, in ECHAM5 they are grouped together and the fields actually exchanged are the net solar heat flux ($F_S = F_{SW}$) and the non-solar heat flux ($F_{NS} = F_{LW} + F_{LH} + F_{SH}$):

$$F_H^k = F_S^k + F_{NS}^k \quad (2)$$

Note that the ECHAM5 model makes use of a fractional grid to represent the sea ice and ocean surface, in the sense that each component of the heat flux is computed for both a sea ice and an open water boundary conditions and then combined according to a sea ice / open water fractional mask. This fractional mask is derived from the sea ice concentration coming from the OPA8.2/LIM model and changing at every coupling time step. Therefore a total of 4 heat flux fields are exchanged from ECHAM5 to OPA8.2/LIM.

Solar and non-solar heat fluxes over ocean

In the coupler, the solar and non-solar heat fluxes over ocean are extrapolated over continental area and then interpolated using a bilinear interpolation. After the interpolation the fluxes are sent directly to the ocean/sea ice model.

The conservation of energy exchanged between the atmosphere and the ocean is imposed by computing the global integrals of the fluxes over the open water part of the no-land surface of the respective model, and thereafter correcting the fluxes received by OPA8.2, as here described.

The global integral of the solar and non solar fluxes over the open water part of the no-land bottom surface of the atmospheric model are computed on the atmospheric grid as:

$$I_{NS}^a = \int_{S^a} (1 - f_{si}^a) F_{NS}^a ds \quad (3)$$

$$I_S^a = \int_{S^a} (1 - f_{si}^a) F_S^a ds \quad (4)$$

where f_{si}^a is the sea ice fraction and S^a is the ocean area, both defined on the atmospheric grid. Given the limitations of the coupler (which currently does not allow to exchange single numbers), the integrals are sent as two additional fields with a constant value over the whole domain. Within the ocean model, the received interpolated non-solar flux (\tilde{F}_{NS}^o) on the ocean grid is corrected as following:

$$\Phi_{NS}^o = \tilde{F}_{NS}^o + C_{NS} \quad (5)$$

$$C_{NS} = \frac{I_{NS}^a - I_{NS}^o}{A^o} \quad (6)$$

where the integrals over the ocean grid are computed as:

$$I_{NS}^o = \int_{S^o} (1 - f_{si}^o) \tilde{F}_{NS}^o ds \quad (7)$$

$$A^o = \int_{S^o} (1 - f_{si}^o) ds \quad (8)$$

and f_{si}^o is the sea ice fraction on the ocean grid. Note that f_{si}^o is the updated sea ice fraction while f_{si}^a is the sea ice fraction exchanged at the previous coupling time step.

In the ocean model, the received solar heat flux (\tilde{F}_S^o) is corrected differently in order to avoid negative values:

$$\Phi_S^o = \gamma_S \tilde{F}_S^o \quad (9)$$

$$\gamma_S = I_S^o / I_S^a \quad (10)$$

where the integral of the solar heat flux over the ocean grid is computed as:

$$I_S^o = \int_{S^o} (1 - f_{si}^o) \tilde{F}_S^o ds \quad (11)$$

Solar and non solar heat fluxes over sea ice

In order to avoid the interpolation with unrealistic fluxes at the ocean/sea ice edge, fluxes over sea ice are extrapolated over ice-free ocean grid points before the interpolation, in the coupler. The coupler has been modified in order to re-compute the neighbor points and weights needed by the extrapolation at each coupling time step. This was necessary because the sea ice cover is different at each coupling time step and neighbor points and weights need to be updated accordingly. Normally, the coupler uses a numerical flag to identify the grid points involved in the extrapolation. The flag value is specified in the *namcouple* configuration file and is assigned at each masked grid point just before the extrapolation step. The mask used in the normal procedure is the land-sea mask and as a result only land points are marked for extrapolation. In order to mark the ice-free ocean grid points as well, these are pre-filled with the flag value in the atmospheric model just before the exchange with the coupler. In this way the coupler identifies ice-free ocean grid point as masked points taking them into account in the extrapolation step. Thereafter, the fluxes are interpolated using a bilinear interpolation. After the interpolation the fluxes are sent directly to the ocean/sea ice model. No energy conservation is imposed for the fluxes over sea ice.

Atmosphere water flux, runoff and snow fall

The atmosphere water flux computed from ECHAM5 and passed to the OPA8.2/LIM is:

$$F_w = E - P \quad (12)$$

where E is the evaporation and P is the total precipitation (liquid + solid) computed by the atmosphere model. The river runoff variable is passed from the atmosphere to the ocean/seaice model, but it is set to zero, because the hydrological model is not implemented in the atmosphere model. All the fluxes are in $\text{kg m}^{-2} \text{s}^{-1}$. Positive values mean downward fluxes.

In addition, the snow fall ($\text{kg m}^{-2} \text{s}^{-1}$) is also passed as a separate field (note that for the water mass balance it is already included in the total precipitation) because the sea ice model uses it both to make further sea ice and to calculate its contribution to the heat balance of the surface ocean (ice free surface, open water).

In the coupler, the water flux F_w and the snow fall fields are extrapolated over the continents and then interpolated using a bilinear interpolation. The global integrals over the no-land area of the water flux fields are conserved.

In OPA8.2, the conservation of the water mass is imposed by including a climatological river runoff (activated by macro number 4 of Table 2).

Horizontal wind stresses.

The flux of momentum is realized through the exchange of the zonal and meridional components of the surface wind stress (in Pa). The atmospheric model computes the wind stresses both on the sea ice and open water surfaces, for all no-land grid points. In the coupler, the wind stress fields are extrapolated over continents and interpolated using a bicubic interpolation.

CO₂ flux, CO₂ partial pressure, and wind speed

The closure of the atmosphere-ocean branch of the carbon cycle is achieved through the exchange of the CO₂ flux ($\text{kg m}^{-2} \text{s}^{-1}$) from the ocean to the atmosphere, and the exchange of the CO₂ partial pressure (μatm) and 10 m wind speed (m s^{-1}) from the atmosphere to the ocean (macro number 7 of Table 2 and macro 6 of Table).

The flux of CO₂ from the ocean is computed by PELAGOS (in *co2calc.f90* and *pelagos_step.F*), accumulated by OPA8.2 (in *stpcmo.F*) and exchanged through OASIS3 just like any other oceanic field. Once received by ECHAM5, the CO₂ flux enters in the 3D transported atmospheric CO₂ as a surface source term inside the vertical diffusion (*vdiff.f90*). Positive values of the flux mean CO₂ uptake by the ocean.

In the coupler, the CO₂ flux (from OPA8.2) is interpolated using a first order conservative remapping, to conserve its global integral, and the atmospheric CO₂ partial pressure and the wind speed at 10 m (both from ECHAM5) are extrapolated over land grid points and then interpolated using a bicubic interpolation.

2.2. Atmosphere, land and vegetation model

2.2.1. Atmosphere

The atmosphere general circulation model used in the ESM is ECHAM5 (Roeckner et al. 2003, 2006). The ECHAM5 model numerically solves the primitive equations for the general circulation of the atmosphere on a sphere. The dynamical part of ECHAM5 is formulated in spherical harmonics. The horizontal triangular truncation used in the CMCC ESM is T31. In the vertical, a flexible coordinate is used, enabling the ECHAM5 model to use either the usual terrain following sigma coordinate or a hybrid coordinate for which upper-level model surfaces flatten over steep terrain, becoming surfaces of constant pressure in the stratosphere. The CMCC ESM uses 19 vertical levels. Moist processes are treated in a different way using a mass conserving algorithm for the transport (Lin and Rood, 1996) of the different water species and potential chemical (and passive) tracers. The transport is determined on the Gaussian grid.

Changes with respect to the previous cycle, the ECHAM4 model, involve the physical basis of the representation of cloud and radiative processes and their interaction, the representation of orographic and non-orographic gravity wave drag, a consistent framework for the simulation of the troposphere and stratosphere. Other novel (more technical) features include a flux form advection scheme, tracers and aerosol interfaces for coupling with chemistry and aerosols models, scenario

handling and multiple fluxes at the surface for coupling with ocean and sea ice models. Technical software changes introduced in ECHAM5 have made the model more flexible compared to its predecessors. ECHAM5 has been tested on various platforms and it includes options like a single column version, a simple data assimilation (nudging), and coupling to a mixed layer ocean (Q-flux approach). A detailed description is reported in Roecker et al. (2003). Sensitivity of the ECHAM5 model to horizontal and vertical resolution in the troposphere and lowermost stratosphere is discussed in Roecker et al. (2006), the hydrological cycle in Hagemann et al. (2006), radiative fluxes in Wild and Roeckner (2006), and surface albedo and snow cover in Roesch and Roeckner (2006).

2.2.2. Land and vegetation

The Surface Interactive Land VegetAtion (SILVA, Alessandri 2006) model has been developed in order to suitably represent land surface processes and their associated variability. The SILVA model is designed for being used in coupled mode with an atmospheric general circulation model in order to represent the biophysical feedbacks between the land surface and the atmosphere. A precursor of the SILVA model including only the physical coupling was used in the ECHAM4 general circulation model (Alessandri et al. 2007). The biophysical version of the SILVA model, which includes also carbon and vegetation dynamics, is discussed in Alessandri et al. (2008, in preparation). In the following, a brief description of the main features of SILVA and its implementation in ECHAM5 are reported.

In the SILVA model, the parameterizations of the momentum, heat and water flux exchanges at the interface between the land-surface and the atmosphere have been developed following the SECHIBA (Schematisation des Echanges Hydriques a l'Interface entre la Biosphere et l'Atmosphere", Ducoudre et al. 1992) scheme approach. The vegetation and carbon dynamics and the CO₂ flux exchange have been developed using the core parameterizations of VEGAS (VEgetation-Global-Atmosphere-Soil, Zeng et al. 2004).

The SILVA model represents soil hydrology and thermodynamics, snow and vegetation processes relevant to climate. The model computes mechanistically surface characteristics such as albedo, roughness length, conductance and evapotranspiration as a function of the soil water content and of the vegetation state.

The characteristics of 4 Plant Functional Types (PFTs) have been implemented, in order to represent the vegetation diversity. Each PFT may be present simultaneously in one grid element (besides bare soil). This approach takes into account the subgrid-scale distribution of the vegetation types and is often referred to as "mosaic approach". This means that the surface fluxes (of momentum, water, energy and carbon respectively) are computed separately for each fractional surface cover. Then the total flux exchanged with the atmosphere is determined as an area-weighted average for each grid box.

The modeled terrestrial carbon cycle includes vegetation dynamics. It starts from photosynthetic carbon assimilation in the leaves and the allocation of this carbon into three vegetation carbon pools: leaf, root and wood. After accounting for respiration, the biomass turnover from these three vegetation carbon pools cascades into a fast soil carbon pool, an intermediate and a slow soil pool. Temperature and moisture dependent decomposition of these carbon pools returns carbon back into atmosphere.

2.2.3. *Coupling between the atmosphere and the land-vegetation*

At the interface between the atmosphere and the land, the coupling between SILVA and ECHAM5 is achieved by means of a fully implicit coupling numerical scheme for the water and energy fluxes. This scheme has been implemented with an energy-conserving “Neumann closure” of the atmospheric vertical diffusion at the surface (Polcher et al. 1998; Alessandri et al. 2007). The carbon exchanges between land and atmosphere are instead computed with an explicit coupling numerical scheme.

The closure of the land-atmosphere branch of the carbon cycle is achieved by coupling the land surface and vegetation SILVA model with ECHAM5; activating in ECHAM5 a 3-dimensional passive tracer for the transport of the atmospheric CO₂ concentration; and using the CO₂ tracer in the radiation scheme of ECHAM5.

The SILVA model consists of a set of subroutines, which implement the land surface and vegetation processes with its own I/O functionalities through the IOIPSL library (Polcher et al. 2001). The communication between SILVA and ECHAM5 takes place through a single subroutine where all the biophysical fields are exchanged. All the required modifications to the ECHAM5 source code are enabled through the pre-processor macro number 6 of Table 2. After compilation, SILVA can be switched on and off through the logical flag LLSVM in the *runcctl* namelist of ECHAM5. When SILVA is enabled the ECHAM5 original surface computations are bypassed.

In ECHAM5, two new modules were created for incorporating SILVA. The module `mo_memory_lsvm` (*mo_memory_lsvm.f90*) contains the definition of some diagnostic variables and sets up a new memory stream `lsvm` for their output. The module `mo_lsvm` (*mo_lsvm.f90*) defines some variables used for the exchange between ECHAM5 and SILVA and contains the routine `init_lsvm` that handles the initialization of the sub-model and the domain decomposition for the parallelization. `init_lsvm` is called from `scan1` (*scan1.f90*) during the initialization at the first model time step. The call to SILVA takes place during the vertical exchange computations inside the routine `vdiff` (*vdiff.f90*).

The activation of a passive tracer in ECHAM5 is done via *new_tracer* namelist, by specifying the name of the tracer, its units, its GRIB code and initial value. The physical processes (transport and mixing) to which the tracer is subject, the memory allocation and the I/O operations for the tracer are thereafter automatically handled by ECHAM5.

In ECHAM5, the radiation scheme may use different types of radiative agents, according to a flag that specifies how the agent is represented. In module `mo_radiation` (*mo_radiation.f90*), the case `ico2=1` has been implemented in order to represent the CO₂ as a varying 3-D tracer in the radiation scheme.

Note that SILVA uses the atmospheric CO₂ concentration and computes and saves the CO₂ flux (within the macro 6 of Table 2), while the inclusion of the flux in the tracer equation and the modification of the radiation scheme are part of macro 7 of Table 2.

2.2.4. *Coupling to the ocean, sea ice, and biogeochemistry model*

The routines dealing with the coupling of ECHAM5 to an ocean model are located in the module `mo_couple` (contained in the file *mo_couple.f90*). ECHAM5 receives the information about the coupling from OASIS3 as specified in the configuration file *namcouple* of OASIS3. The routines in

`mo_couple` have to be modified (via macros) to be coherent with the specification defined in the *namcouple* configuration file of OASIS3. These modifications are activated through a set of pre-processor macros (Table 2) by compiling the code.

In order to perform a coupled run with the physical core of the ESM, the ECHAM5 model needs: (1) the first 5 macros of Table 2 activated; and (2) the logical flag `LCOUPLE=.true.` in the *runcctl* namelist of the model code in the job-script.

For running the ESM with the closure of the carbon cycle active, in addition to the above recipe for the physical core, the ECHAM5 model needs: (3) the macro number 6 of Table 2; (4) the logical flag `LLSVM=.true.` in the *runcctl* namelist of the model code in the job-script; and (5) the macro number 7 of Table 2.

Points (3) and (4) are for activating SILVA, and point (5) for activating the CO₂ tracer and closing the atmosphere-land and atmosphere-ocean branches of the carbon cycle.

For running the ESM with prescribed atmospheric CO₂ concentration (without the closure of the carbon cycle), the ECHAM5 model needs: Points (1) to (4) as described above; and (5b) the macro number 8 of Table 2. The task of this latter macro is only the exchange of the CO₂ partial pressure and the 10 m wind speed from the atmosphere to the ocean (to enable PELAGOS to compute and save the CO₂ flux).

The ECHAM5 model employs a master-slave strategy for both the parallelization and the coupling. The master process (UNIX sense, one of the virtual executables) is the only process that communicates with OASIS3, gathers (scatters) the fields to be sent to (received from) the coupler at every coupling time step just before (after) the exchange.

At the beginning of a coupled run, the `control` routine (in *control.f90*) of ECHAM5 calls the routine `couple_init` (*mo_couple.f90*). Within the `couple_init` routine, the communication with OASIS3 is established, the information about the fields to be exchanged is received (sent by the coupler), and the partitioning of the fields is defined (by ECHAM5).

In ECHAM5, the exchange with the coupler takes place inside the main time integration loop in `stepon` (*stepon.f90*). At the beginning of this loop, the routine `couple_get_o2a` (*mo_couple.f90*) is called (task: receive the OPA8.2/LIM/PELAGOS fields from OASIS3) while near the end of the loop the routine `couple_put_a2o` (*mo_couple.f90*) is called (task: send the atmospheric accumulated fields to OASIS3). These routines are called at every model time step but the respective sending/receiving action is actually performed only at times which correspond to coupling time steps, as indicated in the file *namcouple* [see Valcke (2006) for details]. The fields coming from OASIS3 (the SST, the sea ice related fields and the CO₂ flux) directly fill the respective ECHAM5 variables following the call to `couple_get_o2a` (*mo_couple.f90*). The accumulation is performed by the routine `collect` (*collect.f90*) called at the end of the grid point computations in `physc` (*physc.f90*) when the heat and water fluxes, the wind stresses, the wind speed, and the CO₂ partial pressure have been updated.

2.3. Ocean, sea ice and biogeochemistry model

2.3.1. Ocean and sea ice

The ocean general circulation model (OGCM) used in the ESM is OPA8.2 (Océan Parallélisé version 8.2, Madec et al. 1999). OPA8.2 is a primitive equation model which is numerically solved on a global ocean curvilinear grid known as ORCA (Madec and Imbard 1996). ORCA2 has a resolution of 2 degrees of longitude and a variable mesh of 0.5-2 degrees of latitudes from the equator to the poles. The southern pole grid is also refined to resolve the circumpolar currents. The vertical grid has 31 levels (the 31st level is below the bottom) with variable layer depth and a constant 10 m step in the top 150 m.

Horizontal momentum is diffused with a Laplacian operator and a 2-D spatially-varying kinematic viscosity coefficient, which is reduced at the equator except close to the western boundaries. The horizontal diffusion of tracers is computed along the isopycnal surfaces as described in Madec et al. (1999) with a eddy diffusivity coefficient of $2000 \text{ m}^2 \text{ s}^{-1}$. The eddy-induced velocity parametrization (Gent and McWilliams 1990) is implemented with a coefficient that depends on the growth rate of baroclinic instabilities (it usually varies from $15 \text{ m}^2 \text{ s}^{-1}$ to $3000 \text{ m}^2 \text{ s}^{-1}$). Lateral boundary conditions are set to zero fluxes of heat and salt and no-slip conditions at the solid boundaries.

Vertical eddy diffusion of momentum and tracers is parameterized with a 1.5 turbulence closure model. The background minimum vertical eddy diffusivity is set to $1.2 \cdot 10^{-5} \text{ m}^2 \text{ s}^{-1}$. Double diffusivity of salt and temperature is also activated. In the case of vertical density instability, diffusivity is enhanced to $100 \text{ m}^2 \text{ s}^{-1}$ in order to parameterize convective adjustments. The bottom boundary conditions are set to zero for heat and salt, while a linear friction is applied on momentum. Temperature and salinity are restored to climatological values below the mixed layer in the Mediterranean and Red seas.

The model uses an implicit free surface instead of a rigid lid parameterization and the water fluxes are completed with climatological river run-off values.

The Louvain-la-Neuve sea Ice Model (LIM) is a thermodynamic-dynamic sea ice model directly coupled with OPA8.2. The version used in the ESM is LIM2, which is detailed in Fichefet and Morales Maqueda (1997, 1999) and Goosse and Fichefet (1999). The LIM implementation and its behavior in OPA8.2 is reported in Timmermann et al. (2005).

Sensible heat storage and vertical heat conduction within snow and ice are determined by a three-layer model (one layer for snow and two layers for ice). The vertical heat diffusion equation for snow and ice is solved by means of a fully implicit numerical scheme. The model allows for the presence of leads within the ice pack. Vertical and lateral growth/decay rates of the ice are obtained from prognostic energy budgets at both the bottom and surface boundaries of the snow-ice cover and in leads. When the load of snow is large enough to depress the snow-ice interface under the water level, seawater is supposed to infiltrate the entirety of the submerged snow and to freeze there, forming a snow ice cap.

For the momentum balance, sea ice is considered as a two-dimensional continuum in dynamical interaction with atmosphere and ocean. The physical fields that are advected (on a staggered Arakawa B-grid, as opposed to the C-grid used in OPA8.2, which implies a further on-line

interpolation of the ocean velocities) are the ice concentration, the snow volume per unit area, the ice volume per unit area, the snow enthalpy per unit area, the ice enthalpy per unit area, and the brine reservoir per unit area. A no-slip condition is imposed on land boundaries.

LIM is coupled with OPA8.2 every 6 time steps of the ocean (parameter `nfice` in the OPA *namelist*). The ocean state variables are thus accumulated and averaged at every ocean-sea ice coupling time step.

2.3.2. *Biogeochemistry*

The PELAgic biogeochemistry for Global Ocean Simulations model (PELAGOS, Vichi et al. 2007a,b) has been further extended to incorporate a full description of the dissolved inorganic carbon (DIC) dynamics and adequately simulate the ocean carbon cycle components relevant to climate change issues.

The PELAGOS model consists of the global ocean version of the Biogeochemical Flux Model (BFM, <http://bfm.cmcc.it>) and its coupling to the OPA ocean general circulation model. The marine ecosystem part of PELAGOS, as well as of the BFM, is a biomass-based set of differential equations based on the ERSEM approach to biogeochemical modeling (Baretta et al. 1995). The climatological features of the model have been analysed in a perpetual year context in Vichi et al. (2007b), while a biogeographic validation of inter-annual simulations is presented in Vichi et al. (2008, submitted). The version including the DIC dynamics and the computation of surface exchange fluxes is reported in Vichi et al. (in preparation).

The PELAGOS model is written in a generalized mathematical formulation that allows the description of lower trophic levels and major inorganic and organic components of the marine ecosystem from a unified functional perspective (Vichi et al. 2007a). The pelagic state variables of PELAGOS are three unicellular planktonic autotrophs (picophytoplankton, nanophytoplankton and diatoms), three zooplankton groups (nano-, micro- and meso-) and bacterioplankton. The other chemical functional families are nitrate, ammonium, orthophosphate, silicate, dissolved bioavailable iron, oxygen, carbon dioxide and dissolved and particulate (non-living) organic matter (POM, DOM), for a total of 44 state variables. The implementation of carbonate chemistry for the closure of the carbon cycle adds 2 dynamical (transported) variables that are total alkalinity and total dissolved inorganic carbon, and 5 diagnostic variables for the carbonate speciation (CO_2 , bicarbonate and carbonate concentrations, CO_2 partial pressure and pH).

2.3.3. *Coupling between the ocean and the biogeochemistry*

The biogeochemical model equations are discretized on the same grid of the OPA8.2 model. Advective terms are computed by means of a numerical scheme available in the OPA model for the transport of tracers (Foujols et al. 2000). The need for using positive-definite and monotonic advection schemes strongly affects the computational cost of the model. The advection of physical variables in OPA 8.2 is solved with a second-order centered differencing scheme. This scheme, however, does not satisfy any of the requirements of positiveness and monotonicity, therefore it cannot be used for the transport of biological variables. The advection scheme used for the PELAGOS variables is the Monotonic Upstream centered Scheme for Conservation Laws (MUSCL, Hourdin and Armengaud, 1999). Eddy-induced transport is not activated for the PELAGOS variables, because it creates numerical instabilities and negative concentrations. The

background eddy diffusivity coefficient is set to $10^{-6} \text{ m}^2 \text{ s}^{-1}$, which is about one order of magnitude lower than for the ocean active tracers (see file *orca2numerics.nml*).

The compilation of PELAGOS in OPA8.2 is enabled through the pre-processor macro number 5 of Table . After compilation, PELAGOS can be switched off through the variable `ndtttrc` in the *orca2numerics.nml* namelist, by setting `ndtttrc=0`.

The coupling between the biological and the transport terms is done with a time-splitting integration technique. First the biological reaction term is solved with a simple Euler-forward integration that gives an estimate of the local solution, which is thereafter integrated with the standard OPA numerics (but the modifications described above).

PELAGOS is computed every 4 time steps of the ocean model (variable `ndtttrc` in the *orca2numerics.nml* namelist) using the actual ocean state variables.

2.3.4. Coupling to the atmosphere model

The OPA8.2/LIM model obtains the information about the coupling by reading the namelist `NAMCPL` (inside the configuration file *namelist*) in the call to the routine `parlec` (*parlec.F*). The information contained in the `NAMCPL` namelist is the coupling frequency, number of the fields exchanged, and the list of the fields exchanged.

The initialization of a coupled run in OPA8.2/LIM is located in the routine `inicmo` (*inicmo.F*). Here OPA8.2/LIM model establishes the communication with OASIS3 and defines the fields to be exchanged.

The exchange with the coupler takes place inside the time integration loop and involves three routines, one for the send procedure to OASIS3 and two for the receive procedure: The fluxes from the atmosphere are received in the routine `flx` (*flx.F* and *flx.coupled.clio.h*) and the wind stresses are received in the routine `tau` (*tau.F* and *tau.coupled.clio.h*). The accumulation of the fields to be sent to the atmosphere and their sending is done in the routine `stpcmo` (*stpcmo.F*). All the sending/receiving actions are performed at the model time step that corresponds to the coupling time step. The information (in number of timesteps, coupling frequency) for the coupling time step is specified in `nexco` variable of the `NAMCPL` namelist and should be consistent with what specified in the *namcouple* configuration file of the OASIS3 coupler.

Within the OPA8.2/LIM model, the incoming fluxes are first used by the LIM seaice component, for computing the seaice evolution and other thermal calculations and then passed back to the main routines of the OPA8.2 model. Therefore, for grid-points of OPA8.2/LIM partially covered by seaice, the LIM model calculates the flux exchange within the seaice slab and produces a flux that is thereafter spatially averaged with the ice-free flux of that grid. The so averaged flux is then passed to the OPA8.2 model.

In order to perform a coupled run with the physical core of the ESM, the OPA8.2/LIM model needs: (1) macros 1 to 4 and macro 8 of Table activated; and (2) the `NAMCPL` namelist properly specified for this case.

For running the ESM with the closure of the carbon cycle active, the OPA8.2/LIM model needs: (1) macros 1 to 6 and macro 8 of Table activated; and (2) the `NAMCPL` namelist properly specified for this case.

For running the ESM with prescribed atmospheric CO₂ concentration (without the closure of the carbon cycle), the OPA8.2/LIM model needs also the first 6 macros and macro 8 of Table activated, but a different NAMCPL namelist. Specifically, the number of fields and their listing is different.

2.4. Code Structure

2.4.1. *Compiling environment*

The IC-C-ESM code is located in the ../ICCESM directory and is subdivided in the following 6 sections (directories, see Table 3):

1. Coupler component source (`oasis3`)
2. Atmospheric component source (`echam5`)
3. Ocean component source (`opa`)
4. Sea ice component source (`lim`)
5. Land surface and vegetation component source (`silva`)
6. Marine biogeochemistry component source (`pelagos`)

The model is designed to run on the NEC-SX6 vector supercomputer. The compilation can be done using NEC cross-compilers on a front-end machine mounting the NEC-SX6 filesystem.

In order to build the coupled model the following prerequisites are needed:
(i) the MPI library; (ii) the NetCDF library; (iii) the GNU make.

A set of makefile templates was created to manage the compilation process. These makefile templates are found in the following directories: `oasis3`, `echam5`, and `opa`. The user needs to modify these templates (minor changes for the definition of paths, compiler options, CPP macros, etc...) to set up the build environment, as described in the respective `README` file.

The OASIS3 coupler must be compiled first because the model components need modules and libraries provided by OASIS3. To compile OASIS3 follow the instructions found in the `README` file inside the `oasis3` directory (see Appendix).

Once OASIS3 is compiled the compilation of the model components can proceed in any order, even at the same time. The compilation of the ocean component is similar to that of the OASIS3 coupler as explained in the `README` file inside the `opa` directory. A slightly different procedure is needed to compile the atmospheric component as explained in the `README.coupled` file inside the `echam5` directory.

Three binary executables are generated at the end of the compilation process:

- (1) coupler (OASIS3) executable;
- (2) atmosphere - land surface - vegetation component (ECHAM5+SILVA) executable;
- (3) ocean – seaice - biogeochemistry component (OPA+LIM+PELAGOS) executable.

2.4.2. Running environment

The running environment is divided in 2 sections (directories):

1. experiment management (`../ICCESM/experiments/EXPID`)
2. experiment directory tree (`../EXPID`)

where `EXPID` indicates the generic name of the experiment.

Note that the experiment management directory tree `experiments/EXPID` is located in the `../ICCESM` main directory and that the `EXPID` subdirectories need to be created for every new experiment. The `../EXPID` directory is usually placed on a fast filesystem and must be organized as shown in Table 4 (the user must create the directory structure as show in the table).

The shell script `run_EXPID.sh`, located in the `experiments/EXPID` directory, is the one used to run the experiment. The script needs to have specified the environment variables of the experiment to be run.

A chain submission procedure is applied to avoid too long jobs on the computing platform. In our current configuration, the model is designed to run 1 month of simulation for each job submission. The information regarding the month to integrate after the first submission is stored in a text file named `EXPID.date` which is generated by the `run_EXPID.sh` script during the first submission. The `EXPID.date` file contains: year, month, day and number of months that have already been done.

The `run_EXPID.sh` script is submitted to the NEC-SX NQS batch system through the `qsub` command and executes the following steps:

1. Set the environment variables related to:
 - experiment name
 - model components name, spatial resolution, time step length
 - paths of the directory tree
 - number of processes to use in ECHAM5
 - experiment date and duration of the job (using as input the `EXPID.date` file) and of the entire simulation
2. Modify the namelists according to the job to run:
 - `namcouple` for the coupler
 - `namelist.echam` for the atmospheric component
 - `run.def` for the land surface and vegetation component
 - `namelist` for the ocean component
 - `run.param.li` for the sea-ice
 - `pelagos.nml` for the marine biogeochemistry component
3. Get the executables, their namelists, input and restart files in the scratch directory where the job will run
4. Launch the model
5. Save the output and restart files in the storage directories
6. Update the `EXPID.date` file for the next job
7. Resubmit itself to perform the next month (until the end of the experiment).

The executable launched by the `run_EXPID.sh` script is the coupler executable `OASIS3`. Thereafter, executable `OASIS3` starts the other 2 executables involved in the coupling according to the information stored in its namelist `namcouple` through the dynamic process management feature of `MPI2`.

3. Auxiliary Files

3.1. Initial and Boundary Conditions

Atmospheric component input files:

T31L19_jan_spec.nc	January spectral initial condition (unit.23)
T31_jan_surf.nc	January surface initial condition (unit.24)
T31_o3clim2.nc	Ozone monthly zonal climatology (unit.21)
T31_VLTCLIM.nc	Leaf Area Index monthly climatology (unit.90)
T31_VGRATCLIM.nc	Vegetation ratio monthly climatology (unit.91)
T31_TSLCLIM.nc	Land Surface Temperature monthly climatology (unit.92)
surrta_data	Input for radiation scheme (rrtdata)
T31_so4_nat_clim.nc	Natural sulfate aerosol monthly 3-D climatology (unit.18)
T31_so4_YYYY.nc	Total sulfate aerosol monthly 3-D mean for year YYYY (aeroYYYY)

Land surface and vegetation component input files:

sol.nc	Soil boundary conditions
ca.nc	Vegetation boundary condition
T31_z0_oro_echam5.grd	Roughness length boundary condition (z0_oro.grd)
T31_topgrd.grd	Orography (topgrd.grd)
T31_topgrd_s.grd	Smoothed orography (topgrd_s.grd)

Ocean component input files:

coordinates.nc	Grids coordinates file
bathymetry	Ocean bathymetry file (ASCII)
ahmcoef	Eddy viscosity coefficients (ASCII)
dist.coast.nc	Distance from coastline
EMPave_old.dat	
LEVITUS_1m_Temperature_Pot_Ice_nomask.nc	Potential Temperature Climatology from Levitus
LEVITUS_1m_Salinity_Ice_nomask.nc	Salinity Climatology from Levitus
Runoff_1m_nomask.nc	Climatological Runoff

Sea ice component input files:

inice.param	Initialization namelist
output.param	Output namelist
dynami.param	Sea ice dynamics namelist

thermo.param	Sea ice thermodynamics namelist
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Marine biogeochemistry component input files:

ncin.nml	Input namelist
ncout.nml	Output namelist
ncout_zoom.nml	Output namelist
orca2numerics.nml	Input namelist
pelagic.nml	Input namelist
GLODAP_clim_TALK.nc	Total Alkalinity initial condition
GLODAP_clim_TCO2.nc	Total CO2 initial condition
fe_deposition_tegen_fung_murray_nomask.nc	Iron deposition climatology
smooth_zonal_Fe_SO.nc	Iron initial condition
woa01_clim_nitrate.nc	Nitrate initial condition
woa01_clim_phosphate.nc	Phosphate initial condition
woa01_clim_silicate.nc	Silicate initial condition

Coupler input files:

cf_name_table.txt	CF standard name table
grids_echam5_T31_orca_r2.nc	Models grid coordinates
masks_echam5_T31_orca_r2.nc	Model land-sea masks
areas_echam5_T31_orca_r2.nc	Model grid cells area
rmp_orlt_to_at31_DISTWGT.nc	SCRIPR interpolation weights
rmp_at31_to_orlt_BILINEA.nc	SCRIPR interpolation weights
rmp_orlt_to_at31_BILINEA.nc	SCRIPR interpolation weights
rmp_at31_to_orlt_BICUBIC.nc	SCRIPR interpolation weights
rmp_at31_to_orlu_BICUBIC.nc	SCRIPR interpolation weights
rmp_at31_to_orlv_BICUBIC.nc	SCRIPR interpolation weights
rmp_orlt_to_at31_CONSERV_FRACAREA.nc	SCRIPR interpolation weights

3.2. Restart files

Atmospheric component restart file:

echam_EXPID_rerun_YYYYMMDD.nc	History file; Format: NetCDF
-------------------------------	------------------------------

Land surface and vegetation component restart file:

sechiba_EXPID_rest_out_YYYYMMDD_NNN.nc	History file; Format: NetCDF
--	------------------------------

Ocean component restart files:

opa_EXPID_restart_YYYYMMDD.nc	History file; Format: NetCDF
opa_EXPID_EMPave_YYYYMMDD.dat	EMP history file; Format: ASCII

Sea ice component restart file:

lim_EXPID_restart_YYYYMMDD.nc	History file; Format: NetCDF
-------------------------------	------------------------------

Marine biogeochemistry component restart file:

EXPID_pelagos_restart_YYYYMMDD.nc	History file; Format: NetCDF
-----------------------------------	------------------------------

Couplert restart files:

oasis3_EXPID_flxatmos_YYYYMMDD.nc	Atmosphere history file; Format: NetCDF
oasis3_EXPID_sstocean_YYYYMMDD.nc	Ocean history file; Format: NetCDF

3.3. Output files

Atmospheric component output file:

echam_EXPID_YYYYMM.01	Output frequency: 12 hours; Format: GRIB
-----------------------	--

Land surface and vegetation component output file:

ISLSCP_out_EXPID_YYYYMM.nc	Output frequency: monthly; Format: NetCDF
----------------------------	---

Ocean component output files:

EXPID_1m_YYYYMMDD_YYYYMMDD_grid_T.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_grid_U.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_grid_V.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_grid_W.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_biotrd.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_CO2.nc	Output frequency: monthly; Format: NetCDF
EXPID_1m_YYYYMMDD_YYYYMMDD_diaznl.nc	Output frequency: monthly; Format: NetCDF

Sea ice component output file:

EXPID_1m_YYYYMMDD_YYYYMMDD_icemod.nc	Output frequency: monthly; Format: NetCDF
--------------------------------------	---

Marine biogeochemistry component output file:

EXPID_1m_YYYYMMDD_YYYYMMDD_pelagos.nc	Output frequency: monthly; Format: NetCDF
---------------------------------------	---

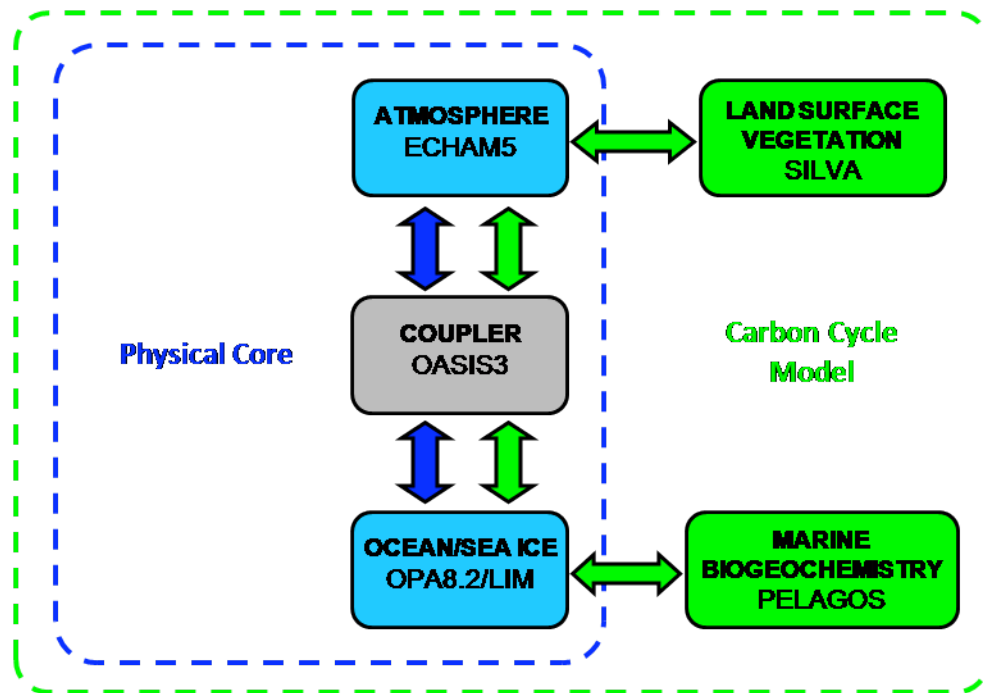


Figure 1: Structure of the ESM.

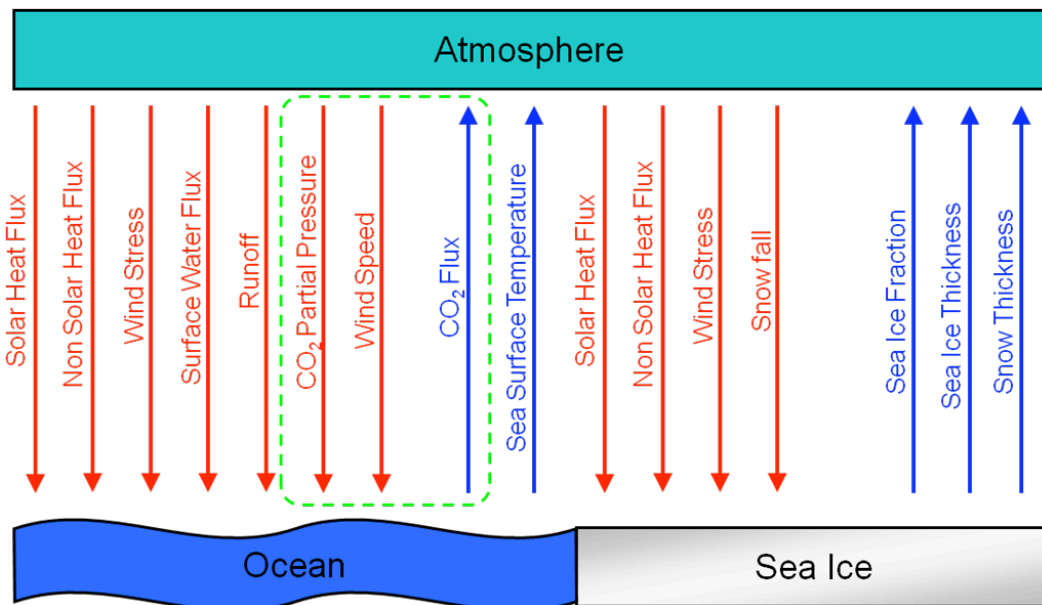


Figure 2 Scheme of the exchanged fields between the atmosphere and the ocean - sea ice models (including carbon related fields).

Table 2 Name of macros added to the ECHAM5 model and short description

	Pre-processor macro	Result
1	__prism	Enable the coupling through the PSMILe library
2	__cpl_opa_lim	Enable the coupling with OPA-LIM
3	use_comm_MPI2	Use MPI2 for communication between models
4	__CLIM_Box	Use the box partition strategy
5	__cpl_maskvalue	Pre-fill ice-free ocean grid points with the mask value
6	SILVA	Enable SILVA (only the physical model and exchange)
7	__cpl_carboncycle	Enable the closure of the carbon cycle
8	__cpl_carboncycle2	Enable to run the ESM with prescribed atmos. CO ₂
9	__cpl_wind_stress	Enable the exchange of sea surface currents (technical test)
10	key_coupled_echam5_intA	Sub macro of cpl_opa_lim, air/seaice interface (technical test)

Table 1 Name of the macros added to the OPA8.2/LIM model and short description

	Pre-processor macro	Result
1	key_coupled	Enable a coupled run
2	key_coupled_prism	Enable the coupling through the PSMILe library
3	key_coupled_echam5	Enable the coupling with ECHAM5
4	key_coupled_clim_runoff	Enable climatological runoff and water mass balance
5	key_passivetr	Enable PELAGOS (version with DIC)
6	key_coupled_echam5_carboncycle	Enable the carbon exchange, atmosphere-ocean/seaice
7	key_coupled_surf_current	Enable the exchange of sea surface currents (technical test)
8	key_coupled_echam5_intB	Sub-macro of #3, atmosphere - seaice interface (DEFAULT)
9	key_coupled_echam5_intA	Sub-macro of #3, air/seaice interface (technical test)

Table 3 ICC ESM directory tree.

```
ICCESM
|-- oasis3
|   |-- config
|   |-- doc
|   |-- libsrc
|   |   |-- anaisg
|   |   |-- anaism
|   |   |-- clim
|   |   |-- fscint
|   |   |-- mpp_io
|   |   |-- psmile
|   |   `-- scrip
|   `-- src
|-- echam5
|   |-- config
|   |-- doc
|   |-- include
|   |-- modules
|   |-- src
|   |-- support
|   `-- util
|-- silva
|   |-- ioips1
|   |-- parameters
|   `-- sechiba
|-- opa
|   |-- config
|   |-- include
|   |-- ioips1
|   `-- src
|-- lim
|   |-- config
|   |-- include
|   `-- src
|-- pelagos
|   |-- config
|   |-- include
|   |-- modules
|   `-- src
|-- experiments
|   `-- EXPID
```

Table 4 EXPID directory tree.

```
EXPID
|-- bin
|-- log
|-- work
|-- input
|   |-- oasis3
|   |-- echam5
|   |-- silva
|   |-- opa
|   |-- lim
|   |-- pelagos
|-- outdata
|   |-- oasis3
|   |-- echam5
|   |-- silva
|   |-- opa
|   |-- lim
|   |-- pelagos
|-- restart
|   |-- oasis3
|   |-- echam5
|   |-- silva
|   |-- opa
|   |-- lim
|   |-- pelagos
```


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5. Appendix

5.1. OASIS3 README

Oasis3
=====

1. About Oasis3
2. Directory content
3. Compiling Oasis3

1. About Oasis3

The aim of OASIS3 is to provide a flexible and user friendly tool for coupling independent general circulation models of the atmosphere and the ocean (A/O-GCMs) as well as other climate component models (sea-ice, land, atmospheric chemistry, ocean biogeochemistry, ...) and regional models. OASIS3 synchronizes the exchanges of coupling fields between the models being coupled, and performs 2D interpolations and transformations needed to express, on the grid of the target model, the coupling fields produced by the source model on its grid. Modularity and flexibility have been particularly emphasized in OASIS3 design.

OASIS3 is the direct evolution of the OASIS coupler developed since more than 10 years at CERFACS (Toulouse, France). OASIS3 is a portable set of Fortran 77, Fortran 90 and C routines. At run-time, OASIS3 acts as a separate mono process executable, which main function is to interpolate the coupling fields exchanged between the component models, and as a library linked to the component models, the OASIS3 PRISM Model Interface Library (OASIS3 PSMILE). OASIS3 supports 2D coupling fields only. To communicate with OASIS3, directly with another model, or to perform I/O actions, a component model needs to include few specific PSMILE calls. OASIS3 PSMILE supports in particular parallel communication between a parallel component model and OASIS3 main process based on Message Passing Interface (MPI) and file I/O using the mpp_io library from GFDL. Portability and flexibility are OASIS3 key design concepts. OASIS3 has been extensively used in the PRISM demonstration runs and is currently used by approximately 15 climate modelling groups in Europe, USA, Canada, Australia, India and Brasil. The current OASIS3 version was compiled and run on NEC SX serie, IBM Power serie and Linux PC cluster. Previous OASIS3 versions were run on many other platforms.

2. Directory content

src/	Oasis3 sources
libsrc/	Oasis3 libraries source (PSMILE, mpp_io, SCRIP, ...)
doc/	Oasis3 documentation (PDFs and LaTeX sources)
config/	Cofiguration files
Makefile.template	Main makefile template
README	This file

Other directories are created during the compilation process.

3. Compiling Oasis3

Compiling Oasis3 can be done using (1) the main makefile template in the root of the Oasis3 source tree AND (2) platform dependent header files in the directory config/ .

Note that GNU make must be used!

Make a copy of the template makefile Makefile.template with name Makefile (cp Makefile.template Makefile). This copy will be the main makefile for the compilation process. Using a copy of the template file ensure that the original one is always available (i.e. in the event of problems). Moreover, the template file can be under revision control. Using a template file ensure that no user-dependent setting is accidentally propagated to the repository of the software through a commit.

The main makefile must be completed (1) with a header file config/make.<platform> specific to the compiling platform used AND (2) with some make variable definition.

The platform specific settings are included from the file config/make.\$(ARCH) where ARCH is a make variable to be defined in the main makefile. Make a copy of the header file config/make.\$(ARCH).template with name config/make.\$(ARCH).

Oasis3 can be built in two modes: full coupler and interpolator-only. The user selects the mode setting the make variable CHAN in the main makefile:

CHAN	MODE
'MPI1/MPI2'	coupler - PSMILE interface
'NONE'	interpolator-only

Set the preprocessor macros you need in the variable CPPDEF in the main makefile and the compiling tools and options in config/make.\$(ARCH) .

Set the path to the NetCDF library and header files in the variable NETCDF_DIR in the file config/make.\$(ARCH) .

3.1 Step-by-step guide

1. Make a copy of the template makefile with name Makefile:
cp Makefile.template Makefile
2. Make a copy of the header file containing platform specific settings in the directory config/ :
cp config/make.<platform>.template config/make.<platform>
3. Set the make variable ARCH in the main makefile to the platform where you want to run on
(e.g. ARCH = nec_sx)
4. Set the make variable CHAN in the main makefile to MPI2 (full coupler) or NONE (interpolator only).
5. Set the preprocessor macros you need in the make variable CPPDEF in the main makefile
6. Change compiling tools and options if you need in config/make.\$(ARCH)
7. Set the path to the NetCDF library and header files in the variable NETCDF_DIR in the file config/make.\$(ARCH)
8. Compile Oasis3:
make

During compilation three new directories are created: build/, lib/ and bin/ . After successful compilation the resulting executable is found in bin/ , libraries are found in lib/, object files and modules are in build/ and its subdirectories. Multiple modes of Oasis3 can coexist as they are separated.

More information can be found in the Oasis3 User Guide in the directory doc/ .

3.2 Compiling on a new platform

All the platform specific settings are in the config/make.<platform> file. If one needs to compile OASIS3 on a platform for which this file doesn't exist he/she can copy and rename the template config/make.nec_sx.template (e.g. cp config/make.nec_sx.template config/make.linux_x86_64.template if one needs to compile OASIS3 on a x86 64-bits Linux platform) and set the make variable ARCH accordingly in the main makefile. Then the steps are the same as explained above.

3.3 Makefile targets

When make is invoked without any target (i.e. make) OASIS3 is compiled in the flavor indicated through the make variable CHAN (i.e. full coupler or interpolator-only). Here is the list of available targets:

oasis3:	same as with no target
default:	same as oasis3
anaig:	compile just the anaig library
anaism:	compile just the anaism library
fscint:	compile just the fscint library
scrip:	compile just the SCRIP library
mppio:	compile just the MPP I/O library
clim:	compile just the CLIM library
psmile:	compile just the PSMILE library
clean:	clean all off OASIS3 except the libraries

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cleanmod:      same as clean
cleanlibs:    clean all off the libraries
realclean:    clean all off OASIS3 (clean + cleanlibs)

cleananaig:   clean just the anaig library
cleananaism:  clean just the anaism library
cleanfscint:  clean just the fscint library
cleanscrip:   clean just the SCRIP library
cleanmppio:   clean just the MPP I/O library
cleanclim:    clean just the CLIM library
cleanpsmile:  clean just the PSMILE library

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5.2. OPA-LIM-PELAGOS README

OPA-LIM-PELAGOS
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1. Directory content
2. Compiling OPA-LIM-PELAGOS

1. Directory content

src/	OPA sources
include/	OPA header files (*.h)
ioipsl/	IOIPSL library sources
config/	Configuration files
Makefile.template	Main OPA makefile template
README	This file
../lim/src	LIM sources
../lim/include	LIM header files (*.h)
../pelagos/src	PELAGOS sources
../pelagos/modules	PELAGOS modules
../pelagos/include	PELAGOS header files (*.h)
../pelagos/config	Configuration files

Other directories are created at compile time.

2. Compiling OPA-LIM-PELAGOS

Compiling OPA-LIM-PELAGOS can be done using

- (1) the main makefile template in the root of OPA source tree
 Makefile.template
- (2) platform dependent header file in the directory config/
 config/make.<platform>

Note that GNU make must be used!

Make a copy of OPA template makefile Makefile.template with name Makefile (cp Makefile.template Makefile). This copy will be the main makefile for the compilation process. Using a copy of the template file ensure that the original one is always available (i.e. in the event of problems). Moreover, the template file can be under revision control. Using a template file ensure that no user-dependent setting is accidentally propagated to the repository of the software through a commit. The main makefile must be completed (1) with a header file config/make.<platform> specific to the compiling platform used AND (2) with some make variable definition.

The platform specific settings are included from the file config/make.\$(ARCH) where ARCH is a make variable to be defined in the main makefile. Make a copy of the header file config/make.\$(ARCH).template with name config/make.\$(ARCH) . Set the preprocessor macros you need in the variable CPPDEF and the compiling tools and options in config/make.\$(ARCH) .

PELAGOS compilation can be switched on/off uncommenting/commenting the line CPPDEF += -Dkey_passivetr in config/make.\$(ARCH) .

Set the path to the NetCDF library and header files in the variable NETCDF_DIR in the file config/make.\$(ARCH) .

2.1 Step-by-step guide

1. Make a copy of the template makefile with name Makefile:
cp Makefile.template Makefile
2. Make a copy of the header file containing platform specific settings in the directory config/ :
cp config/make.<platform>.template config/make.<platform>
3. Set the make variable ARCH in the main makefile to the platform where you want to run on (e.g. ARCH = nec_sx)
4. Set the preprocessor macros you need in the make variable CPPDEF in config/make.\$(ARCH)
5. Change compiling tools and options if you need in config/make.\$(ARCH)
6. Set the path to the NetCDF library and header files in the variable NETCDF_DIR in the file config/make.\$(ARCH)
7. Compile OPA-LIM-PELAGOS:
make

During compilation several new directories are created:

* in opa: build/, lib/ and bin/

* in lim: build and lib/

After succesful compilation the resulting executable is found in opa/bin/ , libraries are found in lib/, object files and modules are in build/ and its subdirectories.

2.2 Compiling on a new platform

All the platform specific settings are in the config/make.<platform> file. If one needs to compile OPA-LIM-PELAGOS on a platform for which this file doesn't exist he/she can copy and rename the template config/make.nec_sx.template (e.g. cp config/make.nec_sx.template config/make.linux_x86_64.template if one needs to compile on a x86 64-bits Linux platform) and set the make variable ARCH accordingly in the main makefile. Then the steps are the same as explained above.

2.3 Makefile targets

Here is the list of available targets:

opa:	same as with no target
default:	same as opa
ioipsl:	compile IOIPSL library only
lim:	compile LIM only
clean:	clean OPA, IOIPSL, LIM, PELAGOS
cleanlim:	clean OPA only
cleanioipsl:	clean IOIPSL library only
cleanlim:	clean LIM only

5.3. ECHAM5-SILVA README

ECHAM5-SILVA
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1. Directory content
2. Compiling ECHAM5-SILVA

1. Directory content

src/	ECHAM sources
modules/	ECHAM Fortran90 modules
include/	ECHAM namelists (*.inc)
config/	Configuration files
support/	ECHAM sources (GRIBEX)
util/	Auxiliary scripts
doc/	Documentation
Makefile.coupled.template	Main ECHAM makefile template
README.coupled	This file
../silva/sechiba	SILVA sources
../silva/parameters	SILVA Fortran 90 modules
../silva/ioipsl	IOIPSL library sources

2. Compiling ECHAM5

Compiling ECHAM5-SILVA can be done using the main makefile template in the root of ECHAM5 source tree Makefile.coupled.template .

Note that GNU make must be used!

Make a copy of ECHAM5 template makefile Makefile.coupled.template with name Makefile.coupled (cp Makefile.coupled.template Makefile.coupled). This copy will be the main makefile for the compilation process. Using a copy of the template file ensure that the original one is always available (i.e. in the event of problems). Moreover, the template file can be under revision control. Using a template file ensure that no user-dependent setting is accidentally propagated to the repository of the software through a commit. The main makefile must be completed with some make variable definition. Set the preprocessor macros you need in the variable CPPKEY and the compiling tools and options.

SILVA compilation can be switched on/off adding/removing the preprocessor macro SILVA to the CPPKEY make variable.

Set the path to the NetCDF library and header files in the variable NETCDFROOT.

3.1 Step-by-step guide

1. Make a copy of the template makefile with name Makefile.coupled:
cp Makefile.coupled.template Makefile.coupled
4. Set the preprocessor macros you need in the make variable CPPKEY
5. Change compiling tools and options if you need
6. Set the path to the NetCDF library and header files in the variable NETCDFROOT
7. Compile ECHAM5-SILVA:
make

After succesful compilation the resulting executable is found in bin/ , libraries are found in lib/, object files and modules are in src/, modules/ and support/ .