The PRISM support initiative, COSMOS and OASIS4

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Abstract

The increasing complexity of Earth system models (ESMs) and computing facilities puts a heavy technical burden on the research teams active in climate modelling. PRISM provides the Earth System Modelling community with a forum to promote sharing of development, maintenance and support of standards and software tools used to assemble, run, and analyse ESMs based on state-of-the-art component models (ocean, atmosphere, land surface, etc..) developed in the different climate research centres in Europe and elsewhere. PRISM is organised as a distributed network of experts who contribute to five "PRISM Areas of Expertise" (PAE): 1) Code coupling and I/O, 2) Integration and modelling environments, 3) Data processing, visualisation and management, 4) Meta-data, and 5) Computing. Some of the tools and concepts developed within PRISM have been incorporated in the **CO**mmunity earth **S**ystem **MO**del**S** (COSMOS) project, like the PRISM Compile and Runtime Environment and the OASIS3 coupler. Within PRISM further development in ongoing, one example being the OASIS4 coupler, which targets next generation Earth system models.

1 The PRISM concept, goals, and organization

PRISM was initially started as a project under the European Union's Framework Programme 5 (FP5, 2001-2004) and its long term support is now ensured by multi-institute funding of 7 partners (CERFACS, France; NEC-CCRLE-NEC, Germany; CGAM, UK; CNRS, France; MPI-M&D, Germany; Met Office, UK; and ECMWF) and 9 associate partners (CSC, Finland; IPSL, France; Météo-France, France; MPI-M, Germany; SMHI, Sweden; and computer manufacturers CRAY, NEC-HPCE, SGI, and SUN) contributing with IT and Earth science experts to the PRISM Support Initiative (PSI)[1], currently for a total of about 8 person-years per year.

The PRISM concept, initially a Euroclivar recommendation, is to increase what Earth system modellers have in common today (compilers, message passing libraries, algebra libraries, etc.) and share also the development, maintenance and support of a wider set of Earth system modelling software tools and standards. This should reduce the technical development efforts of each individual research team, facilitate the assembling, running, monitoring, and post-processing of ESMs based on state-of-the-art component models developed in the different climate research centres in Europe and elsewhere, and therefore promote the key scientific diversity of the climate modelling community. As demonstrated in other fields, sharing software tools is also a powerful incentive for increased scientific collaboration. It also stimulates computer manufacturers to contribute, thereby increasing the tool portability and the optimization of next generation of compute server for ESM needs, and also facilitating computer manufacturer procurement and benchmarking activities. The extensive use of the OASIS coupler illustrates the benefits of a successful shared software infrastructure. In 1991, CERFACS was commissioned to realise specific software for coupling different geophysical component models developed independently by different research groups. The OASIS development team strongly focussed on efficient user support and constant integration of the developments fed back by the users. This interaction snowballed and resulted in a constantly growing community. Today, The OASIS development and support including OASIS3 capitalises about 25 person-years (py) of mutual developments and fulfils the coupling needs of about 15 climate research groups around the world. The effort invested therefore represents, on a first order, 25 py/15 groups = 1,7 py/group, which is certainly much less than the effort that would have been required by each group to develop its own coupler. In addition to that about 8 py have been invested so far into the development of OASIS4.

PRISM represents the first major collective effort at the European level to develop ESM supporting software in a shared and coherent way. This effort is recognised by the Joint Scientific Committee (JSC) and the Modelling Panel of the World Climate Research Programme (WCRP) that has endorsed it as a "key European infrastructure project". It is analogous to the ESMF project[2] in the United States.

PRISM is lead by the PRISM Steering Board (one member per partner) that reviews each year a work plan proposed by the PRISM Core Group composed of PSI Coordinator(s), the

[1] http://prism.enes.org

[2] http://www.esmf.ucar.edu

leaders of the PRISM Areas of Expertise (see the next paragraph), and the chair of the PRISM User Group. The PRISM User Group is composed of all climate modelling groups using the PRISM software tools; given the dissemination of the OASIS coupler, the PRISM User Group is already a large international group.

1.1 PRISM Areas of Expertise

PRISM is organised around five PRISM areas of expertise (PAEs) having the following remits:

- Promote and, if needed, develop software tools for Earth System Modelling. A PRISM tool must be portable, usable independently and interoperable with the other PRISM tools, and freely available for research. There should be documented interest from the community to use the tool and the tool developers must be ready to provide user support.
- Encourage and organise a related network of experts, including technology watch.
- Promote and participate in the definition of community standards where needed.
- Coordinate with other PRISM areas of expertise and related international activities.

1.1.1 PAE "Code coupling and I/O"

The scope of the PAE "Code coupling and I/O" is to:

- develop, maintain, and support tools for coupling climate modelling component codes.
- ensure a constant technology watch on coupling tools developed outside PRISM.
- keep strong relations with the different projects involving code coupling in climate modelling internationally.

The current objectives are to maintain and support the OASIS3 coupler, continue the development of the OASIS4 coupler (see below), but also, through the organisation of workshops, help the community understand the different technical approaches used in code coupling, for example in the PALM coupler (Buis et al. 2006), in the UK Met Office FLUME project (Ford and Riley 2003), in the US ESMF project (Killeen et al 2006), and in the Bespoke Framework Generator (BFG) from U. of Manchester (Ford et al 2006) used in the GENIE project. Currently OASIS3 is used for coupling between the COSMOS components (see section II).

1.1.2 PAE "Integration & modelling environments".

This PAE targets the following environments:

- source version control for software development (including model development).
- code extraction and compilation.
- job configuration (how to set up and define a coupled integration).
- job running (how to control the execution of a coupled integration).
- integration with archive systems.

For source version control, PRISM promotes the use of Subversion (Pilato et al. 2004) and recently moved from CVS to Subversion for its own software distribution server, now located at DKRZ in Hamburg.

Controlling the creation of executable and providing a suitable run time environment were seen as key integration activities within the EU FP5 PRISM project, resulting in the development of the PRISM Compile and Running Environments (SCE & SRE). These tools are built on the concept that software from multiple sources can use a single framework as long as those models can conform to a set of simple standards.

Different groups (ECMWF, IPSL, CERFACS) have also shown strong interest in the UK Met Office Flexible Configuration Management (FCM) tool for version control and/or compilation management. A further review will be conducted in those groups and this tool, together with Subversion, may be considered as a replacement to CVS and extend the simplicity of 'make' in the current SCE. The COSMOS components follow these standards and are integrated into the PRISM SCE and SRE (see section II).

PrepIFS is a flexible User Interface framework provided by ECMWF that allows tailored graphical user interfaces to be built for the configuration of models and other software. It is integrated within the Supervisor Monitor Scheduler (SMS) for the management of networks of jobs across a number of platforms and both products are developed using Web Services technology. SMS and prepIFS have recently been packaged for use within the Chinese climate community. The power of these tools is recognised by PRISM, even if they are not widely used in the European climate community because of the level of commitment and human resources required to run these sophisticated services.

ECMWF is currently developing “prepOASIS”, a Graphical User Interface based on prepIFS but suitable to be run stand alone, to configure a coupled model using the OASIS4 coupler.

1.1.3 PAE “Data processing, visualisation and management”

The overall objective of this PAE is the development of standards and infrastructure for data processing, data archiving and data exchange in Earth system modelling and more general Earth system research (ESR). The huge amounts of data in ESR do not allow for centralised data archiving. Networking between geographically distributed archives is required. Ideally the geographical distribution of federated data archives is hidden to the user by an integrative graphical WWW-based interface. Standards are required in order to establish a data federation and to work in network.

For data processing, this PAE currently analyses CDAT (Climate Data Analysis Tools) and CDO (Climate Data Operators) respectively maintained and developed by PCMDI and MPI-M.

The M&D Group also develops the CERA-2 data model for the World Climate Data Centre, proposing a description of geo-referenced climate data (model output) and containing information for the detection, browse and use of data. An important collaboration is going on with the PAE Metadata and other international initiatives for the development and implementation of metadata standards for the description of model configuration and numerical grids.

Collaboration with PRISM related data archives in the development of data networking and federated archive architectures is also going on. ECMWF MARS software may be another candidate tool for meteorological data access and manipulation even if it is likely to be of interest only to major NWP sites due to its complexity.

1.1.4 PAE “Metadata”

In the last few years metadata has become a hot topic with new schemas and ideas to promote the interchangeability of Earth system models or modelling components as well as data. The PRISM Metadata PAE provides a forum to discuss, develop, and coordinate metadata issues with other national and international projects. The fundamental objective is to develop, document, and disseminate Earth System modelling metadata schemas as well as tools for producing, checking and displaying metadata. Currently, this PAE offers an opportunity to ensure coherence between the following metadata definition efforts:

- Numerical Model Metadata (NMM)[3], developed at University of Reading, is an evolving international metadata standard intended for the exchange of information about numerical code bases, and the models/simulations done using them.
- The CURATOR project (Earth System Curator)[4], a project similar to NMM in the US.
- Numerical grid metadata, developed by Balaji at GFDL, USA, for numerical grid description[5].
- The CF convention for climate and forecast metadata Interface (Eaton et al. 2003) designed to promote the processing and sharing of files created with the netCDF Application Programmer, developed by an international team and now managed by PCMDI and BADC.
- The metadata defined by the OASIS4 developers for description and configuration of the coupling and IO interface in a coupled model.
- The metadata currently defined in the UK Met Office FLUME project to manage and define the process of model configuration.

The goal of this PAE is therefore to integrate these emerging standards, ensure that they meet requirements and needs of the Earth System Modelling community, and disseminate them as "good practice".

1.1.5 PAE "Computing"

Experience has shown that a large variety of technical aspects related to computing are highly important for Earth system modelling. These techniques are in constant flow and evolve with new hardware becoming available. While computer vendors have to be kept informed about requirements emerging from the climate modelling community Earth system modellers still have to be informed about computing issues to preview difficulties and evolutions. PRISM can play a role in that aspect through the new PAE "Computing" devoted to those technology trends. Possible technical topics are file IO and data storage, algorithmic development, portable software to fit the needs of parallel and vector systems.

It is first proposed to establish a group of people willing to contribute with their expertise via mailing list and a sharing of relevant information on the PRISM web site. In particular

[3] http://cgam.nerc.ac.uk/NMM

[4] http://www.earthsystemcurator.org

[5] http://mitgcm.org/eh3/people/balaji/balaji-gridmeta2005.pdf

the activities will cover sharing of knowledge from the work on the Earth Simulator, establishment of links with the DEISA project[6], and providing information about important conferences and workshops. Depending on the number of volunteers and the input from this group, the list of tasks will be revised or extended in the next years.

2 COSMOS

The idea behind COSMOS (**CO**mmunity earth **S**ystem **MO**del**S**) is that a single research institution alone cannot develop the most comprehensive models. COSMOS is a community network towards the development of a fully developed Earth system model. The complexity of ESMs requires the involvement of an interdisciplinary team of scientists to develop Earth system models. This team has to be ready to work together intensively and share the knowledge and expertise of the team partners. So COSMOS constitutes a team of experts to develop a flexible and portable model infrastructure, following and supporting the ideas of the PRISM initiative. The purpose is not only to develop models and their infrastructure, it is also to use them to address challenging problems involving the interactions between different components of the Earth system. These models will be central tools to assess important feedback processes in the Earth system, to assess environmental risks, and to develop mitigation and adaptation strategies.

2.1 Organisation

The most important body of the COSMOS network is the community of Earth system scientists ready to work on and with the scientific tools and endeavours it promotes. The community meets at least once a year for the COSMOS General Assembly. At these meetings it takes strategic decisions, e.g. new scientific co-operation and projects. It also determines the configuration of the board, which should not have more than 12 members, as a workable size. The members of the board need to come from institutions having signed the COSMOS Memorandum of Understanding. Three of these members are the Chair and two Co-chairs; the board decides about these positions. The board calls activity heads for working groups and other activities. The activity heads assignment is to organise and run groups to think about and act upon projects, methods, aspects etc. of Earth system modelling. The activity heads report about the activities of their enterprises to the board and to the community. In their daily business they are interacting intensively with the COSMOS office.

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[6] http://www.deisa.org

The COSMOS office consists of the Science Director, an ex-officio member of the board, and a Project Manager running day-to-day business. The office gets secretarial assistance for office issues and meeting organisation. Support positions for technical work on the model system as well as outreach activities are applied for. The office supports the chair and the co-chairs. It is assigned by the board, and it develops and proposes the strategies and plans for COSMOS.

2.2 The COSMOS Models

The COSMOS network crucially depends upon the availability and easy access to models. These models do not only have to be very well tested and mature, but also scientifically and technologically very advanced. The MPI-M has developed a suite of models in a framework, called " COSMOSv1"[7]. The configurations possible with this modelling framework are indicated in table 1. This is available to the COSMOS network. It is assembled following the PRISM philosophy:

- Coupling of atmosphere and ocean GCMs by OASIS3.
- Configuration of model types and building of executables for specific machines by the standard configuration environment (PRISM SCE)
- Running and data storage by using the standard runtime environment (PRISM SRE) where model configurations can be ported to, run, maintained and developed on supercomputers with relative ease.

This first version of the model of the COSMOS network, called COSMOSv1, has 28 users from 10 countries.

2.3 Atmosphere Chemistry

The chemistry of the atmosphere can be simulated with the new MESSy approach, the Modular Earth Submodel System[8]. It has been successfully coupled to ECHAM5, and applied in multiyear integrations in different configurations and resolutions. ECHAM5/MESSy can be used to simulate ozone and related chemistry of the lower and middle atmosphere up to the mesopause at about 80 km, with no artificial boundaries applied, e.g., between the troposphere and stratosphere. The modular structure allows the selection of particular configurations to increase or decrease the level of detail in describing processes such as tropospheric multiphase chemistry, aerosols, transport and

[7] http://www.mpimet.mpg.de/en/wissenschaft/modelle/model-distribution/available-models.html

[8] http://www.messy-interface.org

deposition. The COSMOSv1 package integrates in a flexible and modular way models for the circulation of the atmosphere, the ocean and sea ice, and optionally includes processes for aerosols, vegetation, and marine biogeochemistry. The integration of atmospheric chemistry into the COSMOS system will lead to the next generation: COSMOSv2. This will take profit from the ECHAM5 based atmospheric chemistry models:

- ECHAM5-MESSy for tropospheric and stratospheric chemistry (already distributed)
- ECHAM5-HAMMOZ for coupled aerosols and chemistry in the troposphere
- HAMMONIA for the neutral and ionized chemistry, covering the entire atmosphere

The PRISM standard environments of COSMOSv2 will allow for different model configurations, including atmospheric chemistry.

3 The OASIS4 coupler

The OASIS coupler software allows synchronized exchanges of coupling information between numerical codes representing different components of the climate system.

OASIS3 (Valcke 2006) is the direct evolution of previous versions of the OASIS coupler. In addition a new fully parallel coupler OASIS4 is developed within PRISM (Valcke and Redler 2006). Other MPI-based parallel coupling software performing field transformation exists, such as the Mesh based parallel Code Coupling (MpCCI)[9] or the NCAR CCSM Coupler 6 (Cpl6)[10] . The originality of OASIS in general lies in its great flexibility (as the coupling configuration is externally defined by the user) and for OASIS3 and OASIS4 in the additional add-on of the common treatment of coupling and I/O exchanges (again externally defined by the user).

As the climate modelling community is progressively targeting higher resolution climate simulations on massively parallel platforms with coupling exchanges involving a higher number of (possibly 3D) coupling fields at higher coupling frequencies, a completely new fully parallel coupler OASIS4 is developed within PRISM. OASIS4 is a portable set of Fortran 90 and C routines. At run-time OASIS4 acts as a separate parallel executable, the OASIS4 Driver-Transformer, and as a fully parallel model interface library, the OASIS4 PSMILe. The concepts of parallelism and efficiency like the parallel neighbourhood search drove OASIS4 developments, keeping at the same time in its design the concepts of portability and flexibility that made the success of OASIS3 and its predecessors.

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9 http://www.scai.fraunhofer.de/mpcci.html

10 http://www.ccsm.ucar.edu/models/ccsm3.0/cpl6

3.1 Coupling configuration

Each component model to be coupled via OASIS4 should be released with an eXtensible Markup Language (XML)[11] file describing all its potential input and output fields, i.e. the fields that can be received or sent by the component through PSMILe ***get*** and ***put*** actions in the code. Based on those description files, the user produces, either manually or via a Graphical User Interface, the XML configuration files. As for OASIS3, the OASIS4 Driver extracts the configuration information at the beginning of the run and sends it to the different model PSMILes, which then perform the appropriate coupling or I/O actions during the run. OASIS4 is also highly flexible in the sense that any duration of run, any number of component models, any number of coupling and I/O fields, and particular coupling or I/O parameters for each field, can be specified.

3.2 Process management

In a coupled run using OASIS4, the component models remain separate executables. If only MPI1 is available (Snir et al. 1998), the OASIS4 main processes (driver plus transformer routines) and the component models must all be started at once in the job script. If some or all of the components are programmed as subroutines of a main program (e.g. ocean and sea ice as subroutines of ocean general circulation model) these components can still be coupled via OASIS4 PSMILe routines provided that the subroutine are run concurrently. This can usually be achieved by running the subprograms on different processes which is configurable through the XML file and the use of appropriate PSMILe interface routines. If the MPI library supports the MPI2 standard (Gropp et al. 1998) the user has the option to start only the OASIS4 driver process which then launches the different component models and transformer processes using the *MPI_Comm_spawn_multiple* functionality. The OASIS4 driver can spawn the different processes on different machines. In both cases, all processes are necessarily integrated from the beginning to the end of the run, and each coupling field is exchanged at a fixed frequency defined in the XML file for the whole run; in that sense, OASIS4 supports static coupling only.

Figure 1 illustrates the different ways of communication between the individual physical components with a coupled application. Ocean and sea ice are programmed as subroutines of a main program. In this examples we assume that the two grids are identical and data can be exchanged directly through the PSMILe bypassing the transformer processes. Atmosphere and chemistry are programmed as separate executables. As they again work on identical grids data are exchanged directly (indicated by the lower red

[11] http://www.w3.org/XML

double arrow). As those grids are different from the ocean and sea ice data exchanged with those components go through the parallel transformer.

3.3 Coupling field transformation and regridding

During the run the OASIS4 Driver (root) process takes over the functionality of the transformer and participates together with the other Transformer processes manages the transformation and regridding of 2D or 3D coupling fields. The (parallel) Transformer performs only the weight calculation and the regridding *per se*; the neighbourhood search, i.e. the search of the source points determination for each target point that contribute to the calculation of its regridded value, is performed in parallel in the source PSMILe.

During the simulation time stepping, the OASIS4 parallel Transformer can be considered as an automaton that reacts to what is demanded by the different component model PSMILes: receive data for transformation (source component process) or send transformed data (target component process). The OASIS4 Transformer therefore acts as a parallel buffer in which the transformations take place. Currently, only 2D and 3D nearest-neighbour, 2D and 3D linear, and bicubic regridding, and 2D conservative remapping techniques are implemented, but there are plans to implement also 3D cubic grid interpolation and 3D conservative remapping.

3.4 Communication: the OASIS4 PSMILe software layer

To be coupled via OASIS4, the component models have to include specific calls to the OASIS4 PSMILe software layer. The OASIS4 PSMILe Application Programming Interface (API) was kept as close as possible to OASIS3 PSMILe API; this ensures a smooth and progressive transition between OASIS3 and OASIS4.

The OASIS4 PSMILe supports fully parallel MPI-based communication, either directly between the models for those pairs of source and target grid points for which an exact match was found (including automatic repartitioning if needed) or via the parallel Transformer, and file I/O using the GFDL mpp_io library. Note that the mpp_io library has been extended to work optionally with the parallel NetCDF library (pNetCDF) [12] to allow for parallel file I/O via MPI-IO inside pNetCDF. The detailed communication pattern among the different component model processes is established by the PSMILe, using the results of the regridding or repartitioning neighbourhood search. This search is based on the source and target identified for each coupling exchange by the user in the XML configuration files and on the local domain covered by each component process. The search uses an efficient

[12] http://cucis.ece.northwestern.edu/projects/PNETCDF

multigrid algorithm and is done in parallel in the source PSMILe, which ensures that only the useful part of the coupling field is extracted and transferred.

Besides these new parallel aspects, the OASIS4 PSMILe follows the same end-point communication and user-defined external configuration principles than the OASIS3 PSMILe.

3.5 The OASIS4 users

OASIS4 portability and scalability was demonstrated with different "toy" models during the EU FP5 PRISM project. OASIS4 was also used to realize a coupling between the MOM4 ocean model and a pseudo atmosphere model at GFDL (Geophysical Fluid Dynamic Laboratory) in Princeton (USA), and with pseudo models to interpolate data onto high resolution grids at IFM-GEOMAR in Kiel, Germany.

Currently, work is going on with OASIS4 at:

- the Swedish Meteorological and Hydrological Institute (SMHI) in Sweden for coupling regional ocean and atmosphere models (first physical case studies are already realized);
- the European Centre for Medium-Range Weather Forecast (ECMWF), KNMI in the Netherlands, and Météo-France in France in the framework of the EU GEMS project, for 3D coupling between atmosphere and atmospheric chemistry models;
- at the UK MetOffice for global ocean-atmosphere coupling
- at CERFACS and Météo-France
- ACCESS

After the current beta-testing phase, the first official OASIS4 version should be available to the public in 2007.

4 Final Remarks

PRISM is already a success as it allows a community of developers facing similar technical problems in Earth system modelling to share their expertise and ideas. The difference in the level of buy-in for the different tools developed during the FP5 project helped identified for which tool standardisation is more or less achieved, for which tools convergence is wanted, and for which tools it is currently not a target. The strength of the current decentralised PRISM organisation is to allow "best of breed" software tools to naturally emerge, although this means that PRISM relies on the developments done in the different partner groups to propose technical software solution to Earth system modellers. In the areas for which this philosophy does not apply and for which standards have to be pre-defined, for example for metadata definition, the big contribution of PRISM is to provide a visible entry point of the European ESM software community for international coordination, for example with the American ESMF project within the WCRP framework. Given its institutional long term support, PRISM is now well placed to seek additional funding to support more networking and coordination activities or to help specific technical developments. And of course, more European or non-European collaborators are today most welcome to bring in additional expertise and to ensure a wider diffusion of the PAE tools and standards.

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Table 1. Model Configurations with COSMOSv1

	Model Components
Atmosphere GCM	ECHAM5
Ocean GCM	MPIOM
Ocean + Biogeochemistry	MPIOM-HAMOCC
Atmosphere / Ocean GCM	ECHAM5 / OASIS3 / MPIOM
Carbon Cycle	ECHAM5-JSBACH/OASIS3/MPIOM-HAMOCC
Aerosol system	ECHAM5-HAM / OASIS3 / MPIOM-HAMOCC

Figure 1. Example for a possible coupled model configuration.