OASIS3-MCT User Guide

OASIS3-MCT_4.0

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How to get assistance?

Assistance can be obtained as listed below.

Phone Numbers and Electronic Mail Adresses

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Sophie Valcke		CERFACS	

How to get documentation ?

The documentation can be downloaded from the OASIS web site under the URL :
http://oasis.enes.org

Contents

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Chapter 1

Introduction

In 1991, CERFACS started the development of a software interface to couple existing ocean and atmosphere numerical General Circulation Models. Today, different versions of the OASIS coupler are used by about 45 modelling groups all around the world on different computing platforms[1]. OASIS sustained development is ensured by a collaboration between CERFACS and the Centre National de la Recherche Scientifique (CNRS) and its maintainance and user support is regularly reinforced with additional resources coming from European an national projects.

The current OASIS3-MCT internally uses MCT, the Model Coupling Toolkit[2] (Larson et al 2005) (Jacob et al 2005), developed by the Argonne National Laboratory in the USA. MCT implements fully parallel remapping, as a parallel matrix vector multiplication, and parallel distributed exchanges of the coupling fields, based on pre-computed remapping weights and addresses. Its design philosophy, based on flexibility and minimal invasiveness, is close to the OASIS approach. MCT has proven parallel performance and is, most notably, the underlying coupling software used in National Center for Atmospheric Research Community Earth System Model (NCAR CESM).

OASIS3-MCT is a portable set of Fortran 77, Fortran 90 and C routines. Low-intrusiveness, portability and flexibility are OASIS3-MCT key design concepts. After compilation OASIS3-MCT is a coupling library to be linked to the component models, and which main function is to interpolate and exchange the coupling fields to form a coupled system. OASIS3-MCT supports coupling of 2D logically-rectangular fields but 3D fields and 1D fields expressed on unstructured grids are also supported using a one dimension degeneration of the structures. Thanks to MCT, all transformations, including remapping, are performed in parallel on the set of source or target component processes and all coupling echanges are now executed in parallel directly between the component processes via Message Passing Interface (MPI). OASIS3-MCT also supports file I/O using netcdf.

The developments realised in the different versions of OASIS3-MCT are described in Appendix B. In spite of the significant changes in underlying implementation, usage of OASIS3-MCT in the codes has largely remained unchanged with respect to previous OASIS3 versions. To communicate with another component, or to perform I/O actions, a component model needs to include few specific calls of the Application Programmig Interface (API) OASIS3-MCT coupling library. The *namcouple* configuration file is also largely unchanged, although several options are either added, deprecated, not used or not supported.

Results obtained with IS-ENES2 coupling technology benchmarks show that OASIS3-MCT performs as well as, and even better at very high number of cores, than other coupling technologies, at least for up to O(10000) cores. It is therefore very likely that OASIS3-MCT will provide an efficient and easy-to-use coupling solution for many climate modelling groups in the few years to come.

[1] A list of coupled models realized with OASIS can be found at https://verc.enes.org/oasis/oasis-dedicated-user-support-1/some-current-users

[2] www.mcs.anl.gov/research/projects/mct/

1.1 Step-by-step use of OASIS3-MCT

To use OASIS3-MCT for coupling models (and/or perform I/O actions), one has to follow these steps:

1. Obtain OASIS3-MCT source code (see chapter 1.2).
2. Get familiar with OASIS3-MCT by going through the tutorial steps. The tutorial sources are given in directory `examples/tutorial` and all explanations are provided in the document `tutorial.pdf` therein.
3. Identify the coupling or I/O fields and adapt the codes to implement the coupling exchanges with the OASIS3-MCT coupling library based on MPI message passing. The OASIS3-MCT coupling library uses NetCDF and therefore can also be used to perform I/O actions from/to disk files. For more detail on how to use the OASIS3-MCT API in the codes, see chapter 2.
4. Define all coupling and I/O parameters and the transformations required to adapt each coupling field from the source model grid to the target model grid; on this basis, prepare OASIS3-MCT configuring file *namcouple* preferably using the Graphical User Interface (see chapter 3). OASIS3-MCT supports different interpolation algorithms as described in chapter 4. Remapping files can be computed online using the SCRIP options, or offline and read in during the run using the MAPPING transformation.

   We strongly recommend to tests off-line the quality of the chosen transformations and remappings using the environment available in `examples/test_interpolation` and explanations provided in the document `test_interpolation.pdf` therein.
5. Generate required auxiliary data files (see chapter 5).
6. Compile OASIS3-MCT, the component models and start the coupled experiment. Details on how to compile and run a coupled model with OASIS3-MCT can be found in section 6.

If you need extra help, do not hesitate to contact us (see contact details on the back of the cover page).

1.2 OASIS3-MCT sources

OASIS3-MCT sources are available from CERFACS SVN server. To obtain more detail on downloading the sources, please fill in the registration form at https://verc.enes.org/oasis/download/oasis-registration-form .

OASIS3-MCT directory structure is the following one:

```
- oasis3-mct/lib/psmile          OASIS3-MCT coupling library
                /scrip           SCRIP interpolation library
                /mct             Model Coupling Toolkit Coupling Software

- oasis3-mct/doc                 OASIS3-MCT User Guide

- oasis3-mct/util/make_dir       Utilities to compile OASIS3-MCT
                 /lucia          Tool for load balancing analysis

- oasis3-mct/examples            Environment to compile, run and use
                                 different toy coupled models.
```

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Chapter 2

Interfacing a component code with OASIS3-MCT

At run-time, OASIS3-MCT performs parallel exchange of coupling data between parallel components and sub-components and allows remapping (interpolation), time integration or accumulation and other transformations of these coupling fields.

This chapter describes how to adapt the component codes to couple them through OASIS3-MCT.

OASIS3-MCT supports coupling exchanges between parallel components and sub-components deployed in diverse configurations; the different possibilities and how to use the OASIS3-MCT library accordingly are described in section 2.1. The OASIS3-MCT Application Programming Interface (API) includes different classes of modules or routines that are described in details in section 2.2. Finally, in section 2.3, different coupling algorithms are illustrated and details on how to reproduce them with OASIS3-MCT are provided, together with more information on the `LAG` and `SEQ` indices.

2.1 Configurations of components supported

Since OASIS3-MCT_3.0, coupling exchanges between components and sub-components deployed in a much larger diversity of configurations are now supported. This is illustrated on figure 2.1 and how to use the OASIS3-MCT library accordingly is detailed on figure 2.2. All OASIS3-MCT API routines are also described in details in section 2.2.

We call here an "executable" a compiled code forming a part of or the whole coupled system (started with the mpirun or mpiexec command). A "component" is the ensemble of processes, or tasks, within the coupled system calling `oasis_init_comp` with the same `comp_name` argument (see section 2.2.2). A "sub-component" is the subset of tasks within a component sending or receiving coupling fields on a specific grid; of course, a component may have only one sub-component that gathers all its tasks.

Practical examples of how to use the OASIS3-MCT library are also given in `examples/ tutorial` and `examples/test_1bin_ocnice` (see sections 6.3.1 and 6.3.2).

Since OASIS3-MCT_3.0, it is possible to (the text between [and] refers to figure 2.1) :

- to implement coupling exchanges between two components or sub-components running concurrently on separate sets of tasks within two different executables (as before) [A, D, E, J];
- to implement coupling exchanges between two components or sub-components running concurrently on separate sets of tasks within one same executable [B, F, I];
- to implement coupling exchanges within one executable between two concurrent sub-components [C]
- to implement coupling exchanges within one executable between two sub-components running sequentially on overlapping sets of tasks (i.e. a task can be coupled to itself calling both the "put and

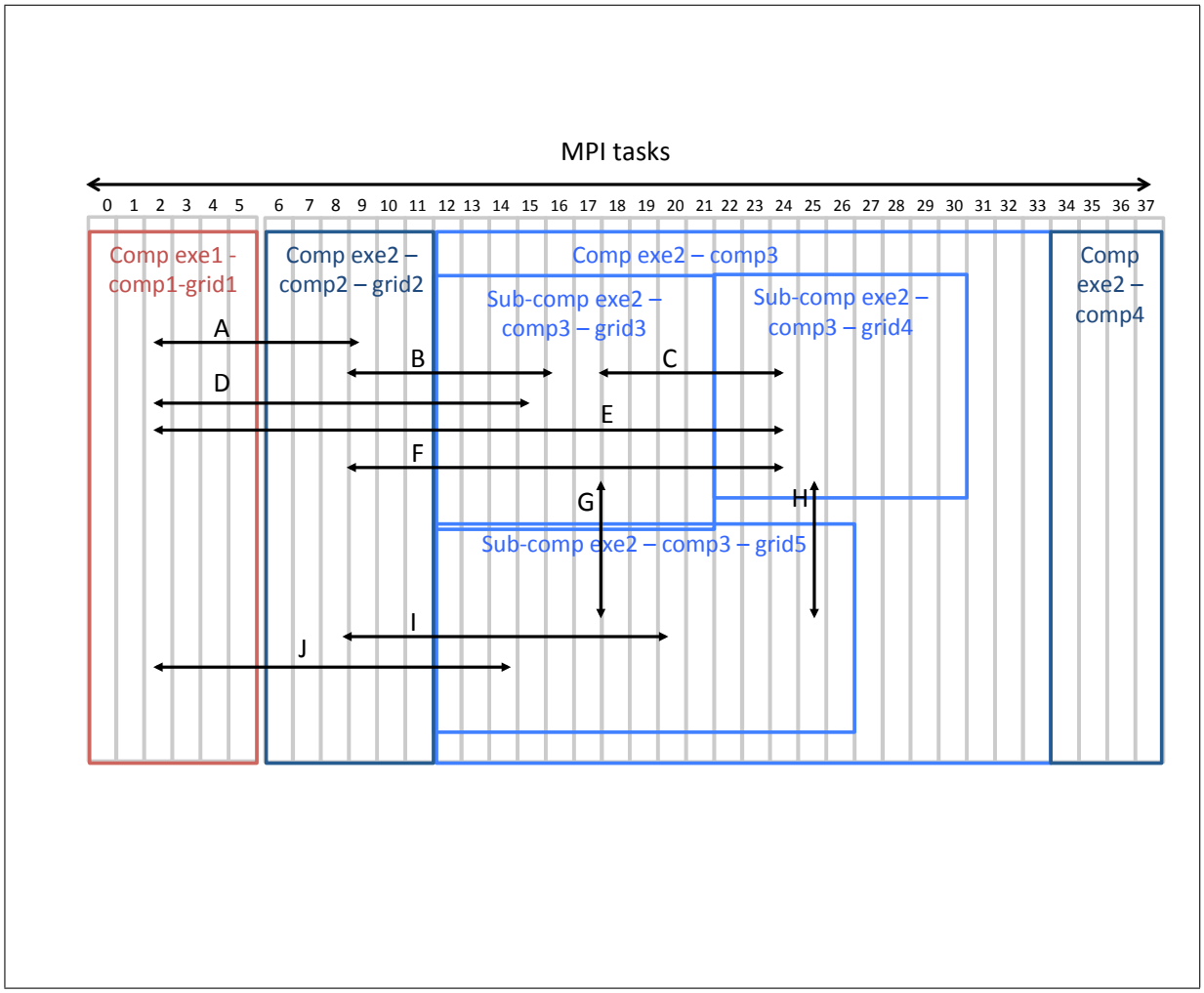


Figure 2.1: The different configuration of components supported by OASIS3-MCT_3.0. Two executables `exe1` and `exe2` are running concurrently on separate sets of MPI tasks (0-5 for `exe1` and 6-37 for `exe2`). Executable `exe1` includes only one component `comp1` that has coupling fields defined on only one grid `grid1` (decomposed on all its 6 tasks). Executable `exe2` includes 3 components, `comp2`, `comp3`, and `comp4` running concurrently respectively on tasks 6-11, 12-33 and 34-37. Component `comp2` participates in the coupling with fields defined on only one coupling grid `grid2` (decomposed on all its 5 tasks) while `comp4` does not participate at all in the coupling. Component `comp3` has 3 sub-components, respectively exchanging coupling fields defined on `grid3` (tasks 12-21), `grid4` (tasks 22-30) and `grid5` (tasks 12-26, therefore overlaping with both `grid3` and `grid4`); finally, `comp3` has 3 tasks (31-33) not involved in the coupling. Sub-components exe2-comp3-grid3 and exe2-comp3-grid5, or sub-components exe2-comp3-grid4 and exe2-comp3-grid5 are examples of coupling between sub-components running sequentially on overlapping sets of tasks.

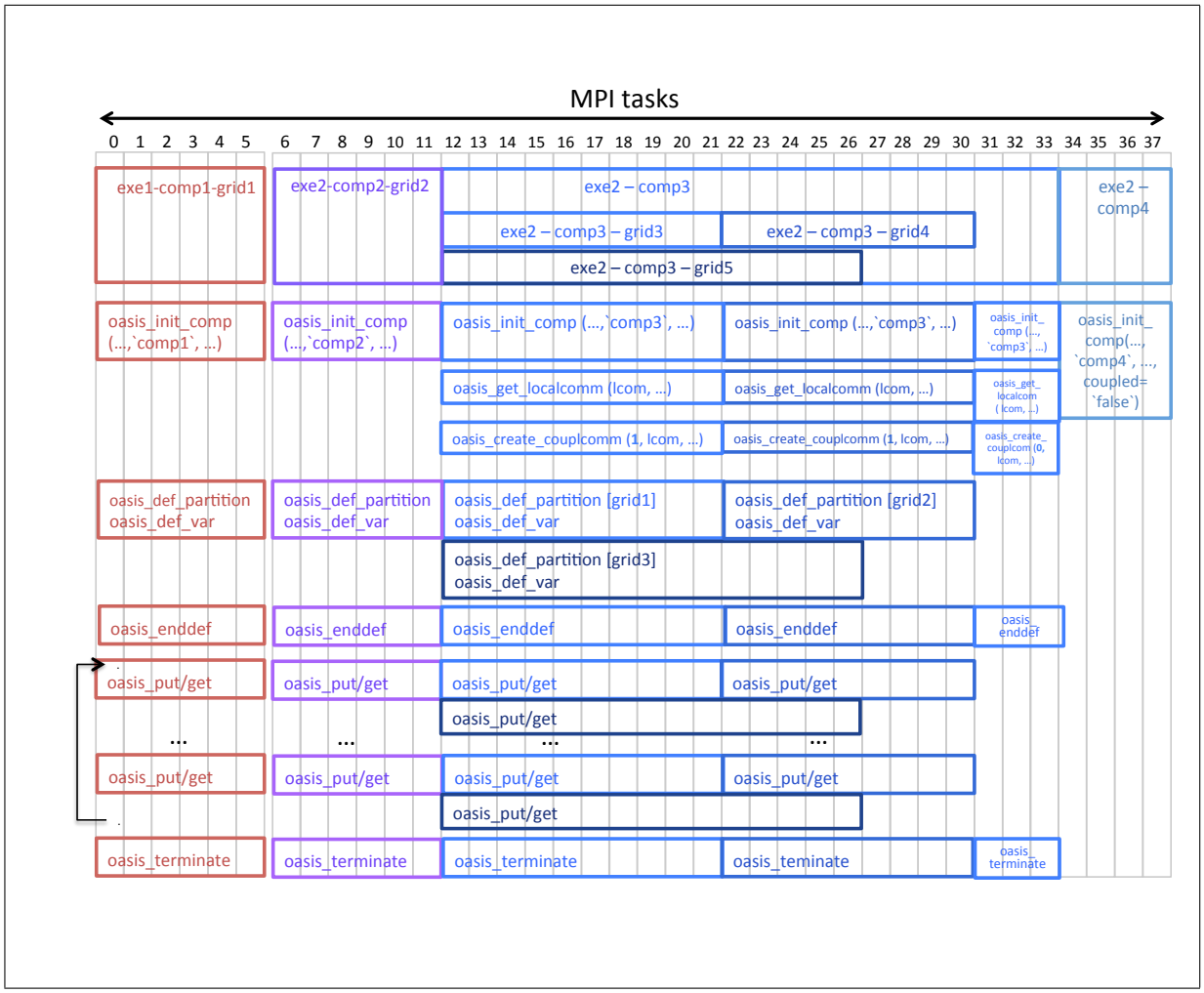


Figure 2.2: The sequence of OASIS3-MCT calls that have to be implemented in the codes so to allow the configuration of components described on figure 2.1. Each MPI tasks has to call `oasis_init_comp` once with the name of its component as 2^{nd} argument. As none of `comp4` tasks is participating to the coupling, `comp4` tasks calls `oasis_init_comp` with `coupled=.false.` as 4^{th} argument and does not call any other OASIS3-MCT routine. As some of `comp3` tasks are participating to the coupling, all `comp3` tasks have to call `oasis_init_comp`, `oasis_get_localcomm`, `oasis_create_couplcomm`, `oasis_enddef` and `oasis_terminate` (these are the only routine to be called by `comp3` tasks 31-33 not participating to the coupling). To initialise the coupling exchanges, the tasks of a sub-component holding a field decomposed on a specific grid have to call the `oasis_def_partition` to express the decomposition of the grid, `oasis_def_var` to declare the coupling field and `oasis_enddef`. Finally, the tasks of a sub-component exchanging coupling fields have to call `oasis_put` and `oasis_get` accordingly.

the "get of the exchange) [G, H]

- to have some tasks of a component not participating to the coupling exchanges [tasks 31-33 of `exe2-comp3`]
- to have all processes of a component not participating to the coupling exchanges [`exe2-comp4`, tasks 34-37]

The sequence of OASS3-MCT API routines that have to be called in the different cases is detailed on figure 2.2. These routines are also described in detail in the next section.

2.2 OASIS3-MCT Application Programming Interface (API)

To interact with the rest of the coupled system, few calls of the OASIS3-MCT library routines, which sources can be found in `oasis3-mct/lib/psmile` directory, have to be implemented in the component codes. They belong to the following classes:

1. Module to use (section 2.2.1)
2. Initialisation (section 2.2.2)
3. Partition definition (section 2.2.3)
4. Grid data file definition (section 2.2.4)
5. Coupling-I/O field declaration (section 2.2.5)
6. End of definition phase (section 2.2.6)
7. Coupling-I/O field sending and receiving (section 2.2.7)
8. Termination (section 2.2.8)
9. Optional auxiliary routines (section 2.2.9)

2.2.1 Module to use in the code

To use OASIS3-MCT library, a user needs to add in his code:

- `USE mod_oasis`

  or
- `USE mod_prism`

Both use statements are valid but only one needs to be used in a particular component. This single use statement provides all methods required. The methods, datatypes, and capabilities are identical for both the `mod_prism` or `mod_oasis` interfaces, the only difference being the name of the interface. The interface in module `mod_prism` is provided for backwards compatability with prior versions of OASIS3. Use of module `mod_oasis` is recommended and provides access to a set of updated routine names that will continue to evolve in the future, always ensuring backward compatibility. In the following sections, both the `mod_prism` and `mod_oasis` interface names are defined and a single description of the interface arguments is provided.

2.2.2 Initialisation

Coupling initialisation

- `CALL oasis_init_comp (compid, comp_name, ierror, coupled, commworld)`
- `CALL prism_init_comp_proto (compid, comp_name, ierror, coupled, commworld)`
  - `compid [INTEGER; OUT]`: returned component ID
  - `comp_name [CHARACTER; IN]`: component name; maximum length of 80 characters

- `ierror [INTEGER; OUT]`: returned error code
- `coupled [LOGICAL, OPTIONAL; IN]`: flag to specify if the calling task is participating or not to the coupling (`.true.` by default).
- `commworld [INTEGER, OPTIONAL; IN]` : optional argument to specify the global communicator gathering the components of the coupled model. If not specified, `MPI_COMM_WORLD` will be used as the default communicator to startup. All components of the coupled model must specify the same `commworld` argument.

This routine must called by all tasks of all components whether of not they are involved in the coupling [1].

A component is defined as the ensemble of tasks calling `oasis_init_comp` with the same `comp_name` argument. If and only if all tasks of a component are excluded from the coupling, the logical `coupled` can be set to `.false.` for this component tasks; in this case, `oasis_init_comp` is the only API routine that needs to be called by the component tasks. If at least one tasks of a component is participating to the coupling, all component tasks have to call `oasis_init_comp` with `coupled=.true.` (by default); in this case, the component tasks not participating to the coupling will also have to call `oasis_get_localcomm`, `oasis_create_couplcomm`, `oasis_enddef` and `oasis_terminate`.

Communicator for internal parallelisation

- `CALL oasis_get_localcomm (local_comm, ierror )`
- `CALL prism_get_localcomm_proto (local_comm, ierror )`
  - `local_comm [INTEGER; OUT]`: value of local communicator
  - `ierror [INTEGER; OUT]`: returned error code.

  This routine returns the value of a local communicator gathering only the tasks of the component, i.e. the tasks that called `oasis_init_comp` with the same `comp_name` argument.

  This may be needed as all executables of the coupled system are started in a pseudo-MPMD mode with MPI1 and therefore share automatically the same MPI_COMM_WORLD communicator. Another communicator has to be used for the internal parallelisation of each component. OASIS3-MCT creates this local communicator `local_comm` based on the value of the `comp_name` argument in the `oasis_init_comp` call.

  Retrieving a local communicator `local_comm` is also needed if `oasis_create_couplcomm` is called, as `local_comm` is an argument of this routine (see below).

- `CALL oasis_create_couplcomm(icpl, local_comm, coupl_comm, kinfo)`
- `CALL prism_create_couplcomm(icpl, local_comm, coupl_comm, kinfo)`
  - `icpl [INTEGER; IN]`: coupling process flag
  - `local_comm [INTEGER; IN]`: MPI communicator with all processes of the component
  - `coupl_comm [INTEGER; OUT]`: returned MPI communicator gathering only component processes participating in the coupling
  - `kinfo [INTEGER; OUT; OPTIONAL]`: returned error code

  This routine creates a coupling communicator for a subset of processes. It is mandatory to call this routine if only a subset of the component processes participate in the coupling (e.g. `comp3` in figure 2.2); in that case, the processes involved in the coupling have to call it with icpl=1 while the other have to call it with icpl = MPI UNDEFINED. Argument local_comm is the MPI communicator

[1] The component may also call MPI_Init explicitly, but if so, has to call it before calling `oasis_init_comp`; in this case, the component also has to call MPI_Finalize explicitly, but only after calling `oasis_terminate`.

associated with all processes of the component returned by oasis_get_localcomm. The new coupling communicator is returned in coupl_comm.

If this communicator already exists in the code, the component should simply provide it to OASIS3-MCT with:

- `CALL oasis_set_couplcomm(coupl_comm, kinfo)`
- `CALL prism_set_couplcomm(coupl_comm, kinfo)`
  - `coupl_comm [INTEGER; IN]`: MPI communicator gathering only component processes participating in the coupling
  - `kinfo [INTEGER; OUT; OPTIONAL]`: returned error code

  This routine allows to provide a local coupling communicator to OASIS3-MCT, given that it already exists in the code. The value of `coupl_comm` must be the value of this local coupling communicator for the processes participating to the coupling and it must be `MPI_COMM_NULL` for processes not involved in the coupling.

2.2.3 Partition definition

The coupling fields sent or received by a component are usually scattered among the different component processes. With OASIS3-MCT, all processes exchanging coupling data have to express in a global index space the local partitioning of the different grids onto which the data is expressed (see 2.2.4 for the grid definition). The processes not implied in the coupling do not have to call this routine (for backward compatibility with OASIS3-MCT_2.0, they may still call it describing a null partition, i.e. with `ig_paral(:)=0`).

- `CALL oasis_def_partition (il_part_id, ig_paral, ierror, isize, name)` or
- `CALL prism_def_partition_proto (il_part_id, ig_paral, ierror, isize, name)`
  - `il_part_id [INTEGER; OUT]`: partition ID
  - `ig_paral [INTEGER, DIMENSION(:), IN]`: vector of integers describing the local grid partition in the global index space; has a different expression depending on the type of the partition; in OASIS3-MCT, 5 types of partition are supported: Serial (no partition), Apple, Box, Orange, and Points (see below).
  - `ierror [INTEGER; OUT]`: returned error code.
  - `isize [INTEGER, OPTIONAL, IN]`: Optional argument, mandatory if the coupling data is exchanged for only a subdomain of the global grid; in this case, `isize` must give the total number of grid points.
  - `name [CHARACTER, OPTIONAL, IN]`: Optional argument associating a name to the partition, mandatory if oasis_def_partition is called either for a grid decomposed not across all the processes of a component or if the related oasis_def_partition are not called in the same order on the different component processes; this argument is new since OASIS3-MCT_3.0 and is linked to the greater flexibility in the configuration of components supported (see 2.1); it has a maximum length of 120 characters.

Serial (no partition)

This is the choice for a grid entirely supported by only one process . In this case, we have `ig_paral(1:3)`:

- `ig_paral(1)` = 0 (indicates a Serial "partition")
- `ig_paral(2)` = 0
- `ig_paral(3)` = the total grid size.

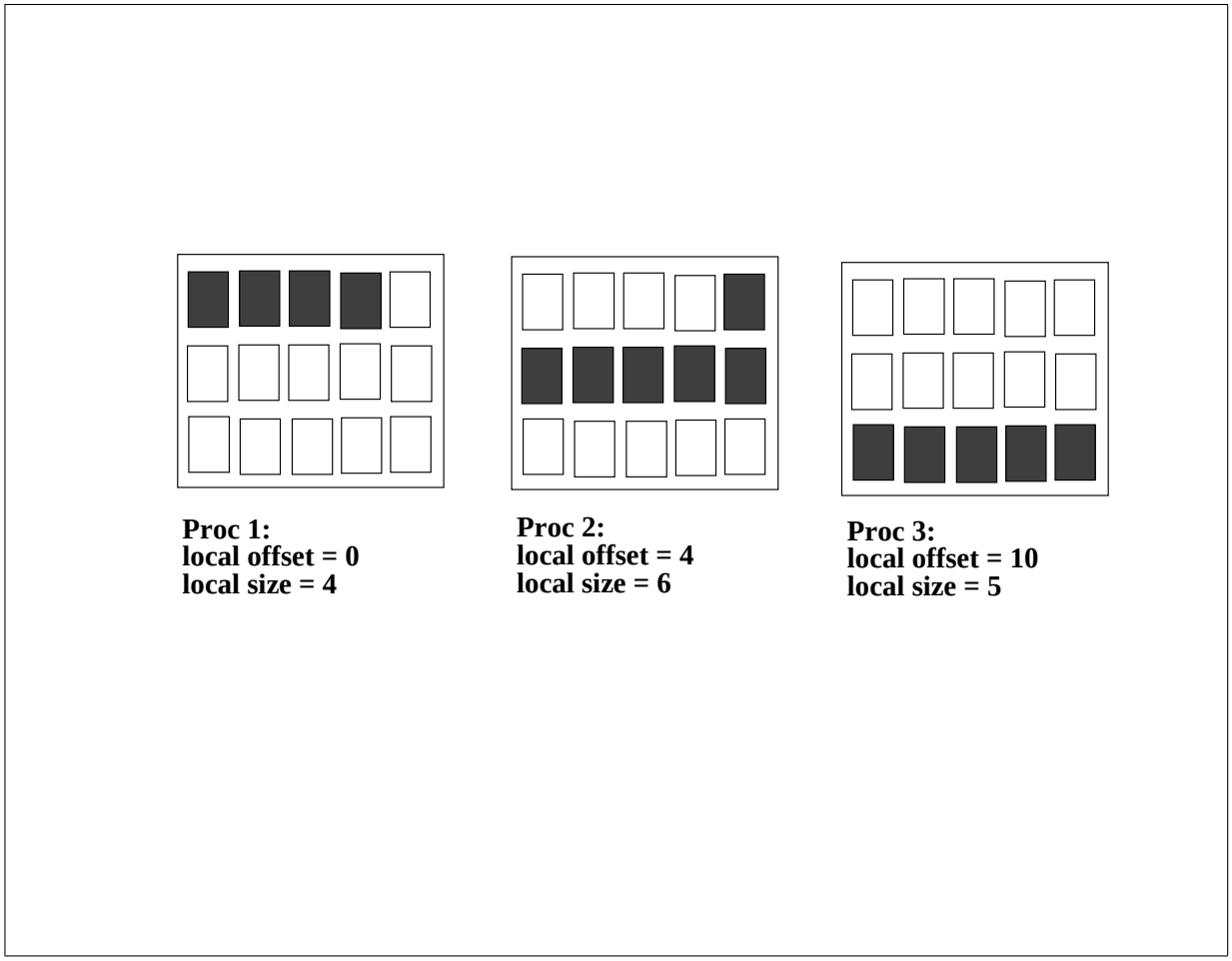


Figure 2.3: Apple partition. It is assumed here that the global index starts at 0 in the upper left corner.

Apple partition

Each partition is a segment of the global domain, described by its global offset and its local size. In this case, we have `ig_paral(1:3)`:

- `ig_paral(1)` = 1 (indicates an Apple partition)
- `ig_paral(2)` = the segment global offset
- `ig_paral(3)` = the segment local size

Figure 2.3 illustrates an Apple partition over 3 processes.

Box partition

Each partition is a rectangular region of the global domain, described by the global offset of its upper left corner, and its local extents in the X and Y dimensions. The global extent in the X dimension must also be given. In this case, we have `ig_paral(1:5)`:

- `ig_paral(1)` = 2 (indicates a Box partition)
- `ig_paral(2)` = the upper left corner global offset
- `ig_paral(3)` = the local extent in x
- `ig_paral(4)` = the local extent in y
- `ig_paral(5)` = the global extent in x.

Figure 2.4 illustrates a Box partition over 3 processes.

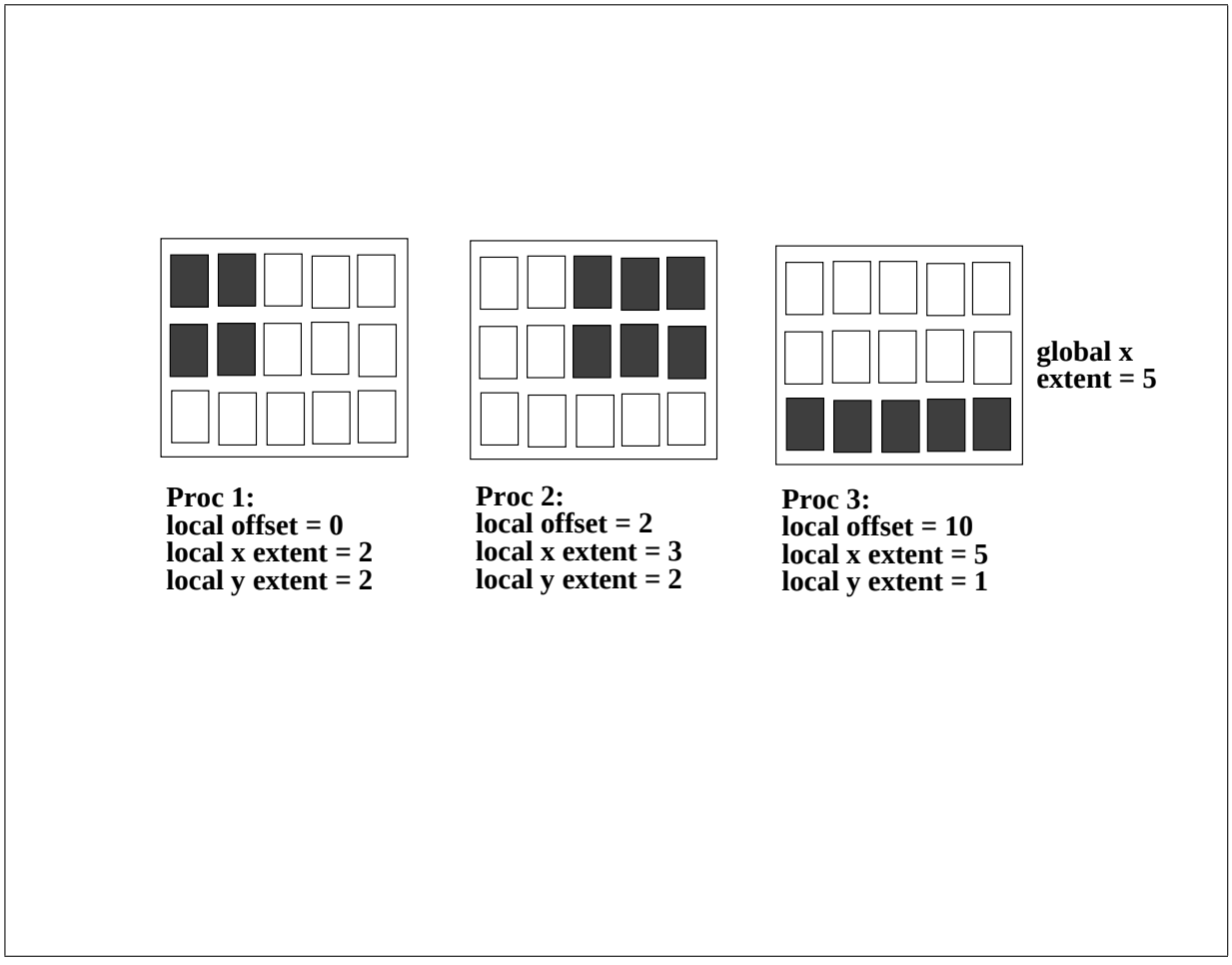
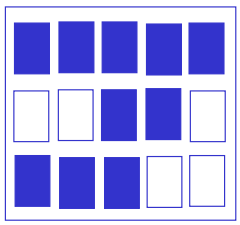


Figure 2.4: Box partition. It is assumed here that the global index starts at 0 in the upper left corner.



Proc 1:
nbr of segments = 3

1st segment offset = 0
1st segment size = 5
2nd segment offset = 7
2nd segment size = 2
3rd segment offset = 10
3rd segment size = 3

Figure 2.5: Orange partition for one process. It is assumed here that the global index starts at 0 in the upper left corner.

Orange partition

Each partition is an ensemble of segments in the global domain. Each segment is described by its global offset and its local extent. In this case, we have `ig_paral(1:N)` where `N = 2 + 2*number of segments`

- `ig_paral(1)` = 3 (indicates a Orange partition)
- `ig_paral(2)` = the total number of segments for the partition (limited to 200 presently, see note for ig_paral(4) for Box partition above)
- `ig_paral(3)` = the first segment global offset
- `ig_paral(4)` = the first segment local extent
- `ig_paral(5)` = the second segment global offset
- `ig_paral(6)` = the second segment local extent
- ...
- `ig_paral(N-1)` = the last segment global offset
- `ig_paral(N)` = the last segment local extent

Figure 2.5 illustrates an Orange partition with 3 segments for one process. The other process partitions are not illustrated.

Points partition

This partition is a list of global indices associated with each process. The index naming is arbitrary but must be consistent between all processes involved in the partition description. In this case, we have

`ig_paral(1:N)` where `N = 2 + number of points`

- `ig_paral(1)` = 4 (indicates a Points partition)
- `ig_paral(2)` = number of points in the partition
- `ig_paral(3)` = the first global index
- `ig_paral(4)` = the second global index
- ...
- `ig_paral(N)` = the last global index

2.2.4 Grid data file definition

Grid data files (see section 5.1) are required by OASIS3-MCT for specific operations , i.e. *grids.nc* and *masks.nc* for `SCRIPR` (see section 4.3), and *masks.nc* and *areas.nc* for `CONSERV` (see section 4.4). These grid data files can be created by the user before the run or can be written directly at run time by the components with the following routines. If a grid data files does not exist, the corresponding routine will create it; if the grid data file exists, the routine can be used to **add** grid definition fields but it will not **overwrite** grid definition fields already existing in the file with the same grid name.

These routines can be called only by one component process to write the whole grid or by each process holding a part of a grid. In the former case, optional argument `il_part_id` is not needed and the arrays (see below) handling the longitudes of the grid points or corners (`lon`, `clon`), the latitudes of the grid points or corners (`lat`, `clat`), the masks (`mask`) and areas (`area`) of the grid cells need to cover the whole grid; in the later case, the `il_part_id` returned by `oasis_def_partition` needs to be provided as input argument and the arrays need to cover only the local partition of the grid .

- `CALL oasis_start_grids_writing (flag)` or
- `CALL prism_start_grids_writing (flag)`
  - `flag [INTEGER; OUT]`: always 1

  Must be called to start the grid writing process.

- `CALL oasis_write_grid (cgrid, nx_global, ny_global, lon, lat, il_part_id)`
- `CALL prism_write_grid (cgrid, nx_global, ny_global, lon, lat, il_part_id)`
  - `cgrid [CHARACTER; IN]`: grid name prefix (see 3.3 and 5.1); maximum length of 64 characters (4 are usually used for historical reasons)
  - `nx_global [INTEGER; IN]` : first dimension of the global grid
  - `ny_global [INTEGER; IN]` : second dimension of the global grid (`=0` if the grid is expressed as a 1D vector)
  - `lon [REAL, DIMENSION(nx,ny); IN]` : single or double real array of longitudes covering the whole grid (`nx=nx_global`, `ny=ny_global`) or only the local partition (degrees East).
  - `lat [REAL, DIMENSION(nx,ny); IN]` : single or double real array of latitudes covering the whole grid (`nx=nx_global`, `ny=ny_global`) or only the local partition (degrees North)
  - `il_part_id [INTEGER, OPTIONAL; IN]`: partition ID returned by `oasis_def_partition`, see 2.2.3; needed if each component task holding a part of a decomposed grid writes its own part of the grid.

  Writes the component grid longitudes and latitudes. Longitudes must be given in degrees East in the interval -360.0 to 720.0. Latitudes must be given in degrees North in the interval -90.0 to 90.0. Note that if some grid points overlap, it is recommended to define those points with the same number (e.g. 90.0 for both, not 450.0 for one and 90.0 for the other) to ensure automatic detection of overlap by

OASIS3-MCT (which is essential to have a correct conservative remapping SCRIPR/CONSERV, see section 4.3).

- CALL oasis_write_corner (cgrid, nx_global, ny_global, nc, clon, clat, il_part_id))
- CALL prism_write_corner (cgrid, nx_global, ny_global, nc, clon, clat, il_part_id))
  - cgrid , nx_global , ny_global , il_part_id : as for oasis_write_grid
  - nc [INTEGER; IN] : number of corners per grid cell (always 4 in the version)
  - clon [REAL, DIMENSION (nx,ny,nc);IN] : single or double real array of corner longitudes covering the whole grid (nx=nx_global, ny=ny_global) or only the local partition (in degrees_East)
  - clat [REAL, DIMENSION (nx,ny,nc);IN] : single or double real array of corner latitudes covering the whole grid (nx=nx_global, ny=ny_global) or only the local partition (in degrees_North)

  Writes the grid cell corner longitudes and latitudes (counterclockwise sense). Longitudes must be given in degrees East in the interval -360.0 to 720.0. Latitudes must be given in degrees North in the interval -90.0 to 90.0. Note also that cells larger than 180.0 degrees in longitude are not supported. Writing of corners is optional as corner information is needed only for SCRIPR/CONSERV (see section 4.3). If called, needs to be called after oasis/prism_write_grid.

- CALL oasis_write_mask (cgrid, nx_global, ny_global, mask, il_part_id)
- CALL prism_write_mask (cgrid, nx_global, ny_global, mask, il_part_id)
  - cgrid , nx_global , ny_global , il_part_id : as for oasis_write_grid
  - mask [INTEGER, DIMENSION(nx,ny) ;IN] : mask array covering the whole grid (nx=nx_global, ny=ny_global) or only the local partition (be careful about the OASIS historical convention (!): 0 = not masked, 1 = masked)

  Writes the component grid mask.

- CALL oasis_write_area (cgrid, nx_global, ny_global, area, il_part_id)
- CALL prism_write_area (cgrid, nx_global, ny_global, area, il_part_id)
  - cgrid , nx_global , ny_global , il_part_id : as for oasis_write_grid
  - area [REAL, DIMENSION(nx,ny); IN] : single or double real array of grid cell areas covering the whole grid (nx=nx_global, ny=ny_global) or only the local partition

  Writes of the component grid cell areas. Needed only for CONSERV operation (see section 4.4).

- CALL prism_terminate_grids_writing() or
- CALL oasis_terminate_grids_writing()

The creation of the different grid data files is effective in the routine oasis_enddef.

2.2.5 Coupling field declaration

All processes of a component that send or receive a coupling field, or a part of it, needs to declare the coupling field.

Processes not implied in the coupling do not have to call this routine at all (for backward compatibility with OASIS3-MCT_2.0, they may still call it with any name and il_part_id).

- CALL oasis_def_var (var_id, name, il_part_id, var_nodims, kinout, var_actual_shape, var_type, ierror) or

- `CALL prism_def_var_proto(var_id, name, il_part_id, var_nodims, kinout, var_actual_shape, var_type, ierror)`
  - `var_id [INTEGER; OUT]`: coupling field ID. Note that all coupling fields appearing in the *namcouple* must be defined with a call to `oasis_def_var`; not doing so would lead to an abort. But all fields defined with a call to `oasis_def_var` must not necessarily appear in the *namcouple*. If a field does not appear in the *namcouple*, the `var_id` returned by the `oasis_def_var` will be equal to -1; the value of the `var_id` should be tested and the corresponding `oasis_put` and `oasis_get` should not be called if `var_id` equals -1. These constraints are imposed to avoid that a typo in the *namcouple* would lead to coupling exchanges not corresponding to what the user intends to activate.
  - `name [CHARACTER; IN]`: field symbolic name (as in the *namcouple*); maximum length of 80 characters
  - `il_part_id [INTEGER; IN]`: partition ID returned from `oasis_def_partition` (see section 2.2.3)
  - `var_nodims [INTEGER, DIMENSION(2); IN]`: var_nodims(1) is not used anymore in OASIS3-MCT so its value can be anything but it is still part of the oasis_def_var arguments; var_nodims(2) is the number of fields in a bundle (this will be 1 for unbundled fields or greater than 1 for fields that are bundled).
  - `kinout [INTEGER; IN]`: `OASIS_In` or `PRISM_In` (i.e. = 21) for fields received by the component; `OASIS_Out`, `PRISM_Out` (i.e. = 20) for fields sent by the component [2].
  - `var_actual_shape [INTEGER, DIMENSION(2*var_nodims(1)); IN]`: vector of integers giving the minimum and maximum index for each dimension of the coupling field array; for the current OASIS3-MCT version, the minimum index has to be 1 and the maximum index has to be the extent of the dimension.
  - `var_type [INTEGER; IN]`: type of coupling field array; put `OASIS_Real` or `PRISM_Real` (i.e. = 4) for single or double precision real arrays. All coupling data is treated as double precision in the coupling layer, but conversion to or from single precision data is supported in the interface.
  - `ierror [INTEGER; OUT]`: returned error code.

2.2.6 End of definition phase

All processes of components at least partly involved in the coupling (e.g. `comp3` in figure 2.2) have to close the definition phase. Different configurations of components and corresponding use of `oasis_enddef` are described in section 2.1 and on figures 2.1 and 2.2.

- `CALL oasis_enddef (ierror)`
- `CALL prism_enddef_proto(ierror)`
  - ierror [INTEGER; OUT]: returned error code.

2.2.7 Sending "put" and receiving "get" actions

This section describes how to send (put) and receive (get) fields through the coupling interface. This interface supports several ranks and types of coupling fields. First, the fields passed into the interface can be 4 byte or 8 byte reals. The field decomposition must be consistent with the decomposition defined in the grid partition (see 2.2.3)[3] Third, the fields can be bundled, i.e. have an extra (non-spatial) dimension

[2] Parameters OASIS_In, PRISM_In, OASIS_Out, PRISM_Out are defined in oasis3-mct/lib/psmile/src/mod_oasis_parameters.F90

[3] But the decomposition of each field can be either one dimensional or two dimensional and does not have to match the rank of the grid partition.

like for a field covering different ice categories. The bundled dimension is always the last dimension in any field passed into the get and put routines. And the size of the bundle dimension must match the value defined for the variable in var_nodims(2) in the `oasis_def_var` interface (see section 2.2.5).

So in general, the fields passed into the get and put interface can have rank 1, 2, or 3 and include the following possible options where fld can be a 4 byte or 8 byte real array.

- 1D, fld(:) = an single, unbundled field of decomposition rank 1.
- 2D, fld(:,:) = a single, unbundled field of decomposition rank 2.
- 1D bundled, fld(:,:) = a bundled set of fields of decomposition rank 1. The size of the second dimension must equal the number of fields in the bundle, defined by var_nodims(2) in the `oasis_def_var` interface.
- 2D bundled, fld(:,:,:) = a bundled set of fields of decomposition rank 2. The size of the third dimension must equal the number of fields in the bundle, defined by var_nodims(2) in the `oasis_def_var` interface.

Different bundled fields can have different numbers of fields, but for a given bundled field, the number of fields must match on the send and receive side. This is explicitly checked within the coupling layer and will lead to an abort if not done correctly. It is possible to define a 1D bundled or 2D bundled field with a bundle dimension of 1, i.e. for a bundle that contains only one single field.

Finally, the bundled field option can be used to bundle together multi-level variables, multiple related fields, and other types of fields. The fields must share a common partition and common namcouple settings (e.g. interpolation) to be bundled. While this is a useful feature for multi-level fields, **this does not mean that 3D interpolation is supported**. Each field in the bundle is treated internally as a separate field in the coupling layer without any information about the relationship between the fields in the bundle. In fact, the bundled field variables are internally renamed and a field number is appended to the variable name to keep track of the distinct fields in the bundle. That updated variable name will appear in restart and output files.

Sending a coupling (or I/O) field or writing a coupling restart file

In the component time step loop, each process sends its part of the coupling (or I/O) field.

- `CALL oasis_put (var_id, date, fld1, info, fld2, fld3, fld4, fld5, write_restart)`
- `CALL prism_put_proto(var_id, date, fld1, info, fld2, fld3, fld4, fld5, write_restart)`
  - `var_id [INTEGER; IN]`: field ID (returned from corresponding `oasis_def_var`, see section 2.2.5)
  - `date [INTEGER; IN]`: number of seconds (or any other time units as long as the same are used in all components and in the *namcouple*) at the time of the call (by convention at the beginning of the timestep)
  - `fld1 [REAL, IN]`: coupling (or I/O) field array; can be 1D, 2D, bundled 1D, or bundled 2D, see baove.
  - `info [INTEGER; OUT]`: returned info code:
    - `OASIS_Sent` (=4) if the field was sent to another component
    - `OASIS_LocTrans` (=5) if the field was only used in a time transformation (not sent, not output)
    - `OASIS_ToRest` (=6) if the field was written to a restart file only
    - `OASIS_Output` (=7) if the field was written to an output file only
    - `OASIS_SentOut` (=8) if the field was both written to an output file and sent to another component

    * OASIS_ToRestOut (=9) if the field was written both to a restart file and to an output file.
    * OASIS_WaitGroup (=14) if the field was not sent because it is part of a group. It will be sent only when the oasis_put of the last field in the group will be called; however, the field is buffered and therefore the field array can be modified in the component code when returning from the oasis_put call.
    * OASIS_Ok (=0) otherwise and no error occurred.
  - fld2 [REAL, IN, OPTIONAL]: optional 2^{nd} coupling field array; can be 1D, 2D, bundled 1D, or bundled 2D. Rank and size must match fld1.
  - fld3 [REAL, IN, OPTIONAL]: optional 3^{rd} coupling field array; can be 1D, 2D, bundled 1D, or bundled 2D. Rank and size must match fld1.
  - fld4 [REAL, IN, OPTIONAL]: optional 4^{th} coupling field array; can be 1D, 2D, bundled 1D, or bundled 2D. Rank and size must match fld1.
  - fld5 [REAL, IN, OPTIONAL]: optional 5^{th} coupling field array; can be 1D, 2D, bundled 1D, or bundled 2D. Rank and size must match fld1.
  - write_restart [LOGICAL, IN, OPTIONAL]: optional argument to write an intermediate restart file associated with the variable var_id at the current timestep (see below).

To ensure a proper use of the oasis_put, one has to take care of the following aspects:

- A 2^{nd}, 3^{rd}, 4^{th} and 5^{th} source field can be passed as optional arguments. If so, the 2^{nd}, 3^{rd}, 4^{th} and 5^{th} set of weights present in the remapping file will be applied, respectively (see section 5.4 for the remapping file format). This will be used for example for the SCRIPR/BICUBIC remapping for which a 1^{st}, 2^{nd}, 3^{rd}, 4^{th} set of weights should be respectively applied to the field value, its gradient in the first dimension, its gradient in the second dimension, and its cross-gradient. Bicubic and higher order remapping are therefore supported given that the higher order fields are provided at each time step as oasis_put arguments. Note that if fld3, or fld4, or fld5 are passed, fld2, or fld3 and fld2, or fld4 and fld3 and fld2 must also be passed respectively.
- **Note that from OASIS3-MCT_4.0 onwards, the number of weights in the remapping file and the number of fields in the coupling restart file (when such a file is needed) must strictly match the number of source fields passed to the oasis_put .**
- This routine may be called by the component at each timestep. The convention for the date argument is to indicate the time at the beginning of the timestep. The sending is actually performed if the time obtained by adding the field lag (LAG in the *namcouple*, if any, with LAG=0 by default) to the date corresponds to a time at which it should be activated, given the coupling or I/O period indicated by the user in the *namcouple* (see section 3).
- By convention, the first coupling of a run occurs at date=0 and the final coupling occurs at date = runtime-cpl_period, where runtime is the total time of the run and cpl_period is the coupling period of the field indicated by the user in the *namcouple* (see section 3).
- For a coupling field with a positive lag, the coupling restart file (see section 5.2) is automatically overwritten by the oasis_put when the date+LAG=runtime.
- The total run time should match an integer number of coupling periods.
- If a local time transformation is indicated for the field by the user in the *namcouple* (INSTANT, AVERAGE, ACCUMUL, T_MIN or T_MAX, see section 4), it is automatically performed and the resulting field is finally sent at the coupling or I/O frequency. For non-instant transformations, partially transformed fields will be written to the restart file at the end of the run for use on the next component startup, when needed.
- A coupling field sent by a source component can be associated with more than one target field and component, if specified as so with different entries in the *namcouple* configuration file. In that case, the source component needs to send the field only once and the corresponding data will arrive at

multiple targets as specified in the *namcouple*. Different coupling frequencies and transformations are allowed for different coupling exchanges of the same field. If coupling restart files are required (either if a `LAG` or if a `LOCTRANS` transformation is specified), it is mandatory to specify different files for the different fields.

- Trying to send with `oasis_put` a field declared with a `oasis_def_var` but not defined in the configuration file *namcouple* will lead to an abort. When a field is not defined in the *namcouple*, the field ID returned by the `oasis_def_var` is equal to -1 and the corresponding `oasis_put` should not be called.
- Support to couple multiple fields via a single communication. This is supported through colon delimited field lists in the namcouple (see 3.3.1). All fields will use the namcouple settings for that entry. In the component model codes, these fields are still sent (**put**) one at a time. Inside OASIS3-MCT, the fields are stored and a single mapping and send instruction is executed for all fields. This is useful in cases where multiple fields have the same coupling transformations and to reduce communication costs by aggregating multiple fields into a single communication.

  This option does not put any constraint on the order of the related `oasis_put` and `oasis_get` in the codes.

  As they appear in one single entry line, these fields must share the same coupling restart file but this restart file may contain other fields.
- The optional argument, `write_restart`, in the `oasis_put` routine is **false** by default. If a user sets that argument to true, a restart file will be written for that field **only for that timestep**. The `write_restart` will just save the data that exists at the time of the call, taking into account lags and LOCTRANS operations. In cases where multiple fields are coupled as a single operation in the model (indicated via a list of colon delimited fields in the *namcouple*, see 3.3.1), users are encouraged to specify the `write_restart` flag on ALL `oasis_put` calls at a given time for this set of fields. Intermediate restarts will be created with a timestamp prepended to their filename, like TA000003600_rst4.nc or TC000014400_rst4.nc. A restart file that starts with TA will be a restart file associated with LOCTRANS operations. A restart file that starts with TC will be a restart file associated with coupling operations. The 9 digit timestamp in the filename is the date in seconds at the time of the oasis_put call. The restart filename (ie. rst4.nc) defined in the namcouple for variables will be used to generate a filename for intermediate restart files.

Receiving a coupling (or I/O) field

In the component time stepping loop, each process receives its part of the coupling field.

- `CALL oasis_get (var_id, date, fld, info)`
- `CALL prism_get_proto(var_id, date, fld, info)`
  - `var_id [INTEGER; IN]`: field ID (returned by the corresponding `oasis_def_var`)
  - `date [INTEGER; IN]`: number of seconds (or any other time units as long as the same are used in all components and in the *namcouple*) at the time of the call (by convention at the beginning of the timestep)
  - `fld [REAL, OUT]`: I/O or coupling field array; can be 1D, 2D, bundled 1D, or bundled 2D.
  - `info [INTEGER; OUT]`: returned info code:
    - OASIS_Recvd(=3) if the field was received from another component
    - OASIS_FromRest (=10) if the field was read from a restart file only
    - OASIS_Input (=11) if the field was read from an input file only
    - OASIS_RecvOut (=12) if the field was both received from another component and written to an output file

  - OASIS_FromRestOut (=13) if the field was both read from a restart file and written to an output file
  - OASIS_Ok (=0) otherwise and no error occurred.

To ensure a proper use of the `oasis_get`, one has to take care of the following aspects:

- This routine may be called by the component at each timestep. The `date` argument is automatically analysed and the receiving action is actually performed only if `date` corresponds to a time for which it should be activated, given the period indicated by the user in the *namcouple*. An exchange at the beginning of the run at time=0 is expected.
- Trying to receive with `oasis_get` a field declared with a `oasis_def_var` but not defined in the configuration file *namcouple* will lead to an abort. In this case, the field ID returned by the `oasis_def_var` is equal to -1 and the corresponding `oasis_get` should not be called.
- If a coupling field has a positive lag, the coupling field that matches the `oasis_get` at time=0 will come from a coupling restart file written by the last active `oasis_put` of the previous run (see section 2.3).
- Support to couple multiple fields via a single communication. This is supported through colon delimited field lists in the namcouple (see 3.3.1). All fields will use the namcouple settings for that entry. In the component model codes, these fields are still received (via an `oasis_get`) one at a time. Inside OASIS3-MCT, the fields are stored and a single mapping and receive instruction is executed for all fields. This is useful in cases where multiple fields have the same coupling transformations and to reduce communication costs by aggregating multiple fields into a single communication. If a LOCTRANS transformation is needed for these multiple fields, it is necessary to define a restart file for these multiple fields.

2.2.8 Termination

- `CALL oasis_terminate (ierror)`
- `CALL prism_terminate_proto(ierror)`
  - `ierror [INTEGER; OUT]`: returned error code.

  All processes of components at least partly involved in the coupling (e.g. `comp3` in figure 2.2) have to terminate the coupling by calling this routine[4](normal termination). Different configurations of components and corresponding use of `oasis_terminate` are described in section 2.1 and on figures 2.1 and 2.2.

2.2.9 Auxiliary routines

The following auxiliary routines are currently available.

- `CALL oasis_abort (compid, routine_name, abort_message, rcode)`
- `CALL prism_abort_proto(compid, routine_name, abort_message)`
  - `compid [INTEGER; IN]`: component ID (from `oasis_init_comp`)
  - `routine_name[CHARACTER*; IN]`: name of calling routine
  - `abort_message[CHARACTER*; IN]`: message to be written out.
  - `rcode [INTEGER, OPTIONAL; IN]`: Optional argument. When OASIS aborts, the error code returned to invoking environment is `rcode` if present, else it is 1.

  If a process needs to abort voluntarily, it should do so by calling `oasis_abort`. This will ensure a proper termination of all processes in the coupled model communicator. This routine writes the

[4]If the process called `MPI_Init` (before calling `oasis_init_comp`), it must also call `MPI_Finalize` explicitly, but only after calling `oasis_terminate_proto`.

name of the calling component, the name of the calling routine, and the message to the process debug file (see `$NLOGPRT` in section 3.2). This routine cannot be called before `oasis_init_comp`.

- `CALL oasis_get_debug(debug_value)`
- `CALL prism_get_debug(debug_value)`
  - `debug_value [INTEGER; OUT]`: debug value

  This routine may be called at any time to retrieve the current OASIS3-MCT internal debug level (see `$NLOGPRT` in section 3.2). This is useful if the user wants to return the original debug value after changing it.

- `CALL oasis_set_debug(debug_value)`
- `CALL prism_set_debug(debug_value)`
  - `debug_value [INTEGER; IN]`: debug value

  This routine may be called at any time to change the debug level in OASIS3-MCT. This method allows users to vary the debug level at different points in the component integration.

- `CALL oasis_get_intercomm(new_comm, cdnam, kinfo)`
- `CALL prism_get_intercomm(new_comm, cdnam, kinfo)`
  - `new_comm [INTEGER; OUT]`: mpi intercomm communicator
  - `cdnam [CHARACTER*; IN]`: other component name (i.e. 2nd argument of the call to `oasis_init_comp` in that component)
  - `kinfo [INTEGER; OUT; OPTIONAL]`: returned error code

  This routine sets up an MPI intercomm communicator between the root processors of two components, the local component and the component associated with `cdnam`. This call is collective across the tasks of the two components but other components are not involved.

- `CALL oasis_get_intracomm(new_comm, cdnam, kinfo)`
- `CALL prism_get_intracomm(new_comm, cdnam, kinfo)`
  - `new_comm [INTEGER; OUT]`: mpi intracomm communicator
  - `cdnam [CHARACTER*; IN]`: other component name (i.e. 2nd argument of the call to `oasis_init_comp` in that component)
  - `kinfo [INTEGER; OUT; OPTIONAL]`: returned error code

  This routine sets up an MPI intracomm communicator between the root processors of two components, the local component and the component associated with `cdnam` . This call is collective across the tasks of the two components but other components are not involved.
- `CALL oasis_put_inquire(var_id, date, kinfo)`
- `CALL prism_put_inquire_proto(var_id, date, kinfo)`
  - `var_id [INTEGER; IN]`: field ID (from corresponding oasis_def_var)
  - `date [INTEGER; IN]`: as in `oasis_put`, number of seconds (or any other time units as long as the same are used in all components and in the *namcouple*) in the run at the time of the call
  - `kinfo [INTEGER; OUT]`: returned info code
    - OASIS_Sent(=4) if the field would be sent to another component
    - OASIS_LocTrans (=5) if the field would be only used in a time transformation (not sent, not output)
    - OASIS_ToRest (=6) if the field would be written to a restart file only
    - OASIS_Output (=7) if the field would be written to an output file only

  - OASIS_SentOut (=8) if the field would be both written to an output file and sent to another component (directly or via OASIS3 main process)
  - OASIS_ToRestOut (=9) if the field would be written both to a restart file and to an output file.
  - OASIS_Ok (=0) otherwise and no error occurred.

  This routine may be called at any time to inquire what would happen to the corresponding field (i.e. with same `var_id` and at same `date`) below the corresponding `oasis_put`. This maybe useful if, for example, the calculation of a coupling field is costly and if one wants to compute it only when it is really sent out.

- `CALL oasis_get_ncpl(var_id, ncpl, kinfo)`
- `CALL prism_get_ncpl_proto(var_id, ncpl, kinfo)`
  - `var_id [INTEGER; IN]`: field ID (from corresponding oasis_def_var)
  - `ncpl [INTEGER; OUT]`: number of coupling exchanges in which the field is involved (i.e. when a field is sent to multiple targets)
  - `kinfo [INTEGER; OUT]`: returned info code

  This routine returns the number of coupling exchanges in which the field var_id is involved. This number is needed to get the coupling frequencies with the routine oasis_get_freqs, see below.
- `CALL oasis_get_freqs(var_id, ncpl, cpl_freqs, kinfo)`
- `CALL prism_get_freqs_proto(var_id, ncpl, cpl_freqs, kinfo)`
  - `var_id [INTEGER; IN]`: field ID (from corresponding oasis_def_var)
  - `ncpl [INTEGER; IN]`: number of couplings in which the field is involved (i.e. when a field is sent to multiple targets)
  - `cpl_freqs [INTEGER; DIMENSION(ncpl); OUT]`: coupling period(s) (in number of seconds) of field var_id. There is one coupling period for each coupling exchange in which the field is involved
  - `kinfo [INTEGER; OUT]`: returned info code

  This routine can be used to retrieve the coupling period(s) of field with corresponding `var_id`, as defined in the *namcouple*

2.3 Coupling algorithms - LAG and SEQ concepts

Using the OASIS3-MCT coupling library, the user has full flexibility to reproduce different coupling algorithms. In the components, the sending and receiving routines, respectively `oasis_put` and `oasis_get`, can be called at each component timestep, with the appropriate `date` argument giving the actual time (at the beginning of the timestep), expressed in number of seconds since the start of the run, or in any other time units as long as the same are used in all components and in the *namcouple* (see section 2.2.7). This `date` argument is automatically analysed by the coupling library and depending on the coupling period and the lag chosen by the user for the coupling field in the *namcouple* (`LAG`), different coupling algorithms can be reproduced without modifying the component codes themselves.

With OASIS3-MCT, a sequence index specified for a coupling field in the *namcouple* (`SEQ`), provides the coupling layer with an ability to detect a deadlock before it happens and exit.

The LAG and SEQ concept are explained in more detail below and some examples are provided.

2.3.1 The lag concept

The lag (`LAG`) must be expressed in the time unit used (that must be the same in the components and in the *namcouple*, see section 2.2.7) and can be positive or negative but should never be larger (in absolute magnitude) than the coupling period of any field due to problems with restartability and dead-locking.

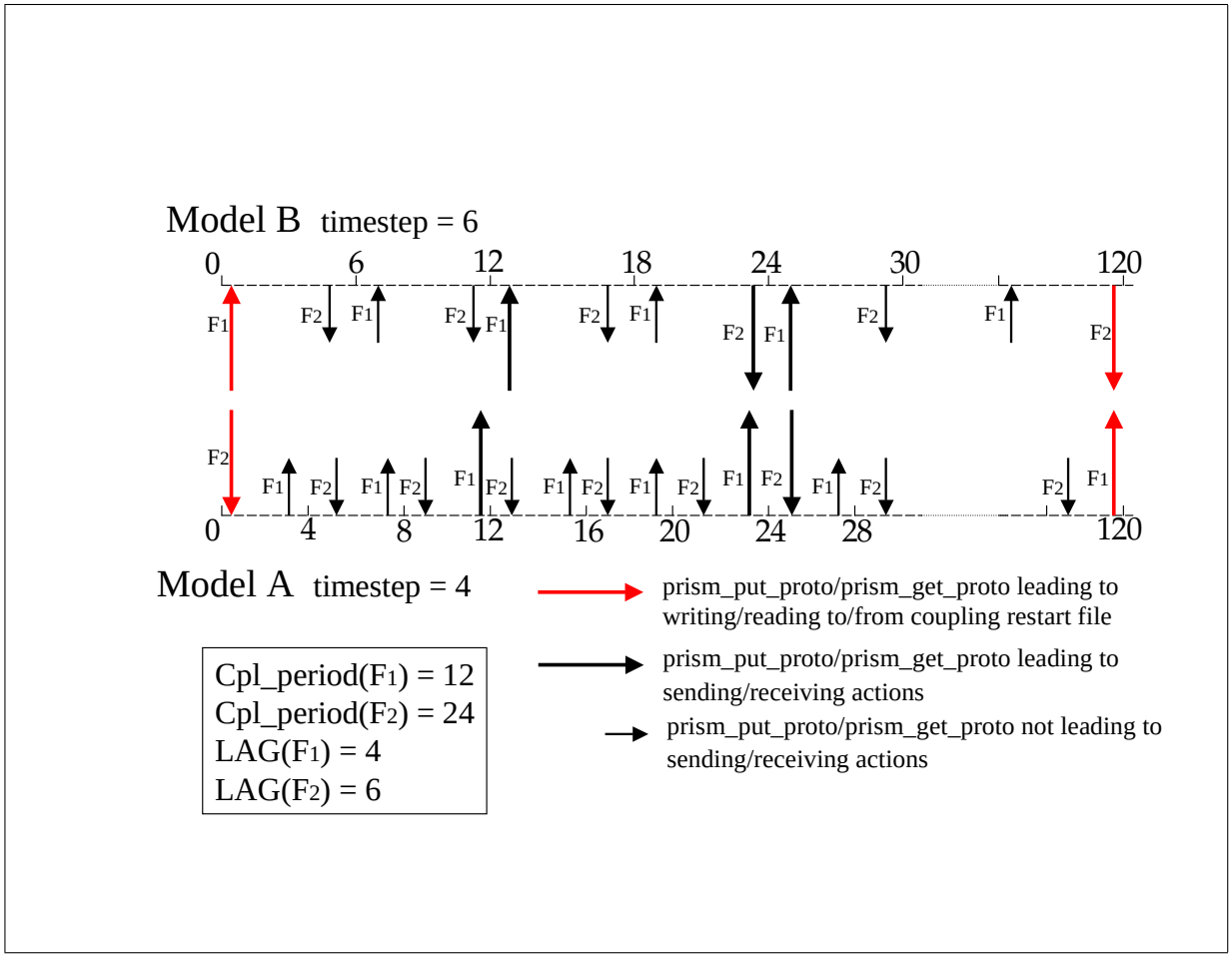


Figure 2.6: LAG concept first example

When a component calls a `oasis_put`, the value of the lag is automatically added to the value of the `date` argument and the "put" is actually performed when the sum `date+lag` is a coupling time; in the target component, this "put" will match a `oasis_get` for which the `date` argument is the same coupling time. So the lag only shifts the time at which the data is sent but not the time at which the data is received.

When the lag is positive, a restart file must be available to initiate the coupling. For a field with positive lag, the source component automatically reads the field in the restart file during the coupling initialization phase (below the `oasis_enddef`) and send the data to match the `oasis_get` performed at time=0 in the target component. The final coupling data on the source side will then be automatically written to the restart file for use in the next run[5].

On the 4 figures in this section, short black arrows correspond to `oasis_put` or `oasis_get` called in the component that do not lead to any "put" or receiving action; long black arrows correspond to `oasis_put` or `oasis_get` called in the components that do actually lead to a "put" or "get" action; long red arrows correspond to `oasis_put` or `oasis_get` called in the component models that lead to a reading or writing of the coupling field from or to a coupling restart file.

1. LAG concept first example

   A first coupling algorithm, exploiting the LAG concept, is illustrated on figure 2.6.

   During a coupling timestep, model A receives F_2 and then sends F_1; its timestep length is 4. During a coupling timestep, model B receives F_1 and then sends F_2; its timestep length is 6. F_1 and F_2 coupling periods are respectively 12 and 24. If F_1/F_2 "put" action by model A/B was used at a coupling timestep to match the model B/A "get" action, a deadlock would occur as both models

[5] When there is a lag, the first and last instance of the source field in the debug netCDF file (EXPOUT fields, see section 3.3) always correspond respectively to the field read from and written to the restart file.

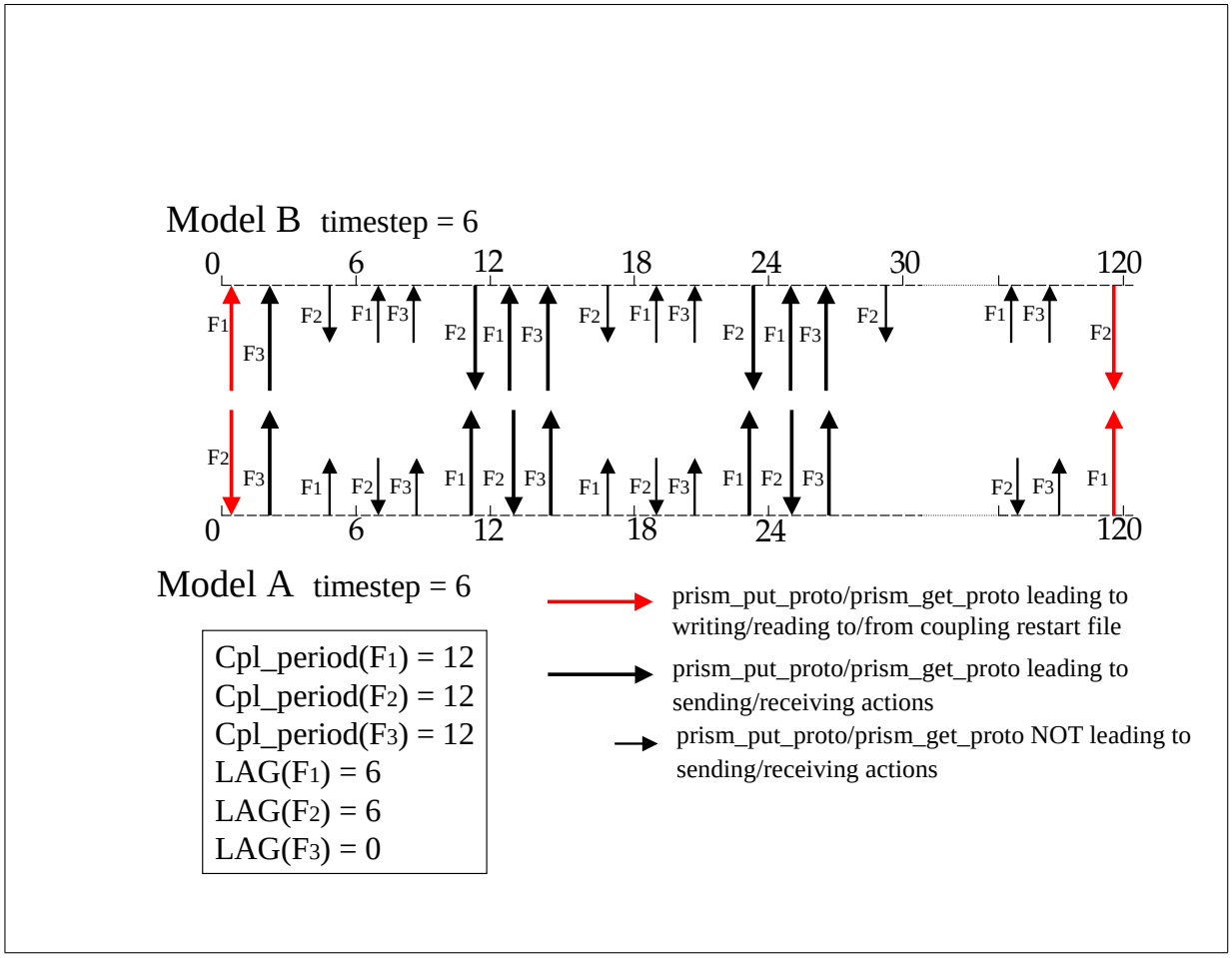


Figure 2.7: LAG concept second example

would be initially waiting on a "get" action. To prevent this, F_1 and F_2 produced at the timestep before have to be used to match respectively the model B and model A "get" actions.

This implies that a lag of respectively 4 and 6 seconds must be defined for F_1 and F_2. For F_1, the `oasis_put` performed at time 8 and 20 by model A will then lead to "put" actions (as 8 + 4 = 12 and 20 + 4 = 24 which are coupling periods) that match the "get" actions performed by `oasis_get` called by model B at times 12 and 24. For F_2, the `oasis_put` performed at time 18 by model B then leads to a "put" action (as 18 + 6 = 24 which is a coupling period) that matches the "get" action performed at time 24 by the `oasis_get` called by model A.

At the beginning of the run, as their LAG index is greater than 0, the first `oasis_get` of F_1 and F_2 will automatically be fulfilled with fields read from their respective coupling restart files. The user therefore has to create those coupling restart files before the first run in the experiment. At the end of the run, F_1 having a lag greater than 0, is automatically written to its coupling restart file below the last F_1 `oasis_put` as the `date+lag` equals the total run time. The analogue is true for F_2. These coupling restart fields will automatically be read in at the beginning of the next run below the respective `oasis_get`.

2. LAG concept second example

   A second coupling algorithm exploiting the LAG concept is illustrated on figure 2.7. During its timestep, model A receives F_2, sends F_3 and then F_1; its timestep length is 6. During its timestep, model B receives F_1, receives F_3 and then sends F_2; its timestep length is also 6. F_1, F_2 and F_3 coupling periods are both supposed to be equal to 12.

   For F_1 and F_2 the situation is similar to the first example. Without any lag specified and without any restart file, a deadlock would occur as both models would be waiting on a "get" action. To prevent

this, F_1 and F_2 produced at the timestep before have to be used to match the model A and model B "get" actions, which means that a lag of 6 must be defined for both F_1 and F_2. For both coupling fields, the `oasis_put` performed at times 6 and 18 by the source model then lead to "put" actions (as 6 + 6 = 12 and 18 + 6 = 24 which are coupling periods) that match the "get" action performed at time 12 and 24 by the `oasis_get` called by the target model.

For F_3, sent by model A and received by model B, no lag needs to be defined: the coupling field produced by model A at the coupling timestep can be "consumed" by model B without causing a deadlock situation.

As in the first example, the `oasis_get` performed at the beginning of the run for F_1 and F_2, will automatically receive data read from their coupling restart files, and the last `oasis_put` performed at the end of the run automatically write them to their coupling restart file. For F_3, no coupling restart file is needed.

We see here how the introduction of appropriate LAG indices results in receiving in the target component the coupling fields produced by the source component the time step before; this is, in some coupling configurations, essential to avoid deadlock situations.

2.3.2 The sequence concept

The order of coupling operations in the system is determined solely by the order of calls to send (`oasis_put` or "put") and receive (`oasis_get` or "get") data in the components in conjunction with the setting of the lag in the *namcouple*. Data that is received is always blocking while data that is sent is non-blocking with respect to the component making that call. It is possible to deadlock the system if the relative orders of puts and gets in different components are not compatible.

With OASIS3-MCT, the sequence (SEQ) index in the *namcouple* file now provides the coupling layer with an ability to detect a deadlock before it happens and exit. It does this by tracking the order of get and put calls in components compared to the SEQ specified in the *namcouple*. If there are any inconsistencies, the component will abort gracefully with a useable error message before the system deadlocks. If there are any coupling dependencies in the system, use of the SEQ index is recommended for diagnosis but has no impact on the ultimate solution and is NOT required.

In the following two examples, there are two models, each "put" a field to the other at every coupling period without any lags. In the first case, there is no dependency as each model first sends and then receives some data.

```
 model1          model2
 ------          ------
put(fld1)       put(fld2)
get(fld2)       get(fld1)
```

In this case, there is no sequencing dependency and the value of SEQ must be identical (or unset) in the *namcouple* description of the fld1 and fld2 coupling. If by mistake, SEQ is set to 1 for fld1 and 2 for fld2, then the coupled model will abort because at runtime, the coupler will detect in model 2 that fld2 was sent before fld1 was received which is out of sequence as defined by the SEQ settings.

In the next example, there is a dependency in the sequencing.

```
 model1          model2
 ------          ------
put(fld1)       get(fld1)
                fld2=g(fld1)
get(fld2)       put(fld2)
```

In model2, fld2 depends on fld1. If SEQ is not used and if, for example, model1 does not have the consistent ordering of the put and get shown above (required by model2), then the models would deadlock and hang. If this dependency is known, there is a benefit in setting SEQ=1 for fld1 and SEQ=2 for fld2;

at runtime, if the sequencing of model1 or model2 does not match the above diagram, then the coupling layer will detect it and will exit gracefully with an error message.

Again, the SEQ namecouple setting is only diagnostic and is not required.

Chapter 3

The configuration file *namcouple*

The OASIS3-MCT configuration file *namcouple* contains, below pre-defined keywords, all user-defined information necessary to configure a particular coupled run.

The *namcouple* is a text file with the following characteristics:

- the keywords used to separate the information can appear in any order;
- the number of blanks between two character strings is non-significant;
- all lines beginning with # are ignored and considered as comments;
- blank lines are supported, but only since OASIS3-MCT_4.0 version.

The first part of *namcouple* is devoted to configuration of general parameters such as the total run time or the desired debug level. The second part gathers specific information on each coupling (or I/O) field, e.g. their coupling period, the list of transformations or remapping to be performed by OASIS3-MCT and associated configuring lines (described in more details in chapter 4).

In OASIS3-MCT, several *namcouple* inputs have been deprecated but, for backwards compatibility, they are still allowed. These inputs will be noted in the following text using the notation "UNUSED" and not fully described. Information below these keywords is obsolete; they will not be read and will not be used.

In the next sections, a *namcouple* example is given and all configuring parameters are described. Additional lines containing different parameters for each transformation are described in section 4. A realistic *namcouple* can be found in `oasis3-mct/examples/tutorial/data_oasis3/` directory.

3.1 An example of a simple *namcouple*

The following simple *namcouple* configures a run into which e.g. an ocean, an atmosphere and an atmospheric chemistry components are coupled. The ocean running on grid `toce` provides only the SOSSTSST field to the atmosphere (grid `atmo`), which in return provides the field CONSFTOT to the ocean. One field COSENHFL is exchanged from the atmosphere to the atmospheric chemistry (also running on grid `atmo`), and one field SOALBEDO is read from a file by the ocean.

```
########## First section ##############################################
 $NFIELDS
    4
#
 $RUNTIME
    432000
#
 $NLOGPRT
   2     1
```

```
#
 $NUNITNO
   901     920
#
 $NMAPDEC
   decomp_wghtfile
#
 $NMATXRD
   ceg
#
 $NWGTOPT
   ignore_bad_index
#
 $SEQMODE
 $CHANNEL
 $JOBNAME
 $NBMODEL
 $INIDATE
 $MODINFO
 $CALTYPE
#
########## Second section ##############################################
#
 $STRINGS
#
# Field 1
 SOSSTSST SISUTESU 1 86400  5  sstoc.nc  EXPORTED
 182  149  128  64  toce  atmo   LAG=+14400  SEQ=+1
 P 2 P 0
 LOCTRANS CHECKIN MAPPING  BLASNEW CHECKOUT
#
  AVERAGE
  INT=1
  map_toce_atmo_120315.nc src opt
  1.0  1
  CONSTANT     273.15
  INT=1
#
# Field 2
 CONSFTOT SOHEFLDO 6 86400  4   flxat.nc  EXPORTED
 atmo   toce  LAG=+14400  SEQ=+2
 P 0 P 2
 LOCTRANS  CHECKIN  SCRIPR CHECKOUT
#
  ACCUMUL
  INT=1
  BILINEAR LR SCALAR LATLON 1
  INT=1
#
# Field 3
 COSENHFL  SOSENHFL  37  86400   1  flda3.nc  IGNOUT
```

```
 atmo   atmo LAG=+7200
 LOCTRANS
 AVERAGE
#
# Field 4
 SOALBEDO SOALBEDO  17  86400  0  SOALBEDO.nc  INPUT
```

3.2 First section of *namcouple* file

The first section of *namcouple* uses some predefined keywords prefixed by the $ sign to locate the related information. The $ sign must be the first non-blank character on the line but can be in any column. Only 5 keywords are really used since OASIS3-MCT_3.0 version and 2 of these 5 are optional :

- `$NFIELDS`: On the line below this keyword, put a number equal (or greater) to the total number of field entries in the second part of the *namcouple*. If more than one field are described on the same line, this counts as only one entry.
- `$RUNTIME`: On the line below this keyword, put the total simulated time of the run, expressed in seconds (or any other time units as long as the same are used in all components and in the *namcouple*, see 2.2.7).
- `$NLOGPRT`: The first and second numbers on the line below this keyword refer to the amount of debug and time statistic information written by OASIS3-MCT for each component and process.

  The first number (that can be modified at runtime with the `oasis_set_debug` routine, see section 2.2.9) may be:
  - 0 : production mode. One file debug.root.xx is open by the master process of each component and one file debug_notroot.xx is open for all the other processes of each component to write only error information.
  - 1 : one file debug.root.xx is open by the master process of each component to write information equivalent to level 10 (see below) and also to write memory usage information; one file debug_notroot.xx is open for all the other processes of each component to write error information.
  - 2 : one file debug.yy.xxxxxx is open by each process of each component (with "yy being the component number and "xxxxxx the process number) to write normal production diagnostics and memory usage information
  - 5 : as for 2 with in addition some initial debug info
  - 10: as for 5 with in addition the routine calling tree
  - 12: as for 10 with in addition some routine calling notes
  - 15: as for 12 with even more debug diagnostics
  - 20: as for 15 with in addition some extra runtime analysis
  - 30: full debug information

  The second number defines how time statistics are written out to file *comp_name*.timers_xxxx (with *comp_name* being the component name, see section 2.2.2); it can be:
  - 0 : nothing is calculated or written.
  - 1 : some time statistics are calculated and written in a single file by the processor 0 as well as the min and the max times over all the processors.
  - 2 : some time statistics are calculated and each processor writes its own file ; processor 0 also writes the min and the max times over all the processors in its file.
  - 3 : some time statistics are calculated and each processor writes its own file ; processor 0 also writes in its file the min and the max times over all processors and also writes in its file all the

results for each processor.

For more information on the time statistics written out, see section 6.4.2.

The second number can also be set to -1 to activate the *lucia* tool that can be used to perform an analysis of the coupled components load balance. More information can be found in the README file in `oasis3-mct/util/lucia` directory and report mentioned therein.

- `$NUNITNO`: Optional (new in OASIS3-MCT_4.0); on the line below this keyword are two integers that indicate the minimum and maximum unit numbers to be used for input and output files in the coupling layer. The user should choose values that will NOT conflict or overlap with unit numbers in use in any of the component models. The defaults are 1024 for the minimum and 9999 for the maximum unit number if not explicitly set by the user.
- `$NMAPDEC`: Optional (new in OASIS3-MCT_4.0); on the line below this keyword is a character string that indicates the mapping decomposition value to be used during local mapping. The options are `decomp_1d` and `decomp_wghtfile`. Option `decomp_1d` decomposes the grid in a simple one dimensional way while `decomp_wghtfile` decomposes the grid using the information in the remapping weight file to reduced mapping communication. Option `decomp_wghtfile` will take some extra time in initialization but it should result in faster mapping. The default is `decomp_1d` but it is recommended to test `decomp_wghtfile` to see if that option improves performance. More details can be found in (Craig et al 2018) and in (Valcke et al 2018).
- `$NMATXRD`: Optional (new in OASIS3-MCT_4.0); on the line below this keyword is a character string that indicates the method used to read remapping weights. There are two options, `orig` and `ceg`. In both, the weights are read in chunks by the root process. In the `orig` option, the weights are then broadcasted to all processes and each process then saves the weights needed in order to be consistent with the mapping decomposition. In the `ceg` option, the root process reads the weights and then decides which process each weight should be assigned to. A series of exchanges are then done and just the weights needed on each process are sent. The `orig` method sends much more data but is more parallel. The `ceg` method does most of the work on the root process but less data is communicated. The default option is `ceg`. More details can be found in (Craig et al 2018).
- `$NWGTOPT` : Optional (new in OASIS3-MCT_4.0); on the line below this keyword is a character string that indicates how to handle bad remapping weights. There are four options `abort_on_bad_index`, `ignore_bad_index`, `ignore_bad_index_silently`, and `use_bad_index`. Bad weights are defined as weights in the mapping file for which either the source or destination index are out of bounds relative to the number of grid cells in the grid; in that case, the weight is referencing a gridcell that does not physically exist. Note that an index equal to zero will not be considered as a bad index if the associated weight is also zero. There are other situations where the value of the actual mapping weight is scientifically incorrect, but this is not easy to detect and is not dealt with in OASIS3-MCT.
  - `abort_on_bad_index` will write error messages to the log files and abort if a bad weight index is detected. This is the default option.
  - `ignore_bad_index` will write an error message and then remove bad weights internally before continuing.
  - `ignore_bad_index_silently` will remove bad weights and continue without writing an error message.
  - `use_bad_index` will attempt to keep bad weights in the interpolation computation, but this can result in memory corruption, silent dropping of weights, and incorrect results ; this is not recommended.

  Note that the ability to check mapping files at runtime in OASIS3-MCT is limited. It is always recommended that mapping files be analyzed offline before long production runs are carried out. Checks can be done to make sure the source and destination indices are valid, that weights values are reasonable (for instance, between 0 and 1, although this will depend on the mapping method),

and that the sum of weights on the destination cells are reasonable (for instance, 1, in many cases). In addition, offline tests can be run with analytical functions to verify conservation, gradient preserving features and other characteristics associated with the particular mapping approach.

- `$NNOREST`: Optional (new in OASIS3-MCT_4.0); on the line below this keyword is a character string that can override the requirement that restart files must exist if they are needed. If the character string value starts with T, t, .T, or .t (as in true), then OASIS3-MCT will initialise with zero any variable that normally requires a restart (for instance, variables with LAG > 0) if the restart file does not exist. By default, missing restart files will cause the model to abort. It is strongly recommended that this keyword NOT be used in production runs. It exists to provide a quick shortcut for running technical tests. Note that if `$NNOREST` is true but the restart file nonetheless exists, it will be used.
- `$SEQMODE, $CHANNEL, $JOBNAME, $NBMODEL, $INIDATE, $MODINFO, $CALTYPE`: UNUSED

3.3 Second section of *namcouple* file

The second part of the *namcouple*, starting after the keyword `$STRINGS`, contains coupling information for each coupling (or I/O) field. Its format depends on the field status given by the last entry on the field first line (`EXPORTED`, `IGNOUT` or `INPUT` in the example above). The field may be (status `AUXILARY` is now UNUSED) :

- `EXPORTED`: exchanged between components and transformed by OASIS3-MCT
- `EXPOUT`: exchanged, transformed and also written to two debug NetCDF files, one before the sending action in the source component below the `oasis_put` call (after local transformations `LOCTRANS` and `BLASOLD` if present), and one after the receiving action in the target component below the `oasis_get` call (after all transformations). `EXPOUT` should be used only when debugging the coupled model. The name of the debug NetCDF file (one per field) is automatically defined based on the field and component names.
- `IGNORED`: with OASIS3-MCT, this setting is equivalent to and converted to EXPORTED
- `IGNOUT`: with OASIS3-MCT, this setting is equivalent to and converted to EXPOUT
- `INPUT`: read in from the input file by the target component below the `oasis_get` call at appropriate times corresponding to the input period indicated by the user in the *namcouple*. See section 5.3 for the format of the input file.
- `OUTPUT`: written out to an output debug NetCDF file by the source component below the `oasis_put` call, after local transformations `LOCTRANS` and `BLASOLD`, at appropriate times corresponding to the output period indicated by the user in the *namcouple*.

3.3.1 Second section of *namcouple* for `EXPORTED` and `EXPOUT` fields

The first 3 lines for fields with status `EXPORTED` and `EXPOUT` are as follows:

```
SOSSTSST SISUTESU 1 86400  5  sstoc.nc  EXPORTED
182  149    128  64  toce  atmo   LAG=+14400 SEQ=+1
P 2 P 0
```

where the different entries are:

- Field first line:
  - `SOSSTSST` : symbolic name for the field in the source component (80 characters maximum). It has to match the argument `name` of the corresponding field declaration in the source component; see `oasis_def_var` in section 2.2.5

  - SISUTESU : symbolic name for the field in the target component (80 characters maximum). It has to match the argument name of the corresponding field declaration in the target component; see oasis_def_var in section 2.2.5
  - 1 : UNUSED but still required for parsing
  - 86400 : coupling and/or I/O period for the field, in seconds
  - 5 : number of transformations to be performed by OASIS3 on this field
  - sstoc.nc : name of the coupling restart file for the field (32 characters maximum); mandatory even if no coupling restart file is effectively used (for more detail, see section 5.2)
  - EXPORTED : field status
- Field second line:
  - 182 : number of points for the source grid first dimension (optional)
  - 149 : number of points for the source grid second dimension (optional)[1]
  - 128 : number of points for the target grid first dimension (optional)
  - 64 : number of points for the target grid second dimension (optional)[1]

    These source and target grid dimensions are optional but note that in order to have 2D fields written as 2D arrays in the debug files, these dimensions must be provided in the *namcouple*; otherwise, the fields will be written out as 1D arrays.
  - toce : prefix of the source grid name in grid data files (see section 5.1) (80 characters maximum)
  - atmo : prefix of the target grid name in grid data files (80 characters maximum)
  - LAG=+14400: optional lag index for the field (see section 2.3.1)
  - SEQ=+1: optional sequence index for the field (see section 2.3.2)
- Field third line
  - P : source grid first dimension characteristic ('P': periodical; 'R': regional).
  - 2 : source grid first dimension number of overlapping grid points.
  - P : target grid first dimension characteristic ('P': periodical; 'R': regional).
  - 0 : target grid first dimension number of overlapping grid points.
- The fourth line gives the list of transformations to be performed for this field. In addition, there is one or more configuring lines describing some parameters for each transformation. These additional lines are described in more details in the chapter 4.

Support to couple multiple fields via a single communication

With OASIS3-MCT, it is possible to couple mutiple fields via a single communication. To activate this option, the user must list the related fields on a single entry line (with a maximum of 5000 characters on one line) through a colon delimited list in the *namcouple*, for example:

```
ATMTAUX:ATMTAUY:ATMHFLUX TAUX:TAUY:HEATFLUX 1 3600 3 rstrt.nc EXPORTED
```

All fields will then use the same *namcouple* settings (source and target grids, transformations, etc.) for that entry. In the component model codes, these fields are still apparently sent or received one at a time through individual oasis_put and oasis_get. Inside OASIS3-MCT, the fields are stored and a single mapping and send or receive instruction is executed for all fields. This is useful in cases where multiple fields have the same coupling transformations and to reduce communication costs by aggregating multiple fields into a single communication.

This option does not put any constraint on the order of the related oasis_put and oasis_get in the codes.

As they appear in one single entry line, these fields must share the same coupling restart file but this restart file may contain other fields.

[1] For 1D field, put 1 as the second dimension

3.3.2 Second section of *namcouple* for OUTPUT fields

The first 2 lines for fields with status OUTPUT are as follows:

```
COSHFTOT  COSHFTOT   1   86400  0  fldhftot.nc OUTPUT
atmo   atmo
```

where the different entries are as for EXPOUT fields, except that:

- the source symbolic name must be repeated twice on the field first line,
- the restart file name (here fldhftot.nc) is needed only if a LOCTRANS transformation is present,
- there is no grid dimension (which means that all output fields will be written out in the output files as 1D arrays) and no LAG or SEQ index on the second line; ;

The name of the output file is automatically defined based on the field and component names.

The third line is LOCTRANS if this transformation is chosen for the field. Note that LOCTRANS is the only transformation supported for OUTPUT fields.

3.3.3 Second section of *namcouple* for INPUT fields

The first and only line for fields with status INPUT is:

```
SOALBEDO SOALBEDO  1  86400  0  SOALBEDO.nc  INPUT
```

where the different entries are:

- SOALBEDO: symbolic name for the field in the target component (80 characters maximum, repeated twice)
- 1: UNUSED but still required for parsing (as for EXPORTED fields above)
- 86400: input period in seconds
- 0: number of transformations (always 0 for INPUT fields)
- SOALBEDO.nc: the input file name (32 characters maximum) (for more detail on its format, see section 5.3)
- INPUT: field status.

Chapter 4

Transformations and interpolations

Different transformations and 2D interpolations are available in OASIS3-MCT to adapt the coupling fields from a source model grid to a target model grid. In the following paragraphs, a description of each transformation with its corresponding configuration lines that the user has to write in the *namcouple* file is given. Features that are now deprecated (non functional) compared to prior versions will be noted with the string UNUSED and not described.

4.1 Time transformations

- **LOCTRANS**:

  LOCTRANS requires one configuring line on which a time transformation, automatically performed below the call to oasis_put, should be indicated:

  ```
  # LOCTRANS operation
    $TRANSFORM
  ```

  where $TRANSFORM can be

  - INSTANT: no time transformation, the instantaneous field is transferred;
  - ACCUMUL: the field accumulated over the previous coupling period is exchanged (the accumulation is simply done over the arrays field_array provided as third argument to the oasis_put calls without any specific weighting);
  - AVERAGE: the field averaged over the previous coupling period is transferred (the average is simply done over the arrays field_array provided as third argument to the oasis_put calls without any specific weighting);
  - T_MIN: the minimum value of the field for each source grid point over the previous coupling period is transferred;
  - T_MAX: the maximum value of the field for each source grid point over the previous coupling period is transferred;
  - ONCE: UNUSED, not supported in OASIS3-MCT.

  With OASIS3-MCT, time transformations are supported more generally than with previous OASIS versions with use of the coupling restart file. The coupling restart file allows the partial time transformation to be saved at the end of a run for exact restart at the start of the next run. When LOCTRANS transformations are specified, the initial coupling restart file should not contain any LOCTRANS restart fields. For the following runs, it is mandatory that the coupling restart file contains LOCTRANS restart fields coherent with the current namcouple entries. For example, it will not be possible to restart a run with a multiple field entry in the namcouple with a coupling restart file created by a run not activating this multiple file option.

This is the reason why it is now possible to specify a restart file name on the OUTPUT *namcouple* input line.

4.2 The pre-processing transformations

- **REDGLO** UNUSED
- **INVERT**: UNUSED
- **MASK**: UNUSED
- **EXTRAP**: UNUSED
- **CHECKIN**:

  CHECKIN calculates the global minimum, the maximum and the sum of the source field values (not weighted by the grid cell area) and prints them to the OASIS3-MCT debug file (for the master process of the source component model only under the attribute "diags"). This operation does not transform the field. CHECKIN operation can significantly slow down the simulation. It should not be used in production mode.

  The generic input line is as follows:

  ```
  # CHECKIN operation
      INT = 1
  ```

- **CORRECT**: UNUSED
- **BLASOLD**:

  BLASOLD allows the source field to be scaled and allows a scalar to be added to the field. The prior ability to perform a linear combination of the current coupling field with other coupling fields has been deprecated in OASIS3-MCT. This transformation occurs before the interpolation *per se*.

  This transformation requires at least one configuring line with two parameters:

  ```
  # BLASOLD operation
       $XMULT    $NBFIELDS
  ```

  where $XMULT is the multiplicative coefficient of the source field. $NBFIELDS must be 0 if no scalar needs to be added or 1 if a scalar needs to be added. In this last case, an additional input line is required where $AVALUE is the scalar to be added to the field, which must also be given as a REAL value :

  ```
       CONSTANT   $AVALUE
  ```

4.3 The remapping (or interpolation or regridding)

- **MAPPING**:

  The MAPPING keyword is used to specify an input file to be read and used for remapping; the MAPPING file must follow the SCRIPR format (see section 5.4). As for the other transformations and interpolations, different mappings can be specified for the different coupling fields. In this case grids.nc, masks.nc and areas.nc files are not needed, except if the post-procession global option CONSERV is specified in the namcouple. Then the user must provides the areas.nc file.

  Since OASIS3-MCT_2.0, MAPPING can be used for higher order remapping. Up to 5 different sets of weights (see section 5.4 for the weight file format) can be applied to up to 5 different fields transfered through the oasis_put argument (see section 2.2.7).

  This transformation requires at least one configuring line with one filename and two optional string values:

  ```
       $MAPNAME   $MAPLOC   $MAPSTRATEGY
  ```

- $MAPNAME is the name of the mapping file to read. This is a NetCDF file consistent with the SCRIPR map file format (see section 5.4).
- $MAPLOC is optional and can be either src or dst. With src, the mapping will be done in parallel on the source processors before communication to the destination model processes; this is the default. With dst, the mapping is done on the destination processes after the source grid data is sent from the source model.
- $MAPSTRATEGY is optional and can be either bfb, sum, or opt. In bfb mode, the mapping is done using a strategy that produces bit-for-bit identical results regardless of the grid decompositions; this is the default. With sum, the transform is done using the partial sum approach which generally introduces roundoff level changes in the results on different processor counts. Option opt allows the coupling layer to choose either approach based on an analysis of which strategy is likely to run faster. Usually, partial sums will be used if the source grid has a higher resolution than the target grid as this should reduce the overall communication (in particular for conservative remapping). By default $MAPSTRATEGY = bfb.

Note that if SCRIPR (see below) is used to calculate the remapping file, MAPPING can still be listed in the namcouple to specify a name for the remapping file generated by SCRIPR different from the default and/or to specify a $MAPLOC or $MAPSTRATEGY option.

- **SCRIPR**:

  SCRIPR gathers the interpolation techniques offered by Los Alamos National Laboratory SCRIP 1.4 library (Jones 1999)[1]. SCRIPR routines are in oasis3-mct/lib/scrip. See the SCRIP 1.4 documentation in oasis3/doc/SCRIPusers.pdf for more details on the interpolation algorithms.

  New in OASIS3-MCT_4.0, an hybrid MPI+OpenMP parallel version of the SCRIP library is available. It relies on the MPI parallel layout of the calling model but only enrols one MPI process per node. The number of OpenMP threads per node is set by a dedicated environment variable OASIS_OMP_NUM_THREADS, and for optimum performance, it is recommended to set this variable to the number of cores of the node. The test_interpolation environment (see section 6.3.3) in oasis3-mct/examples/test_interpolation gives a practical example on how to use the SCRIP library in parallel to calculate remapping weight-and-address files. The details of the SCRIP parallelisation can be found in (Piacentini et al 2018) and (Valcke et al 2018)[2] .

  When the SCRIP library performs a remapping, it first checks if the file containing the corresponding remapping weights and addresses exists; if it exists, it reads them from the file; if not, it calculates them and store them in a file. The file is created in the working directory and is by default called rmp_*srcg*_to_*tgtg*_*INTTYPE*_*NORMAOPT*.nc, where *srcg* and *tgtg* are the acronyms of respetively the source and the target grids, *INTTYPE* is the interpolation type, i.e. DISTWGT, GAUSWGT, BILINEAR (**not BILINEA as in OASIS3.3**) or CONSERV and *NORMAOPT* is the normalization option, i.e. DESTAREA, FRACAREA or FRACNNEI for CONSERV only, see below). One has to take care that the remapping file will have the same name even if other details, like the grid masks or the $MAPLOC or $MAPSTRATEGY options, are changed. When reusing a remapping file, one has to be sure that it was generated in exactly the same conditions than the ones it is used for.

  The following types of interpolations are available:

  - DISTWGT performs a distance weighted nearest-neighbour interpolation (N neighbours). All

[1] See also http://climate.lanl.gov/Software/SCRIP/ and the copyright statement in appendix 1.3.3.

[2] Thanks to some preliminary work, few bugs were fixed in the SCRIP library, in particular in the bounding box definition of the grid cells. This solves an important bug observed in the Pacific near the equator for the bilinear and bicubic interpolations for Cartesian grids. However, given these modifications, one cannot expect to get exactly the same results for the interpolation weight-and-adress remapping files with this new parallel SCRIP version as compared to the previous SCRIP version in OASIS3-MCT_3.0. We checked in many different cases that the interpolation error is smaller or of the same order than before. We also observed that the parallelisation does not ensure bit reproducible results when varying the number of processes or threads.

types of grids are supported.

The configuring line is:

```
# SCRIPR (for DISWGT)
    $CMETH $CGRS $CFTYP $REST $NBIN $NV $ASSCMP $PROJCART
```

where:

* $CMETH = DISTWGT.
* $CGRS is the source grid type (LR, D or U)- see appendix A.
* $CFTYP is the field type: SCALAR. The option VECTOR, which in fact leads to a scalar treatment of the field (as in the previous versions), is still accepted. **VECTOR_I or VECTOR_J, i.e. vector fields, are not supported anymore in OASIS3-MCT**. See "Support of vector fields with the SCRIPR remappings" below.
* $REST is a bin search restriction type: LATLON or LATITUDE, see SCRIP 1.4 documentation SCRIPusers.pdf.
* $NBIN the number of restriction bins that must be equal to 1 for DISTWGT, GAUSWGT, BILINEAR or BICUBIC i.e. the bin restriction is not allowed[3]; for details, see (Piacentini et al 2018).
* $NV is the number of neighbours used.
* $ASSCMP, $PROJCART: UNUSED; **vector fields are not supported anymore in OASIS3-MCT.** See "Support of vector fields with the SCRIPR remappings" below.

– GAUSWGT performs a N nearest-neighbour interpolation weighted by their distance and a gaussian function. All grid types are supported.

The configuring line is:

```
# SCRIPR (for GAUSWGT)
    $CMETH  $CGRS  $CFTYP  $REST  $NBIN  $NV $VAR
```

where: all entries are as for DISTWGT, except that:

* $CMETH = GAUSWGT
* $VAR defines the weight given to a neighbour source grid point as proportional to $exp(-1/2 \cdot d^2/\sigma^2)$ where d is the distance between the source and target grid points, and $\sigma^2 = \$VAR \cdot \overline{d}^2$ where $\overline{d}^2$ is the average distance between two source grid points (calculated automatically by OASIS3-MCT).

– BILINEAR performs an interpolation based on a local bilinear approximation (see details in chapter 4 of SCRIP 1.4 documentation SCRIPusers.pdf). Logically-Rectangular (LR) and Reduced (D) source grid types are supported.

– BICUBIC performs an interpolation based on a local bicubic approximation for Logically-Rectangular (LR) grids (see details in chapter 5 of SCRIP 1.4 documentation SCRIPusers.pdf), and on a 16-point stencil for Gaussian Reduced (D) grids. Note that for Logically-Rectangular grids, 4 weights for each of the 4 enclosing source neighbours are required corresponding to the field value at the point, the gradients of the field with respect to *i* and *j*, and the cross gradient with respect to *i* and *j* in that order. OASIS3-MCT will calculate the remapping weights and addresses (if they are not already provided) but will not, at run time, calculate the two gradients and the cross-gradient of the source field (as was the case with OASIS3.3). These 3 extra fields need to be calculated by the source code and transfered as extra arguments of the oasis_put (see fld2, fld3, fld4 in section 2.2.7).

[3]The only exceptions are for Gaussian Reduced (D) grids for (BILINEAR and BICUBIC; in that case, **if the Gaussian-reduced grid is stored from North to South** the number of bins is the number of latitude circles of the grid (minus one, to be precise), independently of $NBIN; **for Gaussian-reduced grid stored from South to North to South, the bin definition will not work and the interpolation will become a 4 distance-weighted nearest-neighbour for all target points.**

For BILINEAR and BICUBIC, the configuring line is:

```
# SCRIPR  (for BILINEAR or BICUBIC)
$CMETH  $CGRS  $CFTYP  $REST  $NBIN
```

where:

* $CMETH = BILINEAR or BICUBIC
* $CGRS is the source grid type: LR or D.
* $CFTYP, $REST, $NBIN are as for DISTWGT.

Note that for DISTWGT, GAUSWGT, BILINEAR and BICUBIC:

* Masked target grid points: the zero value is associated to masked target grid points.
* Non-masked target grid points having some of the source points normally used in the interpolation masked: a N nearest neighbour algorithm using the remaining non masked source points is applied.
* Non-masked target grid points having all source points normally used in the interpolation masked: by default, the nearest non-masked source neighbour is used (ll_nnei hard-coded to .true. in corresponding SCRIP sources).

– CONSERV performs 1st or 2nd order conservative remapping, which means that the weight of a source cell is proportional to area intersected by the target cell (plus some other terms proportional to the gradient of the field in the longitudinal and latitudinal directions for the second order).

The configuring line is:

```
# SCRIPR (for CONSERV)
$CMETH  $CGRS  $CFTYP  $REST  $NBIN  $NORM  $ORDER
```

where:

* $CMETH = CONSERV
* $CGRS is the source grid type: LR, D and U. Note that the grid corners have to given by the user in the grid data file grids.nc or by the code itself in the initialisation phase by calling routine oasis_write_corner (see section 2.2.4) ; OASIS3-MCT will not attempt to automatically calculate them as OASIS3.3.
* $CFTYP, $REST are as for DISTWGT.
* $NBIN is the number of restriction bins that can be more than 1 as bin restriction is effectively allowed for CONSERV; for details, see (Piacentini et al 2018).
* $NORM is the NORMalization option:
  · FRACAREA: The sum of the non-masked source cell intersected areas is used to NORMalise each target cell field value: the flux is not locally conserved, but the flux value itself is reasonable.
  · DESTAREA: The total target cell area is used to NORMalise each target cell field value even if it only partly intersects non-masked source grid cells: local flux conservation is ensured, but unreasonable flux values may result.
  · FRACNNEI: as FRACAREA, except that an additional unmasked source nearest neighbour is used for unmasked target cells that intersect only masked source cells.
* $ORDER: FIRST or SECOND for first or second order conservative remapping respectively (see SCRIP 1.4 documentation).

  For CONSERV/SECOND, 3 weigths are needed; OASIS3-MCT will calculate these weights and corresponding addresses (if they are not already provided) but will not, at run time, calculate the two extra terms to which the second and third weights should be applied; these terms, respectively the gradient of the field with respect to the longitude (θ) $\frac{\delta f}{\delta \theta}$ and the gradient of the field with respect to the latitude (ϕ) $\frac{1}{cos\theta}\frac{\delta f}{\delta \phi}$ need to be calculated by the source code and transfered as extra arguments of the oasis_put (see fld2, fld3 in section 2.2.7). Note that CONSERV/SECOND is not positive definite.

Precautions related to the use of the SCRIPR/CONSERV remapping

- For the 1st order conservative remapping: the weight of a source cell is proportional to area of the source cell intersected by target cell. Using the divergence theorem, the SCRIP library evaluates this area with the line integral along the cell borders enclosing the area. As the real shape of the borders is not known (only the location of the 4 corners of each cell is known), the library assumes that the borders are linear in latitude and longitude between two corners. This assumption becomes less valid closer to the pole; for latitudes above the `north_thresh` or below the `south_thresh` values (see `oasis3-mct/lib/scrip/remap_conserv.F90`, the library evaluates the intersection between two border segments using a Lambert equivalent azimuthal projection. However, problems were observed in some cases for the grid cell located around this `north_thresh` or `south_thresh` latitude. **So by default,** `north_thresh` **and** `south_thresh` **are now in OASIS3-MCT_4.0 by default set to 2.0 and -2.0 respectively**, where as `north_thresh` was set to 1.45 in previous versions.
- Another limitation of the SCRIP 1st order conservative remapping algorithm is that is supposes, for line integral calculation, that $sin(latitude)$ is linear in longitude on the cell borders which again is in general not valid close to the pole.
- For a proper consevative remapping, the corners of a cell have to coincide with the corners of its neighbour cell, with no "holes" between the cells.
- If two cells of one same grid overlay, the one with the greater numerical index must be masked in *masks.nc* for a proper conservative remapping. For example, if the grid cells with *i=1* overlays the grid cells with *i=imax*, the latter must be masked. If none of overlying cells is masked (given the original mask defined in *masks.nc*), OASIS3-MCT must be compiled with the CPP key `TREAT_OVERLAY` which will ensure that these rules are respected. This CPP key was introduced in OASIS3.3.
- If a target grid cell intersects only masked source cells, it will get a zero value unless the `FRACNNEI` normalisation option is used, in which case it will get the nearest non masked neighbour value. Note that the option of having the value 1.0E+20 assigned to these target grid cell intersecting only masked source cells (for easier identification) is not yet availble in OASIS3-MCT.
- With `FRACNNEI` target grid cell intersecting no source cell (either masked or non masked) at all i.e. falling in a "hole" of the source grid will get the non-masked nearest-neighbour value.

Support of vector fields with the SCRIPR remappings

Vector mapping is NOT supported and will not be supported by OASIS3-MCT. For proper treatment of vector fields, the source code has to send the 3 components of the vector projected in a Cartesian coordinate system as separate fields. The target code has to received the 3 interpolated Cartesian components and recombine them to get the proper vector field.

- **INTERP**: UNUSED
- **MOZAIC**: UNUSED; note that `MAPPING` (see above) is the NetCDF equivalent to `MOZAIC`.
- **NOINTERP**: UNUSED
- **FILLING**: UNUSED

4.4 The post-processing stage

- **CONSERV**:

  `CONSERV` performs a global modification of the coupling field. This analysis requires the source and target grid mesh areas to be defined in the *areas.nc* file or transferred to the coupler with `oasis_write_area` (see section 2.2.4). **For a correct CONSERV operation, overlapping grid**

cells on the source grid or on the target grid must be masked. In the *namcouple*, CONSERV requires one input line with one argument and one optional argument:

```
# CONSERV operation
```

where: `$CMETH  $CONSOPT`

- `$CMETH` is the method desired with the following choices
  - with `$CMETH = GLOBAL`, the field is integrated on both source and target grids, without considering values of masked points, and the residual (target - source) is uniformly distributed on the target grid; this option ensures global conservation of the field;
  - with `$CMETH = GLBPOS`, the same operation is performed except that the residual is distributed proportionally to the value of the original field; this option ensures the global conservation of the field and does not change the sign of the field;
  - with `$CMETH = BASBAL`, the operation is analogous to `GLOBAL` except that the non masked surface of the source and the target grids are taken into account in the calculation of the residual; this option does not ensure global conservation of the field but ensures that the energy received is proportional to the non masked surface of the target grid;
  - with `$CMETH = BASPOS`, the non masked surface of the source and the target grids are taken into account and the residual is distributed proportionally to the value of the original field; therefore, this option does not ensure global conservation of the field but ensures that the energy received is proportional to the non masked surface of the target grid and it does not change the sign of the field.
- `$CONSOPT` is an optional argument specifying the algorithm. `$CONSOPT` can be `bfb`, `gather`, `lsum16`, `lsum8`, `ddpdd`, `reprosum` or `opt`. Details on the perfromance of these different options can also be found in (Craig et al 2017) and references there in.
  - The `bfb` option is the default for `CONSOPT` and uses the `reprosum` option (see below).
  - The `gather` option computes global sums by gathering a decomposed array onto the root process before doing an index ordered sum. This is guaranteed to produce identical results for different numbers of processors and decompositions but is expensive both with respect to performance and memory use. This is equivalent to the `bfb` option in previous OASIS versions.
  - The `lsum16` option computes a local sum at quadruple precision before doing an MPI reduction on the local sums at quadruple precision. This is likely to be bit-for-bit for different numbers of processors and decompostions but that's not guaranteed. This is just like `lsum8` but at quadruple precision and a little slower.
  - The `lsum8` option computes a local sum at double precision before doing an MPI reduction on the local sums at double precision. This is NOT likely to be bit-for-bit for different numbers of processors and decompostions. This is just like `lsum16` but at double precision and faster.
  - The `ddpdd` option is a parallel double-double algorithm using a single scalar reduction. It should behave between `lsum8` and `lsum16` with respect to performance and reproducibility. See (He and Ding 2001).
  - The `reprosum` option is a fixed point method based on ordered double integer sums that requires two scalar reductions per global sum. The cost of reprosum will be higher than some of the other methods but it will be bit-for-bit for different processor counts or different decompostions except in extremely rare cases and the cost is significantly less than the `gather` option. See (Mirin and Worley 2012).
  - The `opt` option carries out the global sum using the fastest algorithm generally available. Currently, this is set to `lsum8`.

- **SUBGRID**: UNUSED
- **BLASNEW**:

  BLASNEW performs a scalar multiply or scalar add to any destination field. This is the equivalent of BLASOLD on the destination side. The prior feature that supported linear combinations of the current coupling field with any other fields after the interpolation has been deprecated.

  This analysis requires the same input line(s) as BLASOLD.
- **MASKP**: UNUSED
- **REVERSE**: UNUSED
- **CHECKOUT**:

  CHECKOUT calculates the global minimum, the maximum and the sum of the target field values (not weighted by the grid cell area) and prints them to the OASIS3-MCT debug file (for the master process of the target component model only). These informations are found in the debug file of the master process of the target model under the attribute “diags”. This operation does not transform the field. CHECKOUT operation can significantly slow down the simulation. It should not be used in production mode. The generic input line is as for CHECKIN (see above).
- **GLORED**: UNUSED

Chapter 5

OASIS3-MCT auxiliary data files

OASIS3-MCT uses auxiliary data files, e.g. defining the grids of the models being coupled, containing the field coupling restart values or input data values, or the remapping weights and addresses.

5.1 Grid data files

With OASIS3-MCT, the grid data files *grids.nc, masks.nc* and *areas.nc* are required only for certain operations, i.e. *grids.nc*, and *masks.nc* for `SCRIPR` (see section 4.3) and *masks.nc* and *areas.nc* for `CONSERV` (see section 4.4). These NetCDF files can be created by the user before the run or can be written directly at run time by the processes of each component model using the grid data definition routines (see section 2.2.4). These routines can be used by the component models to add grid fields to the grid files but grid fields are **never** overwritten in the grid files.

The arrays containing the grid information are dimensioned `(nx, ny)`, where `nx` and `ny` are the grid first and second dimension. Unstructured grids or other grids expressed with 1D vectors are supported by setting `nx` to the total number of grid points and `ny` to 1.

1. *grids.nc*: contains the model grid longitudes and latitudes in double precision `REAL` arrays. The array names must be composed of a prefix (4 characters), given by the user in the *namcouple* on the second line of each field (see section 3.3), and of a suffix,".lon" or ".lat", for respectively the grid point longitudes or latitudes.

   If the `SCRIPR/CONSERV` remapping is specified, longitudes and latitudes for the source and target grid **corners** must also be available in the *grids.nc* file as double precision `REAL` arrays dimensioned `(nx,ny,4)` or `(nbr_pts,1,4)` where `4` is the number of corners (in the counterclockwize sense). The names of the arrays must be composed of the grid prefix and the suffix ".clo" or ".cla" for respectively the grid corner longitudes or latitudes. As for the other grid information, the corners can be provided in *grids.nc* before the run by the user or directly by the component code through specific calls (see section 2.2.4).

   Longitudes must be given in degrees East in the interval -360.0 to 720.0. Latitudes must be given in degrees North in the interval -90.0 to 90.0. Note that if some grid points overlap, it is recommended to define those points with the same number (e.g. 360.0 for both, not 450.0 for one and 90.0 for the other) to ensure automatic detection of overlap by OASIS3-MCT.

   The corners of a cell cannot be defined modulo 360 degrees. For example, a cell located over Greenwich will have to be defined with corners at -1.0 deg and 1.0 deg but not with corners at 359.0 deg and 1.0 deg.

   Cells larger than 180.0 degrees in longitude are not supported.

2. *masks.nc*: contains the masks for all component model grids in `INTEGER` arrays. **Be careful to use the historical OASIS convention: 0 -not masked i.e. active- or 1 -masked i.e. not active- for**

each grid point. The array names must be composed of the grid prefix and the suffix ".msk". This file, *masks* or *masks.nc*, is mandatory.

3. *areas.nc*: this file contains mesh surfaces for the component model grids in double precision `REAL` arrays. The array names must be composed of the grid prefix and the suffix ".srf". The surfaces may be given in any units but they must be all the same. This file *areas.nc* is mandatory for the global `CONSERV` post-processing operation; it is not required otherwise.

5.2 Coupling restart files

At the beginning of a coupled run, some coupling fields may have to be initially read from their coupling restart file on their source grid (see the LAG concept in section 2.3). When needed, these files are also automatically updated by the last active `oasis_put` or `prism_put_proto` call of the run (see section 2.2.7) . **Warning**: the date is not written or read to/from the restart file; therefore, the user has to make sure that the appropriate coupling restart file is present in the working directory. The coupling restart files must follow the NetCDF format.

The name of the coupling restart file is given by the 6th character string on the first configuring line for each field in the *namcouple* (see section 3.3). Coupling fields coming from different models cannot be in the same coupling restart files, but for each model, there can be an arbitrary number of fields written in one coupling restart file. One exception is when a coupling field sent by a source component model is associated with more than one target field and model; in that case, if coupling restart files are required, it is mandatory to specify different files for the different fields.

The coupling restart files are also used automatically by OASIS3-MCT to allow partial LOCTRANS time transformation to be saved at the end of a run for exact restart at the start of the next run. When LOCTRANS transformations are specified, the initial coupling restart file should not contain any LOCTRANS restart fields. For the following runs, it is mandatory that the coupling restart file contains LOCTRANS restart fields coherent with the current namcouple entries. For example, it will not be possible to restart a run with a multiple field entry in the namcouple with a coupling restart file created by a run not activating this multiple file option.

In the coupling restart files, the fields must be provided on the source grid in single or double precision REAL arrays and, as the grid data files, must be dimensioned `(nx, ny)`, where `nx` and `ny` are the grid first and second dimension (see section 5.1 above). The shape and orientation of each restart field (and of the corresponding coupling fields exchanged during the simulation) must be coherent with the shape of its grid data arrays.

5.3 Input data files

Fields with status `INPUT` in the *namcouple* will, at runtime, simply be read in from a NetCDF input file by the target model below the `oasis_get` call, at appropriate times corresponding to the input period indicated by the user in the *namcouple*.

The name of the file must be the one given on the field first configuring line in the *namcouple* (see section 3.3.3). There must be one input file per `INPUT` field, containing a time sequence of the field in a single or double precision REAL array named with the same field symbolic name as in the *namcouple* and dimensioned `(nx,ny,time)`. The time variable has to be an array `time(time)` expressed in "seconds since beginning of run". The "time" dimension has to be the unlimited dimension.

5.4 Transformation auxiliary data files

The mapping files to be used for the MAPPING option must be consistent with the files generated by the SCRIP library to be used for the SCRIPR transformations (see also section 4.3). The files are NetCDF containing the following fields:

```
dimensions:
      src_grid_size = xxx ;
      dst_grid_size = xxx ;
      num_links = xxx ;
      num_wgts = xxx ;
variables:
      int src_address(num_links)
      int dst_address(num_links)
      double remap_matrix(num_links, num_wgts)
```

where

- src_grid_size is a scalar integer indicating the total number of points in the source grid. This field is a netCDF dimension.
- dst_grid_size is a scalar integer indicating the total number of points in the target grid. This field is a netCDF dimension.
- num_links is a scalar integer indicating the total number of associated source and target grid point pairs in the file. This field is a netCDF dimension.
- num_wgts is a scalar integer indicating the number of weights per associated grid point pair (up to 5 are supported, see section 2.2.7). This field is a netCDF dimension.
- src_address is a one dimensional array of size num_links. It contains the integer source address associated with each weight. This field is a netCDF variable.
- dst_address is a one dimensional array of size num_links. It contains the integer destination address associated with each weight. This field is a netCDF variable.
- remap_matrix is a two dimensional array of size (num_links, num_wgts). It contains the real weight value(s) associated with the source and destination address. This field is a netCDF variable.

Chapter 6

Compiling, running and debugging

6.1 Compiling OASIS3-MCT

OASIS3-MCT is an MPI code. Compiling OASIS3-MCT libraries can be done in `oasis3-MCT/util/make_dir` with Makefile `TopMakefileOasis3` which must include a header file `make.`*your_platform* specific to the compiling platform used and specified in `oasis3-MCT/util/make_dir/make.inc`.

One of the header files distributed with the release can by used as a template in particular to see how to use MPI librairies and NetCDF librairies. The root of the OASIS3-MCT tree can be anywhere and must be set in the variable `COUPLE` in the `make.`*your_platform* file.

The coupled models must be compiled with the same libraries as the ones used to compile OASIS3-MCT.

The following commands are available:

- `make -f TopMakefileOasis3` or `make oasis3_psmile -f TopMakefileOasis3` (for backward compatibility):

  compiles all OASIS3-MCT libraries *mct*, *scrip* and *psmile*;

- `make realclean -f TopMakefileOasis3`:

  removes all OASIS3-MCT compiled sources and librairies.

Log and error messages from compilation are saved in `/util/make_dir` in the files `COMP.log` and `COMP.err`.

During compilation, a new compiling directory, defined by variable `ARCHDIR` is created. After successful compilation, resulting libraries are found in the compiling directory in `/lib` and object and module files in `/build`.

To interface a component code with OASIS3-MCT and use the module `mod_oasis` (see section 2.2.1), it is enough to include the path of the psmile objects and modules (`$ARCHDIR/build/lib/psmile.MPI1`) during the compilation and to use the psmile library `$ARCHDIR/lib/libpsmile.MPI1.a` when linking[1].

Exchange of coupling fields in single and double precision is now supported directly through the interface (see section 2.2.5), even if all real variables are now treated in double precision internally. For double precision coupling field, there is no need anymore to promote REAL variables to double precision at compilation.

[1] If module `mod_prism` is used in the models, it is necessary to include the path of the psmile and of the mct objects and modules for the compilation (i.e. `$ARCHDIR/build/lib/psmile.MPI1` and `/mct` and to use both the psmile and mct libraries `$ARCHDIR/lib/libpsmile.MPI1.a` and `libmct.a` and `libmpeu.a` when linking.

6.2 CPP keys

The following OASIS3-MCT CPP keys can be specified in `CPPDEF` in `make.`*your_platform* file:

- `TREAT_OVERLAY`: ensures, in `SCRIPR/CONSERV` remapping (see section 4.3), that if two cells of the source grid overlay and none is masked a priori, the one with the greater numerical index will not be considered (they also can be both masked); this is mandatory for this remapping. For example, if the grid line with *i=1* overlaps the grid line with *i=imax*, it is the latter that must be masked; when this is not the case with the mask defined in *masks.nc*, this CPP key forces these rules to be respected.
- `__NO_16BYTE_REALS`: **must** be specified if you compile with **PGF90**.

6.3 Running OASIS3-MCT

Examples of running environments are provided with the sources. See also the instructions on OASIS web site at `https://verc.enes.org/oasis/oasis-dedicated-user-support-1/user-toys` for more details.

6.3.1 The tutorial toy model

A practical example is provided in `oasis3-mct/examples/tutorial` reproducing the coupling between two simple codes, model1 and model2, with OASIS3-MCT.

See the document `tutorial.pdf` there in and the on-line tutorial at `https://verc.enes.org/oasis/oasis-dedicated-user-support-1/user-toys/tutorial-and-test_interpolation-of-oasis3-mct-1` for more details.

6.3.2 The test_1bin_ocnice toy model

Another practical example on how to use OASIS3-MCT is provided in `oasis3-mct/examples/test_1bin_ocnice`. This toy model reproduces the coupling between 5 sub-components within the ocnice executable. See the document `test_1bin_ocnice.pdf` there in for more details.

6.3.3 The test_interpolation environment

This environment available with the sources in `oasis3-mct/examples/test_interpolation` allows the user to test the quality of the interpolations and transformations between his source and target grids by calculating the error of interpolation on the target grid. For more details, see also the document `test_interpolation.pdf` there in.

6.4 Debugging

6.4.1 Debug files

If you experience problems while running your coupled model with OASIS3-MCT, you can obtain more information on what is happening by increasing the `$NLOGPRT` value in your *namcouple*, see section 3.2 for details.

6.4.2 Time statistics files

The variable TIMER_Debug, defined in the *namcouple* (second number on the line below $NLOGPRT keyword), is used to obtain time statistics over all the processors for each routine.

Different output are written (in files named `*.timers_xxxx`) depending on TIMER_Debug value :

- TIMER_Debug=0 : nothing is calculated, nothing is written.
- TIMER_Debug=1 : the times are calculated and written in a single file by the process 0 as well as the min and the max times over all the processes.
- TIMER_Debug=2 : the times are calculated and each process writes its own file ; process 0 also writes the min and the max times over all the processes in its file.
- TIMER_Debug=3 : the times are calculated and each process writes its own file ; process 0 also writes in its file the min and the max times over all processes and also writes in its file all the results for each process.

Note that TIMER_Debug can also be set to -1 to activate the *lucia* tool that can be used to perform an analysis of the coupled components load balance. More information can be found in the README file in `oasis3-mct/util/lucia` directory and report mentioned therein.

The time given for each timer is calculated by the difference between calls to `oasis_timer_start()` and `oasis_timer_stop()` and is the accumulated time over the entire run. Here is an overview of the meaning of the different timers as implemented by default. [2]

- 'total' : total time of the simulation, implemented in `mod_oasis_method`, i.e. between the end of `oasis_init_comp` and the `mpi_finalize` in routine `oasis_terminate`.
- 'init_thru_enddef' : time between the end of `oasis_init_comp` and the end of `oasis_enddef`, implemented in `mod_oasis_method`.
- 'part_definition' : time spent in routine `oasis_def_partition`.
- 'oasis_enddef' : time spent in routine `oasis_enddef`; this routine performs basically all the important steps to initialize the coupling exchanges, e.g. the internal management of the partition and variable definition, the definition of the patterns of communication between the source and target processes, the reading of the remapping weight-and-address file and the initialisation of the sparse matrix vector multiplication.
- 'grcv_00x' : time spent in the reception of field x in `mct_recv` (including communication and possible waiting time linked to unbalance of components).
- 'wout_00x' : time spent in the I/O for field x in routine `oasis_advance_run`.
- 'gcpy_00x' : time spent in routine `oasis_advance_run` in copying the field x just received in a local array.
- 'pcpy_00x' : time spent in routine `oasis_advance_run` in copying the local field x in the array to send (i.e. with local transformation besides division for averaging).
- 'pavg_00x' : time spent in routine `oasis_advance_run` to calculate the average of field x (if done).
- 'pmap_00x'/'gmap_00x' : time spent in routine `oasis_advance_run` for the matrix vector multiplication for field x on the source/target processes.
- 'psnd_00x' : time spent in routine `oasis_advance_run` for sending field x (i.e. including call to `mct_waitsend` and `mct_isend`).
- 'wtrn_00x' : time spent in routine `oasis_advance_run` to write fields associated with non-instant loctrans operations to restart files (see section 5.2 for details).

[2] Many other measures can be obtained by defining the logical `local_timers_on` as `.true.` in different routines or by implementing other timers. Of course, OASIS3_MCT and the model code then have to be recompiled.

- 'wrst_00x' : time spent in routine `oasis_advance_run` to write fields to restart files (see section 5.2 for details).

Appendix A

The grid types for the transformations

As described in section 4 for the different SCRIP remappings, OASIS3-MCT support different types of grids. The characteristics of these grids are detailed here:

- `'LR' grid`: The longitudes and the latitudes of 2D Logically-Rectangular (LR) grid points can be described by two arrays `longitude(i,j)` and `latitude(i,j)`, where i and j are respectively the first and second index dimensions. Streched or/and rotated grids are LR grids. Note that previous OASIS3 A, B, G, L, Y, or Z grids are all particular cases of LR grids.
- `'U' grid`: Unstructured (U) grids do have any particular structure. The longitudes and the latitudes of 2D Unstructured grid points must be described by two arrays `longitude(nbr_pts,1)` and `latitude(nbr_pts,1)`, where nbr_pts is the total grid size.
- `'D' grid`: The Gaussian Reduced (D) grid is composed of a certain number of latitude circles, each one being divided into a varying number of longitudinal segments. In OASIS3-MCT, the grid data (longitudes, latitudes, etc.) must be described by arrays dimensioned `(nbr_pts,1)`, where `nbr_pts` is the total number of grid points. There is no overlap of the grid, and no grid point at the equator nor at the poles. There are grid points on the Greenwich meridian.

Appendix B

Changes between the different versions of OASIS3-MCT

The evolution between the different versions of OASIS3-MCT can be followed in real-time by registering on the Redmine project management site at https://inle.cerfacs.fr/ (see "Register" at the right top of the page). On this site, registered users can browse the sources and consult tickets describing bug fixes and developments. To follow day to day evolution of the OASIS3-MCT sources, it is also possible to have your e-mail added to the list of addresses to which the log files of the SVN checkins are automatically sent; contact oasishelp@cerfacs.fr if you wish to be added to that list.

B.1 Changes between OASIS3-MCT_4.0 and OASIS3-MCT_3.0

Different developments were realised to improve the parallel performance of OASIS3-MCT_4.0. These developments are detailed in (Valcke et al 2018) .

- A new communication method, using the remapping weights to define the intermediate mapping decomposition, offers a significant gain at run time, especially for high-resolution cases running on a high number of tasks, thanks to reduced communication. However, as expected, the new method takes longer to initialize, partly due to the fact that the mapping weight file has to be read twice but also due to the extra cost for the initialization of the different MCT routers. That initialization cost is largely mitigated by an upgrade to MCT 2.10.beta1 which reduces the penalty to few seconds. Generally, it should be worth the extra initial cost to speed up the run time. See `$NMAPDEC` in section 3.2.
- The hybrid MPI+OpenMP parallelisation of the SCRIP library (previously fully sequential) leads to great improvement in the calculation of the remapping weights. The results obtained here show a reduction in the weight calculation time of 2 to 3 orders of magnitude with the new parallel SCRIP library for high-resolution grids. Details are available in (Piacentini et al 2018). The `test_interpolation` environment (see section 6.3.3) gives a practical example on how to use OASIS3-MCT_4.0 to pre-calculate (i.e. in a separate job prior to the real simulation) the remapping weight and address file.

  Thanks to some preliminary work, few bugs were fixed, in particular in the bounding box definition of the grid cells. This solves an important bug observed in the Pacific near the equator for the bilinear and bicubic interpolations for Cartesian grids.

  However, given these modifications, one cannot expect to get exactly the same results for the interpolation weight-and-adress remapping files with this new parallel SCRIP version as compared to the previous SCRIP version in OASIS3-MCT_3.0. We checked in many different cases that the interpolation error is smaller or of the same order than before. We also observed that the parallelisation does not ensure bit reproducible results when varying the number of processes or threads.

- The new methods introduced in the global CONSERV operation reduce its calculation costs by one order of magnitude while still ensuring an appropriate level of reproducibility. This removes the bottleneck foreseen at high resolution with this important, and in few cases still unavoidable, global operation. These new methods are detailed in section 4.4 .

The other new features offered by OASIS3-MCT_4.0 are the following:

- Support for bundled coupling fields.

  Bundled fields is now supported in the `oasis_put` and `oasis_get` interfaces to allow easier coupling of multi-level or other related fields via a single namcouple coupling definition and a single call to `oasis_put` or `oasis_get`. Further details are provided in sec 2.2.7
- Automatic coupling restart writing

  An optional argument `write_restart` was added to the `oasis_put` routine. This argument is false by default but if it is explicitly set to true in the code, a coupling restart file will be written for that field only for that coupling timestep, saving the data that exists at the time of the call (see section 2.2.7).
- Exact consistency between the number of weights and fields

  Exact consistency is now required between number of weights fields in the coupling restart file and the arrays passed as arguments to the `oasis_put` routine. For example, for a 2nd order conservative remapping (CONSERV SECOND), 3 weights are needed and 3 fields must be provided as arguments i.e. the value of the field, its gradient with respect to the longitude and its gradient with respect to the latitude. For a first order conservative remapping (CONSERV FIRST), only one weight and one field are needed. Using a weight file with 3 weights for a first order conservative remapping is no longer allowed.
- Upgrade in the namcouple configuration file

  The namcouple reading routine was cleaned up including a refactoring of the gotos and continue statements, addition of few reusable routines including an abort routine, removal of some dead code, addition of support for blank lines (which are now considered comments), removal of requirement that keywords start at character 2 on a line, removal of requirement for `$END` in the namcouple, and updates to some error messages.
- Other new functionalities with corresponding new namcouple keywords (see section 3.2)
  - `$NUNITNO`: specifies the minimum and maximum unit numbers to be used for input and output files in the coupling layer.
  - `$NMATXRD`: indicates the method used to read mapping weights, either `orig` or `ceg`. In both methods, the weights are read in chunks by the model master task. With the `orig` option, the weights are then broadcast to all other tasks and each task then saves the weights that will be applied to its grid points. With the `ceg` option, the master task reads the weights and then identifies to which other task each weight should be sent. A series of exchanges are then done with each other task involving just the weights needed by that other task. The `orig` method sends much more data but is more parallel, while the `ceg` method does most of the work on the master task but less data is communicated.
  - `$NWGTOPT`: indicates how to handle bad interpolation weights.
  - `$NNOREST` : if true, OASIS3-MCT will initialise any variable that normally requires a coupling restart file with zeros if that file does not exist.

B.2 Changes between OASIS3-MCT_3.0 and OASIS3-MCT_2.0

The main evolution of OASIS3-MCT_3.0 with respect to OASIS3-MCT_2.0 is the support of coupling exchanges between parallel components deployed in much more diverse configurations than before, for

example, within one same executable between components running concurrently on separate sets of tasks or between components running sequentially on overlapping sets of tasks. All details are provided in section 2.1.

This new version also includes:

- memory and performance upgrades
- a new LUCIA tool for load balancing analysis
- new memory tracking tool (gilt)
- improved error checking and error messages
- doxygen documentation
- expanded test cases and testing automation
- testing at high resolution (¿ 1M gridpoints), high processor counts (32k pes), and with large variable counts (¿ 1k coupling fields)
- many bug fixes

B.3 Changes between OASIS3-MCT_2.0 and OASIS3-MCT_1.0

The main changes and bug fixes new in OASIS3-MCT_2.0 are the following:

- Support of `BICUBIC` interpolation, see paragraph `BICUBIC` in section 4.3. If the source grid is not a gaussian reduced grid (D), the gradient in the first dimension, the gradient in the second dimension, and the cross-gradient of the coupling field must be calculated by the model and given as arguments to `oasis_put`, as explained in section 2.2.7. If the source grid is a gaussian reduced grid (D), OASIS3-MCT_2.0 can calculate the interpolated field using only the values of the source field points.
- Support of `CONSERV/SECOND` remapping, see paragraph `CONSERV/SECOND` in section 4.3.
- Support of components exchanging data on only a subdomain of the global grid: a new optional argument, ig_size was added to oasis_def_partition, that provides the user with the ability to define the total number of grid cells on the grid (see section 2.2.3).
- The variable `TIMER_Debug` controlling the amount of time statistics written out is now an optional argument read in the *namcouple*; see the `NLOGPRT` line in 3.2 and all details about time statistics in section 6.4.2.
- Specific problems in writing out the time statistics when all the processors are not coupling were solved (see Redmine issue #497)
- The problem with restart files when one coupling field is sent to 2 target components was solved (see Redmine ticket #522)
- A memory leak in mod_oasis_getput_interface.F90 was fixed thanks to R. Hill from the MetOffice (see Redmine ticket #437)
- A bug fix was provided to ensure that the nearest neighbour option is activated when the option `FRACNNEI` is defined in the *namcouple* for the conservative interpolation .
- The behaviour of OASIS3-MCT was changed in the case a component model tries to send with `oasis_put` a field declared with a `oasis_def_var` but not defined in the configuration file *namcouple*; this will now lead to an abort. In this case, the field ID returned by the `oasis_def_var` is equal to -1 and the corresponding `oasis_put` should not be called. Conversely, all coupling fields appearing in the *namcouple* must be defined with a call to `oasis_def_var`; this constraint is imposed to avoid that a typo in the namcouple would lead to coupling exchanges not corresponding to what the user intends to activate.
- OASIS3-MCT developments are now continuously tested and validated on different computers with a test suite under Buildbot, which is a software written in Python to automate compile and test

cycles required in software project (see https://inle.cerfacs.fr/projects/oasis3-mct/wiki/Buildbot on the Redmine site).

B.4 Changes between OASIS3-MCT_1.0 and OASIS3.3

B.4.1 General architecture

- OASIS3-MCT is (only) a coupling library

  Much of the underlying implementation of OASIS3 was refactored to leverage the Model Coupling Toolkit (MCT). OASIS3-MCT is a coupling library to be linked to the component models and that carries out the coupling field transformations (e.g. remappings/interpolations) in parallel on either the source or target processes and that performs all communication in parallel directly between the component models; there is no central coupler executable anymore[1].

- `MAPPING` transformation to use a pre-defined mapping file

  With `MAPPING`, OASIS3-MCT has the ability to read a predefined set of weights and addresses (mapping file) specified in the *namcouple* to perform the interpolation/remapping. The user also has the flexibility to choose the location and the parallelization strategy of the remapping with specific `MAPPING` options (see section 4.3).

- Mono-process mapping file generation with the SCRIP library

  But as before, OASIS3-MCT_1.0 can also generate the mapping file using the SCRIP library (Jones 1999). When this is the case, the mapping file generation is done on one process of the model components; all previous `SCRIPR` remapping schemes available in OASIS3.3 are still supported besides `BICUBIC` and `CONSERV/SECOND`. (Note: these remapping schemes, not available in OASIS3-MCT_1.0 were reactivated in OASIS3-MCT_2.0, see B.3.)

- MPI2 job launching is NOT supported.

  Only MPI1 start mode is allowed. As before with the MPI1 mode, all component models must be started by the user in the job script in a pseudo-MPMD mode; in this case, they will automatically share the same `MPI_COMM_WORLD` communicator and an internal communicator created by OASIS3-MCT needs to be used for internal parallelization (see section 2.2.2).

B.4.2 Changes in the coupling interface in the component models

- Use statement

  The different OASIS3.3 `USE` statements were gathered into one `USE mod_oasis` (or one `USE mod_prism`), therefore much simpler to use.

- Support of previous `prism_xxx` and new `oasis_xxx` interfaces

  OASIS3-MCT retains prior interface names of OASIS3.3 (e.g. `prism_put_proto`) to ensure full backward compatibility. However, new interface names such as `oasis_put` are also available and should be prefered. Both routine names are listed in chapter 2.

- Auxiliary routines not supported yet

  Auxiliary routines `prism_put_inquire`, `prism_put_restart_proto`, `prism_get_freq` are not supported yet. (Note: `prism_put_inquire` and `prism_get_freqs` were reintroduced in OASIS3-MCT_3.0 and equivalent of `prism_put_restart_proto` in OASIS3-MCT_4.0.)

- Support of components for which only a subset of processes participate in the coupling

[1] As with OASIS3.3, the "put" calls are non-blocking but the "get" calls are blocking. As before, the user has to take care of implementing a coupling algorithm that will result in matching "put" and "get" calls to avoid deadlocks (see section 2.2.7). The lag (LAG) index works as before in OASIS3.3 (see section 2.3)

New routines oasis_create_couplcomm and oasis_set_couplcomm are now available to create or set a coupling communicator in the case only a subset of the component processes participate in the coupling. But even in this case, all OASIS3-MCT interface routines, besides the grid definition (see section 2.2.4) and the "put" and " get" call per se (see section 2.2.7), are collective and must be called by all processes. (Note: this has changed with OASIS3-MCT_3.0.)

- New routines oasis_get_debug and oasis_set_debug

  New routines oasis_get_debug and oasis_set_debug are now available to respectively retrieve the current OASIS3-MCT internal debug level (set by $NLOGPRT in the *namcouple*) or to change it (see section 2.2.9).

B.4.3 Functionality not offered anymore

- SCRIPR/BICUBIC and SCRIPR/CONSERV/SECOND remappings

  As in OASIS3.3, the SCRIP library can be used to generate the remapping/interpolation weights and addresses and write them to a mapping file. All previous SCRIPR remapping schemes available in OASIS3.3 are still supported in OASIS3-MCT_1.0 besides BICUBIC and CONSERV/SECOND because these remapping involve at each source grid point the value of the field but also the value of the gradients of the field (which are not known or calculated). (Note: these remapping schemes, not available in OASIS3-MCT_1.0 were reactivated in OASIS3-MCT_2.0, see B.3.)

- Vector field remapping

  Vector field remapping is not and will not be supported (see "Support of vector fields with the SCRIPR remappings" in section 4.3).

- Automatic calculation of grid mesh corners in SCRIPR/CONSERV

  For SCRIPR/CONSERV remapping, grid mesh corners will not be compute automatically if they are needed but not provided.

- Other transformations not supported

  - The following transformations are not available in OASIS3.3 and will most probably not be implemented as it should be not too difficult to implement the equivalent operations in the component models themselves: CORRECT, FILLING, SUBGRID, MASKP
  - LOCTRANS/ONCE is not explicitely offered as it is equivalent to defining a coupling period equal to the total runtime.
  - The following transformations are not available as they were already deprecated in OASIS3.3 : REDGLO, INVERT, REVERSE, GLORED
  - MASK and EXTRAP are not available but the corresponding linear extrapolation can be replaced by the more efficient option using the nearest non-masked source neighbour for target points having their original neighbours all masked. This is now the default option for SCRIPR/DISTWGT, GAUSWGT and BILINEAR interpolations. It is also included in SCRIPR/CONSERV if FRACNNEI normalization option is chosen (see section 4.3).
  - INTERP interpolations are not available; SCRIPR should be used instead.
  - MOZAIC is not available as MAPPING should be used instead.
  - NOINTERP does not need to be specified anymore if no interpolation is required.
  - Field combination with BLASOLD and BLASNEW; these transformations only support multiplication and addition terms to the fields (see section 4.2).

- Using the coupler in interpolator-only mode

  This is not possible anymore as OASIS3-MCT is now only a coupling library. However, it is planned, in a further release, to provide a toy coupled model that could be use to check the quality of the remapping for any specific couple of grids. (Note: this was done in OASIS3-MCT_2.0.)

- Coupling field CF standard names

  The file cf_name_table.txt is not needed or used anymore. The CF standard names of the coupling fields are not written to the debug files.

- Binary auxiliay files

  All auxiliary files, besides the *namcouple* must be NetCDF; binary files are not supported anymore.

B.4.4 New functionality offered

- Better support of components for which only a subset of processes participate in the coupling

  In OASIS3.3, components for which only a subset of processes participated in the coupling were supported in a very restricted way. In fact, this subset had to be composed of the N first processes and N had to be specified in the *namcouple*. Now, the subset of processes can be composed of any of the component processes and does not have to be pre-defined in the *namcouple*. New routines `oasis_create_couplcomm` and `oasis_set_couplcomm` are now available to create or set a coupling communicator gathering only these processes (see section **??**). (Note: this wass further improved in OASIS3-MCT_3.0.)

- Exact restart for `LOCTRANS` transformations

  If needed, LOCTRANS transformations write partially transformed fields in the coupling restart file at the end of a run to ensure an exact restart of the next run (see section 4.1). For that reason, coupling restart filenames are now required for all *namcouple* entries that use LOCTRANS (with non INSTANT values). This is the reason an optional restart file is now provided on the OUTPUT *namcouple* input line. If the coupling periods of two (or more) coupling fields are different, it is necessary to define two (or more) restart files, one for each field.

- Support to couple multiple fields via a single communication.

  This is supported through colon delimited field lists in the *namcouple*, for example

  ```
  ATMTAUX:ATMTAUY:ATMHFLUX TAUX:TAUY:HEATFLUX 1 3600 3 rstrt.nc EXPORTED
  ```

  in a single *namcouple* entry. All fields will use the *namcouple* settings for that entry. In the component model codes, these fields are still sent ("put") or received ("get") one at a time. Inside OASIS3-MCT, the fields are stored and a single mapping and send or receive instruction is executed for all fields. This is useful in cases where multiple fields have the same coupling transformations and to reduce communication costs by aggregating multiple fields into a single communication. If a LOCTRAN transformation is needed for these multiple fields, it is necessary to define a restart file for these multiple fields. **The coupling fields must be sent and received in the same order as they are defined in the corresponding single entry of the namcouple**.

- Matching one source filed with multiple targets

  A coupling field sent by a source component model can be associated with more than one target field and model (get). In that case, the source model needs to send ("put") the field only once and the corresponding data will arrive at multiple targets as specified in the *namcouple* configuration file. Different coupling frequencies and transformations are allowed for different coupling exchanges of the same field. If coupling restart files are required (either if a `LAG` or if a `LOCTRANS` transformation is specified), it is mandatory to specify different files for the different fields.

  The inverse feature is not allowed, i.e. a single target (get) field CANNOT be associated with multiple source (put) fields.

- The debug files

  The debug mode was greatly improved as compared to OASIS3.3. The level of debug information written out to the OASIS3-MCT debug files for each model process is defined by the $NLOGPRT value in the *namcouple*. All details are provided in section 3.2.

B.4.5 Changes in the configuration file *namcouple*

- The *namcouple* configuration file of OASIS3-MCT is fully backward compatible with OASIS3.3. However, several *namcouple* keywords have been deprecated even if they are still allowed. These keywords are noted "UNUSED" in sections 3.2 and 3.3 and are not fully described. Information below these keywords will not be read and will not be used: $SEQMODE , $CHANNEL, $JOBNAME, $INIDATE, $MODINFO, $CALTYPE.
- Also the following inputs should not appear in the *namcouple* anymore as the related functionality are not supported anymore in OASIS3-MCT (see above): field status AUXILARY, time transformation ONCE, REDGLO, INVERT, MASK, EXTRAP, CORRECT, INTERP, MOZAIC, FILLING, SUBGRID, MASKP, REVERSE, GLORED.
- To get 2D fields in the debug output NetCDF files, the 2D dimensions of the grids must be provided in the *namcouple* (except if the field has the status OUTPUT); otherwise, the fields in the debug output files will be 1D.

B.4.6 Other differences

- IGNORED and IGNOUT fields are converted to EXPORTED and EXPOUT respectively.
- The file `areas.nc` is not needed anymore to calculate some statistics with options CHECKIN and/or CHECKOUT.
- SEQ index is no longer needed to ensure correct coupling sequencing within the coupler. Use of SEQ allows the coupling layer to detect potential deadlocks before they happen and to exit gracefully (see section 2.3.2).
- The I/O library mpp_io is no longer used to write the restart and output files.

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