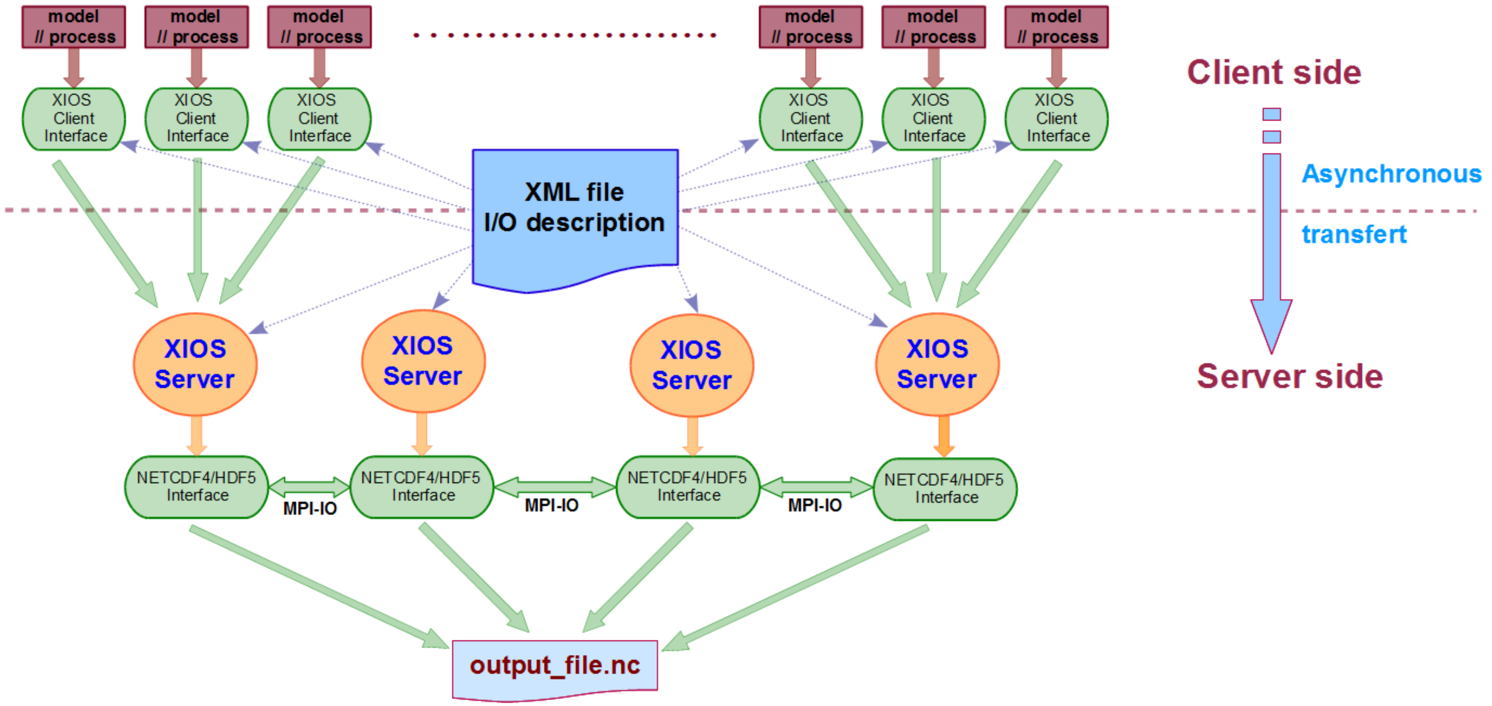
XIOS
where are we and example of use

The IS-ENES3 project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824084

XIOS – 1 : XML / IO / SERVER



Flexible data output description through an external XML file.

XIOS servers : asynchronous processes exclusively dedicated to output

- **Overlap computation and I/O**
- **Rearrange data for better output efficiency**
- **Use parallel I/O for better efficiency**
  - Aggregate I/O bandwidth of parallel file system
  - One piece files, no need to rebuild

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XIOS - 2 : Adding Workflow Functionalities

XIOS-2 embed an internal parallel workflow/dataflow

The XML files describe a parallel task graph

- Incoming data are representing data flux, assigned to a timestamp
  - Each flux can be connected to one or more filters
- Filters are connected to one or more input flux and generate a new flux on output
  - All Filters can be chained to achieve complex treatment
  - All filters are parallel and scalable

Arithmetic filters

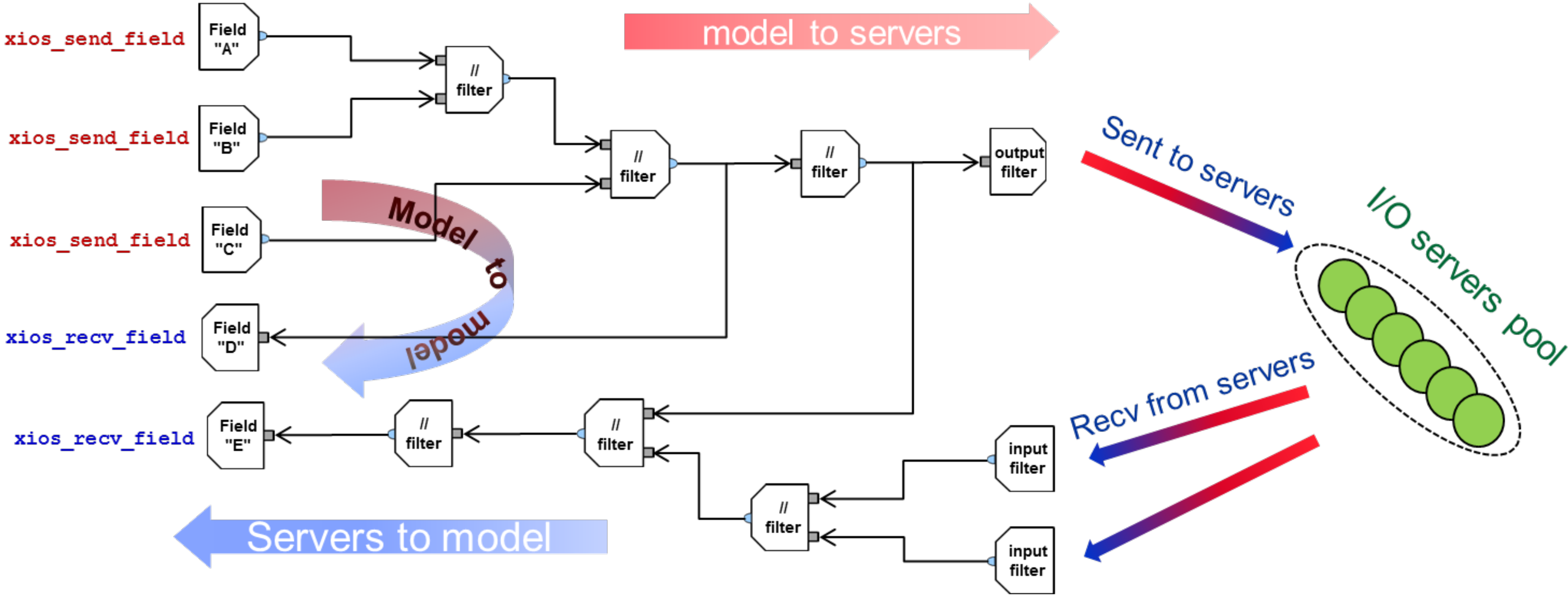
- Combining fields together
- Apply arithmetic operator or function

Temporal filters

- Temporal integration of input flux
- instant, average, maximum, minimum, accumulate

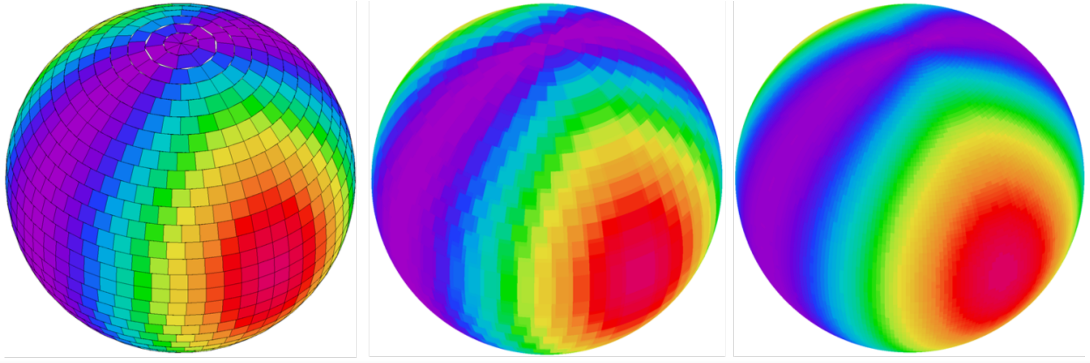
Spatial filters

- Geometrical shape of the input flux is modified
- Defined by a grid transformation from a source grid to a target grid

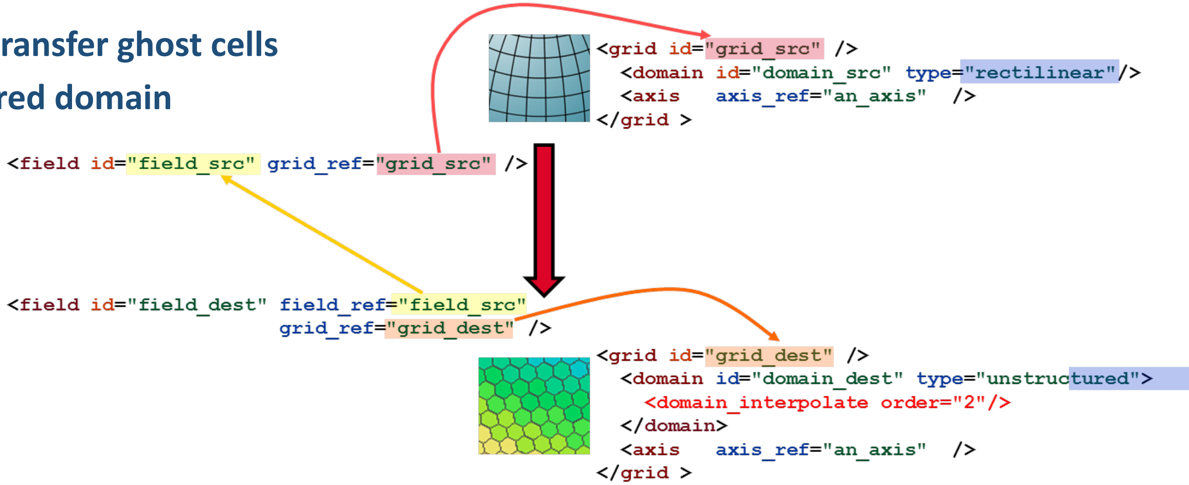


XIOS-2 : AVAILABLE SPATIAL FILTERS

- (domain -> domain): <zoom_domain /> : extract area of interest
- (axis -> axis): <zoom_axis/> : extract part of an axis
- (axis->scalar): <extract_axis_to_scalar/> : axis slice extraction
- (domain->axis): <extract_domain_to_axis/> : latitude or longitude extraction
- (axis->axis): <inverse axis/> : invert axis
- (axis->axis): <interpolate_axis> : axis interpolation, possibly on pressure level
- (domain->domain) : <interpolate_domain/> : horizontal conservative remapping
- (domain): <generate_rectilinear_domain/> : create and/or distribute a rectilinear mesh
- (domain->scalar): <reduce_domain_to_scalar/> : global domain reduction (sum, average, max, min,…)
- (domain->axis): <reduce_domain_to_axis/> : partial domain reduction along i or j direction
- (axis->scalar): <reduce_axis_to_scalar/> : axis reduction (sum, average, max, min, …)
- (scalar->axis): <temporal_splitting/> : diurnal cycle
- (scalar->axis): <duplicate_scalar_to_axis> : duplicate data along a new axis
- (domain->domain) : <reorder_domain/> : reorder indexes of horizontal domain
- (domain->domain): <expand_domain/> : expand local domain at first neighbor and transfer ghost cells
- (domain) : <compute_connectivity/> : find the connectivity of an unstructured domain



Source mesh   Remapping order 1   Remapping order 2



```
<grid id="grid_src" />
  <domain id="domain_src" type="rectilinear"/>
  <axis   axis_ref="an_axis"   />
</grid >

<field id="field_src" grid_ref="grid_src" />

<field id="field_dest" field_ref="field_src"
                       grid_ref="grid_dest" />

<grid id="grid_dest" />
  <domain id="domain_dest" type="unstructured">
    <domain_interpolate order="2"/>
  </domain>
  <axis   axis_ref="an_axis"   />
</grid >
```

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XIOS-2.5 : The CMIP6 workflow compliant version

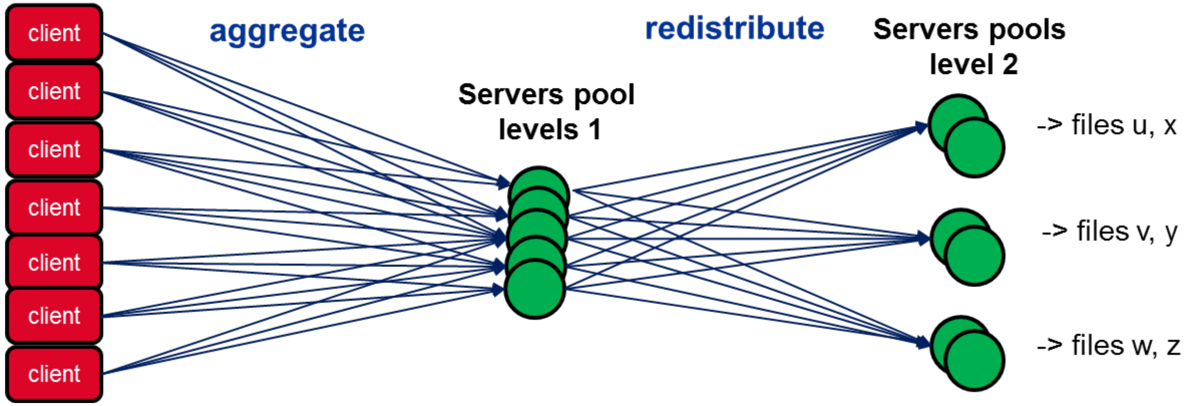
Adding missing functionalities required by CMIP6 workflow

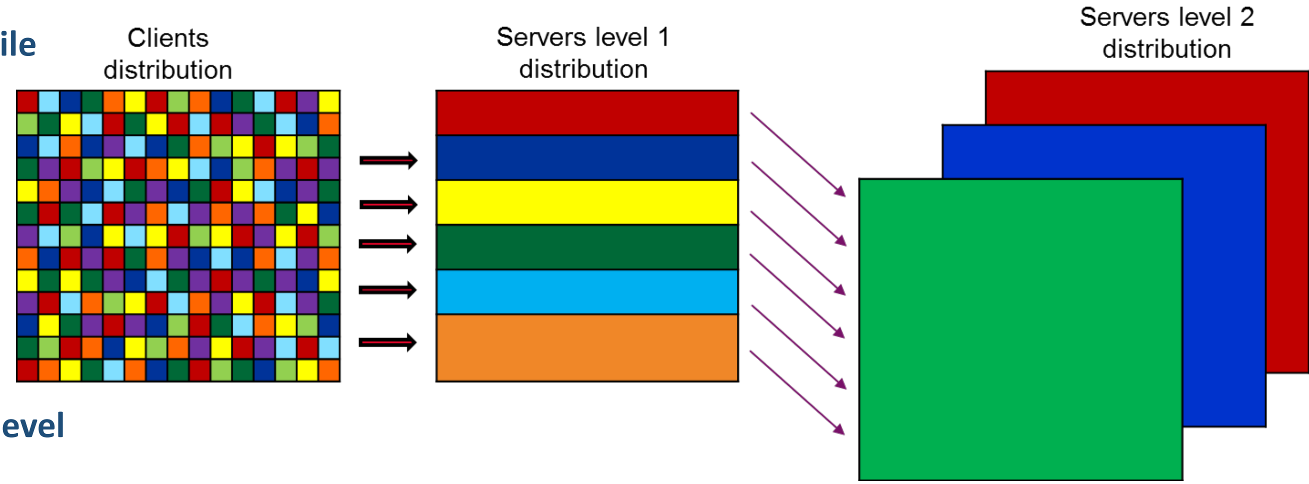
XIOS output fully CF 1.7 compliant

- Axis & coordinates
- Variables and associated metadata
- Time axis management

Automatic time series management

- One file by variable
- Automatic generation of UUID (tracking_id)
- Automatic chunk splitting at a given frequency specifically to an output file
  - Constant size for chunk of file variable
  - Automatic file name suffix corresponding to the period of chunk
- An output file can be reopen and appended by the next run





Adding a second level of servers

- First level will aggregate fields from client and redistribute its to second level
- Second level received field on global mesh and make sequential write
- I/O parallelism is achieved by write sequential files concurrently
  - Increase I/O parallelism performance
  - Enabling compression on the fly using HDF5 filters

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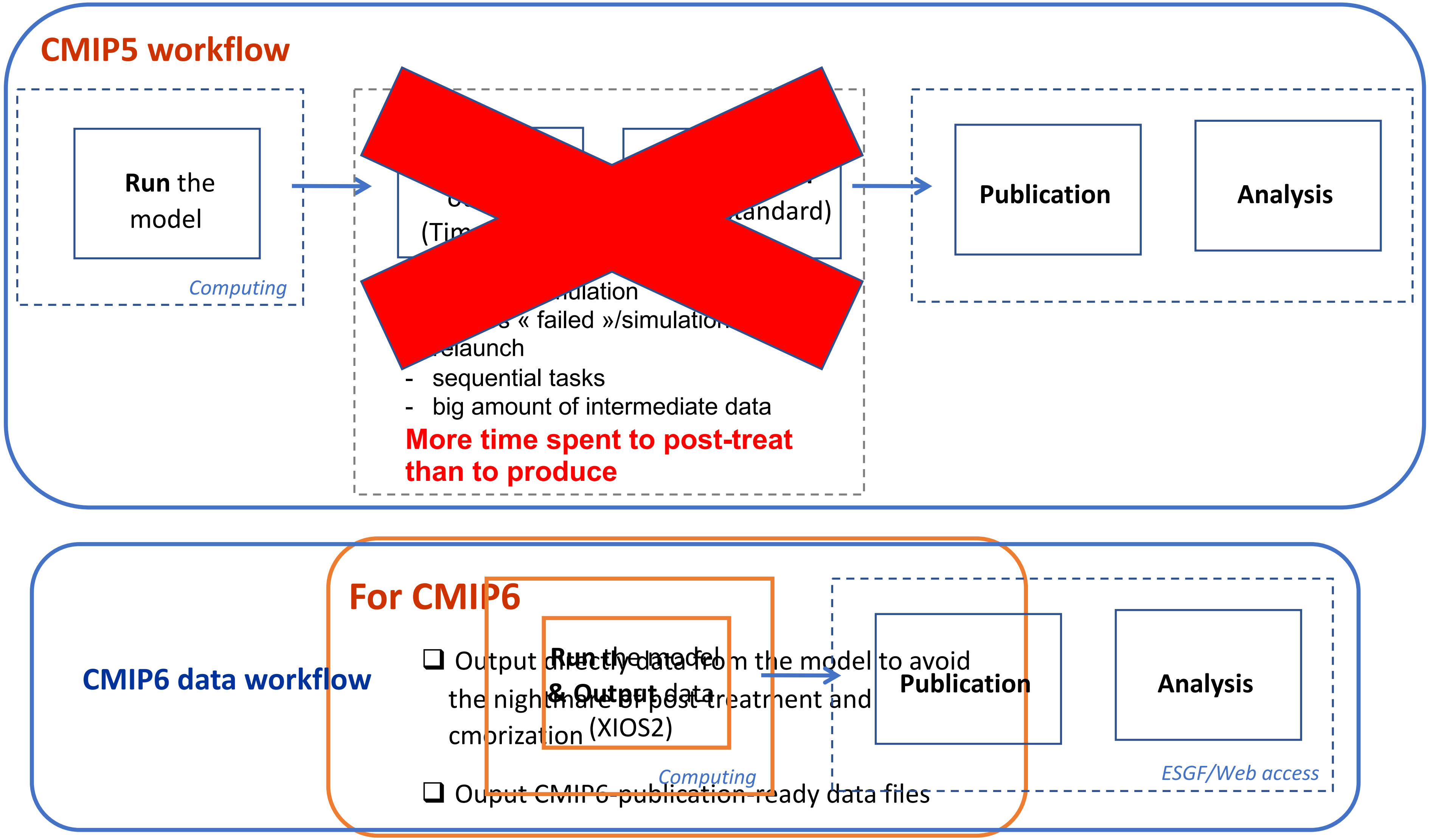
An example of use : the CMIP6 XIOS Workflow

FROM CMIP5 to CMIP6



ulation
s « failed »/simulation
relaunch
- sequential tasks
- big amount of intermediate data

More time spent to post-treat than to produce

For CMIP6

- ❑ Output directly data from the model to avoid the nightmare of post-treatment and cmorization
- ❑ Ouput CMIP6-publication-ready data files

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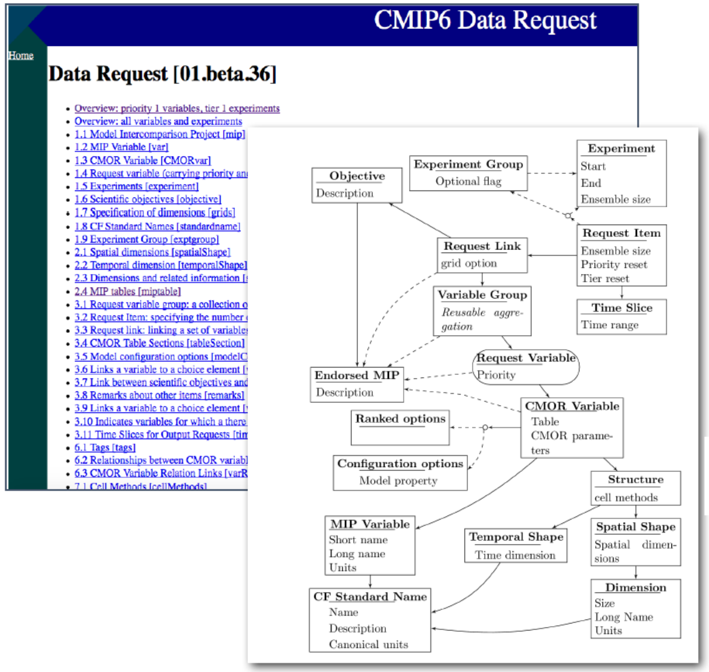
CMIP6 workflow strategy

CNRM and IPSL are sharing the same CMIP6 workflow based on XIOS-2.5

Strategy : automatic translation of CMIP6 data request into XIOS XML configuration files

- **CNRM develop DR2XML tool (S. Sénesi, M.P. Moine)**
  - Translates CMIP6 Data Request to XIOS configuration files (Python script)
- **IPSL implement XIOS missing functionalities**

Data Request python API + XML files
(Martin Juckes)



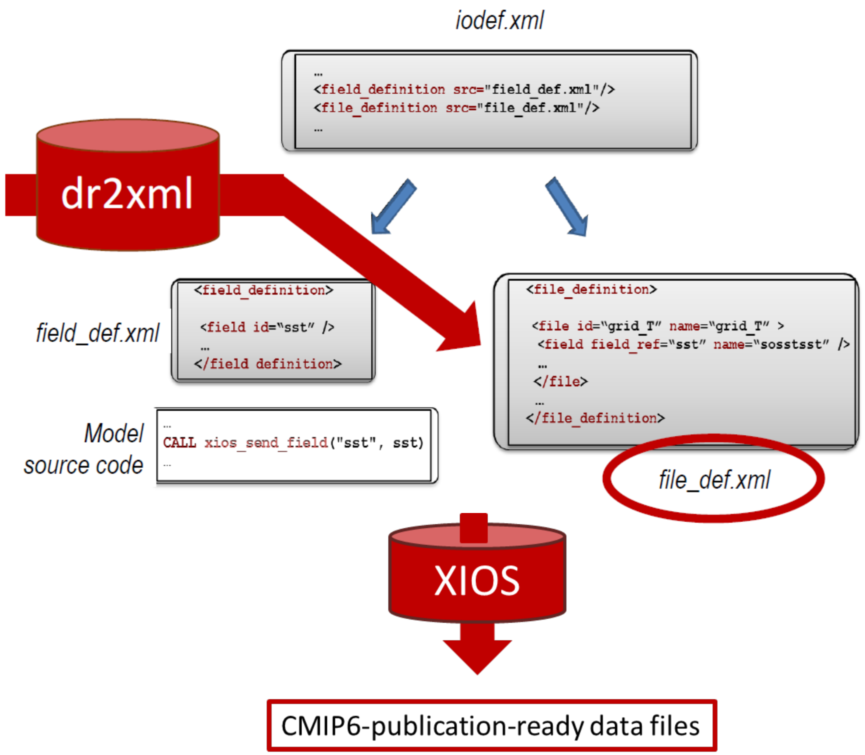
CMIP6 Data Request

Home

Data Request [01.beta.36]

- Overview: priority 1 variables, tier 1 experiments
- Overview: all variables and experiments
- 1.1 Model Intercomparison Project [mip]
- 1.2 MIP Variable [var]
- 1.3 CMOR Variable [CMORvar]
- 1.4 Request variable (carrying priority an
- 1.5 Experiments [experiment]
- 1.6 Scientific objectives [objective]
- 1.7 Specification of dimensions [grids]
- 1.8 CF Standard Names [standardname]
- 1.9 Experiment Group [exptgroup]
- 2.1 Spatial dimensions [spatialShape]
- 2.2 Temporal dimension [temporalShape]
- 2.3 Dimensions and related information [
- 2.4 MIP tables [miptable]
- 3.1 Request variable group: a collection o
- 3.2 Request Item: specifying the number
- 3.3 Request link: linking a set of variables
- 3.4 CMOR Table Sections [tableSection]
- 3.5 Model configuration options [modelC
- 3.6 Links a variable to a choice element [
- 3.7 Link between scientific objectives and
- 3.8 Remarks about other items [remarks]
- 3.9 Links a variable to a choice element [
- 3.10 Indicates variables for which a there
- 3.11 Time Slices for Output Requests [tim
- 6.1 Tags [tags]
- 6.2 Relationships between CMOR variabl
- 6.3 CMOR Variable Relation Links [varR
- 7.1 Cell Methods [cellMethods]

XIOS-enable model
(e.g. NEMO)



iodef.xml

```
…
<field_definition src="field_def.xml"/>
<file_definition src="file_def.xml"/>
…
```

field_def.xml

```
<field_definition>

 <field id="sst" />
 …
</field definition>
```

Model source code

```
…
CALL xios_send_field("sst", sst)
…
```

file_def.xml

```
<file_definition>

 <file id="grid_T" name="grid_T" >
  <field field_ref="sst" name="sosstsst" />
  …
 </file>
 …
</file_definition>
```

CMIP6-publication-ready data files

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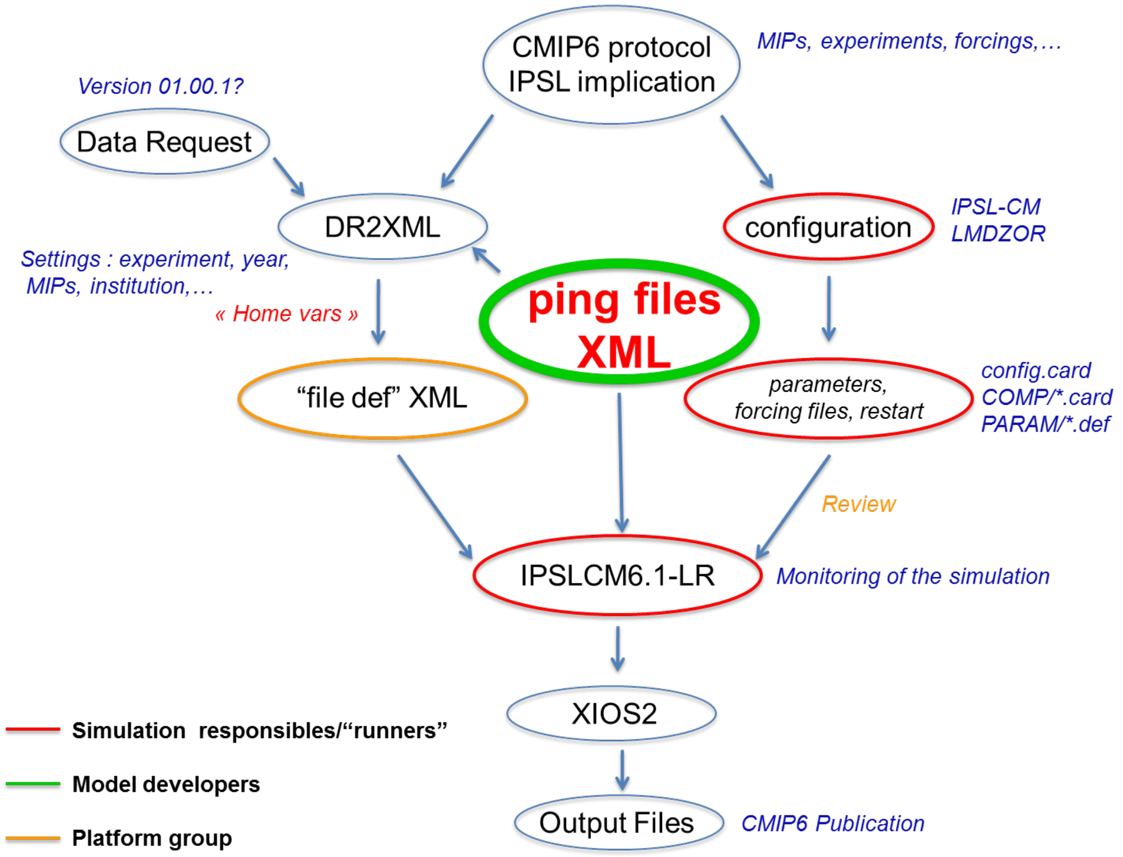
CMIP6 "in situ diagnostics"

- Unit rescaling
- Normalization by area or level height
- Time integration (averaging, minimum, maximum)
- Vertical interpolation in pressure levels
- Extraction on specific pressure levels
- Vertical or global summation
- Horizontal remapping
- Zonal mean
- Diurnal cycle, seasonal means
- Cfsites (points station extraction)
- Transects (flux across ocean straight)
- Many more complex diagnostics (ex : Eliassen Palm flux)



CMIP6 protocol
IPSL implication

MIPs, experiments, forcings,…

Version 01.00.1?

Data Request

DR2XML

Settings : experiment, year, MIPs, institution,…

« Home vars »

configuration

IPSL-CM
LMDZOR

ping files
XML

"file def" XML

parameters, forcing files, restart

config.card
COMP/*.card
PARAM/*.def

Review

IPSLCM6.1-LR

Monitoring of the simulation

XIOS2

Output Files

CMIP6 Publication

🟥 Simulation responsibles/"runners"

🟩 Model developers

🟧 Platform group

~ 90 000 XML code line automatically generated by DR2XML for each experiment

A key for workflow portability : the ping file

- Map the model variable id to data request variable id
- Same workflow has been shared by IPSL and CNRM

IPSL CMIP6 Production

- 28 MIPs, 228 experiments, 850 simulations
- 55 000 years of simulation to perform
- 20 logins for the production campaign
- 200 logins for the climate model development and CMIP6 analysis
- in average 20 000 cores, with peak at 80 000 cores (one week at the end of Curie)
- 300 millions computing hours (development + production)
  - on TGCC (Curie and Irene) and few millions on IDRIS (development)
- 4 Pb of data produced
- 207 000 datasets published = 800 TB

Among the first group (with CNRM) to publish in ESGF

- Most of the experiments done with IPSL-CM6A-LR ~ 200km atm, 100km oce
  - About 16 SYPD on ~ 1000 cores (Intel sandy bridge)

Impact of the CMIP6 XIOS Workflow

- Between 10% and 20% depending of the experiment

Coupled model configuration

- IPSL-CM6A-LR
  - LMDZ –ORCHIDEE 144x143x79
  - NEMO (ORCA1-LIM3-PISCES)
- IPSL-CM6A-ATM-HR
  - LMDZ-ORCHIDEE 512x360x79
- IPSL-CM6A-AER-LR
  - LMDZ –ORCHIDEE 144x143x79
  - NEMO (ORCA1-LIM3-PISCES)
  - INCA (Aerosols)
- IPSL-CM5A2-CHM-VLR
  - LMDZ –ORCHIDEE 96x95x39
  - NEMO (ORCA2-LIM2-PISCES)
  - INCA (NMHC-AER-S)
- IPSL-CM7A-ATM-HR
- DYNAMICO-LMDZ-ORCHIDEE 50km (and 25 km)

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Lessons learned from CMIP6 production workflow

Success :

- Handle complex workflow with ~ thousand of fields with numerous diagnostics
- Efficient management of time series and compression "on the flight" with ~ thousand of files
- Acceptable impact on models performance (~10% -> 20%)
- Remove the post-treatment phases

But :

- Big time overhead at starting time : some minutes depending the configuration
- Huge memory consumption, that increases with resolution
  - On clients and servers
  - need to depopulate nodes for servers
- Difficulties for parallel I/O to scale at large number of servers
- Workflow doesn't scale well at large number of cores (> 10 000)

HiResMIP production test

- IPSL : CMIP6 workflow works for 50 km and 25 km resolution, by reducing the level of output and depopulate
- CNRM : more difficulties to handle their ESM at such resolution

In the state of the art, a 10 km resolution full ESM with such outputs will be probably difficult to reach

All these bottlenecks should be solved in future to address the "exascale" era

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IS-ENES3 : XIOS roadmap

Improve robustness and reliability

Improve XIOS error diagnostics

- Full stack is now output by the exception manager
- Full information (attribute) of the concerned object (field, file, etc…) is output all along the stack

✓ *Done in 2019*

Performance profiling logs

- detailed information to understand performance bottleneck

✓ *Done in 2019*

Output and visualize XIOS workflow graph

- Graphical view of spatial and temporal chained graph composing XIOS workflow
- Graphs generated at the end of execution
- Visualization within a standard web navigator

✓ *Done in 2019*

Development of a test case suite for contiguous integration

- Build a generic test case (binary) that can handle all XIOS functionalities:
  - Test all kind of mesh, including mesh indexation and mask
  - Test for fields on scalar, 1-D, 2-D, 3D or 4-D grid
- Run is defined by a set of parameters list
  - Nb models, nb proc for client, nb proc for servers, selected mesh
- All test case suite will be declined in unitary test and automated after each commit on different supercomputers
  - Compilation is also tested
- Results and regressions are exposed through a navigator

✓ *Done in 2019*
(IS-ENES3 milestone)

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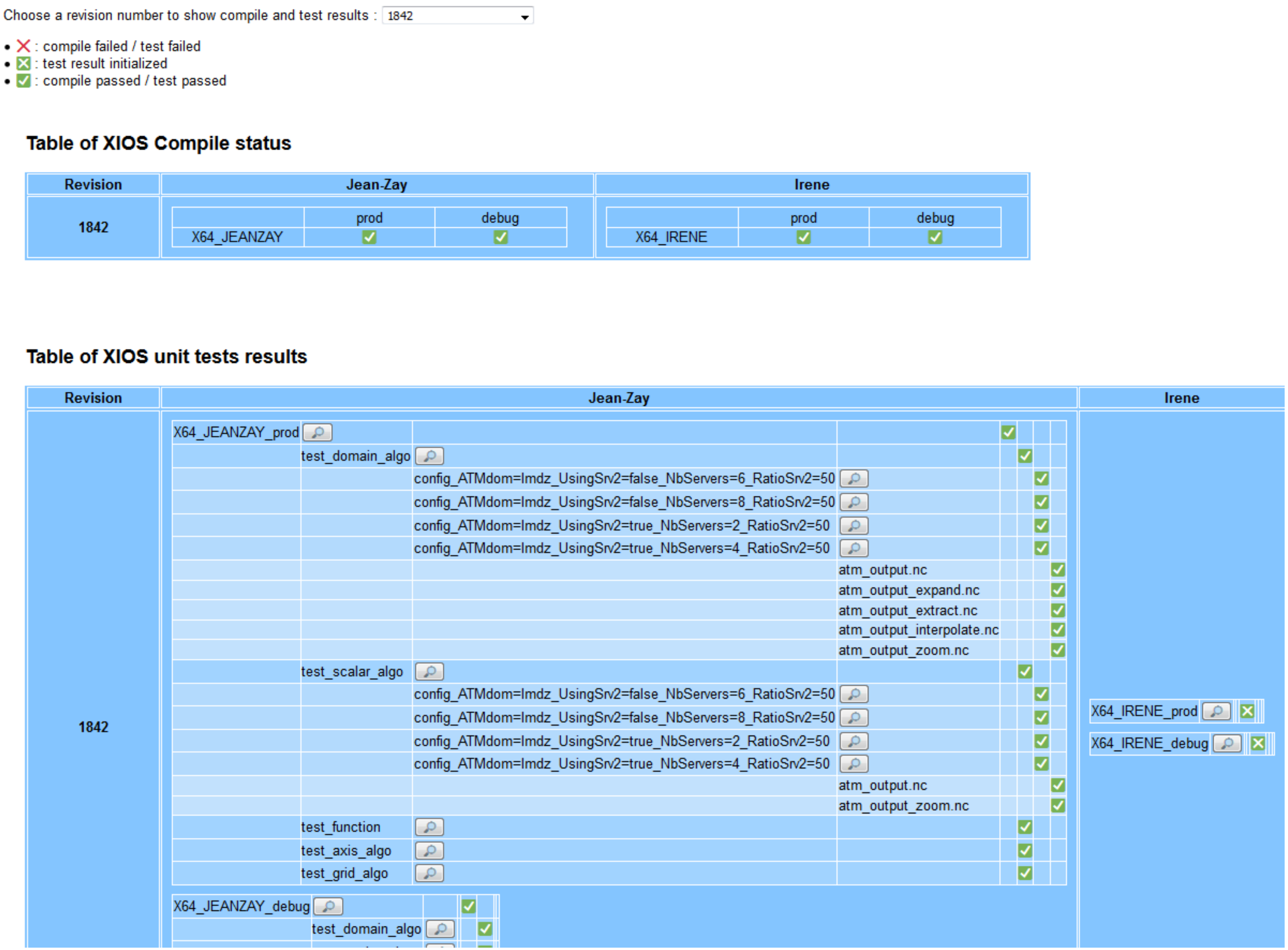

Choose a revision number to show compile and test results : 1842

- ✗ : compile failed / test failed
- ☒ : test result initialized
- ✓ : compile passed / test passed

Table of XIOS Compile status

Revision	Jean-Zay			Irene		
1842		prod	debug		prod	debug
	X64_JEANZAY	✓	✓	X64_IRENE	✓	✓

Table of XIOS unit tests results

Revision	Jean-Zay								Irene
1842	X64_JEANZAY_prod 🔍				✓				X64_IRENE_prod 🔍 ☒ X64_IRENE_debug 🔍 ☒
		test_domain_algo 🔍				✓			
			config_ATMdom=lmdz_UsingSrv2=false_NbServers=6_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=false_NbServers=8_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=true_NbServers=2_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=true_NbServers=4_RatioSrv2=50 🔍				✓		
				atm_output.nc				✓	
				atm_output_expand.nc				✓	
				atm_output_extract.nc				✓	
				atm_output_interpolate.nc				✓	
				atm_output_zoom.nc				✓	
		test_scalar_algo 🔍				✓			
			config_ATMdom=lmdz_UsingSrv2=false_NbServers=6_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=false_NbServers=8_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=true_NbServers=2_RatioSrv2=50 🔍				✓		
			config_ATMdom=lmdz_UsingSrv2=true_NbServers=4_RatioSrv2=50 🔍				✓		
				atm_output.nc				✓	
				atm_output_zoom.nc				✓	
		test_function 🔍				✓			
		test_axis_algo 🔍				✓			
		test_grid_algo 🔍				✓			
	X64_JEANZAY_debug 🔍				✓				
		test_domain_algo 🔍				✓			

IS-ENES3 : XIOS roadmap

Improvement of the internal time line management

Implementing time interpolations

- Remove current limitation : temporal filters are applied at a multiple frequency of model time step
- Time interpolation filter will uncoupled the XIOS workflow from the models time step.
- A lot of practical examples…
  - Enable models with variable time step
  - For reading, a monthly file can be interpolated daily before to be injected into model

Targeted mid 2021

Implementing XIOS restartability

- Currently XIOS is not restartable
  - Model can be stop only at a multiple of the highest frequency of the time filters (averaging)
- Will enable models and XIOS workflow to be shut down at any time and then restarted
  - Longer averaging frequency (yearly means)
  - Decadal seasonal means

Targeted end 2020

Improving spatial filters

- Implement more complex spatial filters by chaining internally already developed primary filters
  - Zonal means, grad , div and curl filters…
- Efficient station output management
- Implement still missing remapping operator
  - nearest neighbor, bilinear

Targeted end 2021

The Consortium

Coordinated by **CNRS-IPSL**, the IS-ENES3 project gathers **22 partners** in **11 countries**

cnrs with cea Sorbonne Université

Met Office

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

BSC

CERFACS

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

SMHI

UK Research and Innovation

UC
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DLR

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METEO FRANCE
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