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INFRASTRUCTURE FOR THE EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

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CPMIP performance metrics for CMIP6: Lessons, recommendations and next steps

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ISENES3 partners

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

Introduction

- Traditional metrics of computational efficiency such as performance counters and scaling curves do not provide us enough about real sustained performance from climate models on different machines.

- CPMIP (Balaji et al. 2017): a set of metrics that can be used for the study of computational performance of Earth System Models (ESMs)
  - the set of metrics has to be universally available from current ESMs
  - the chosen measure has to be easy to collect and should not require specialized instrumentation or software
  - when evaluating the ESMs performance, the configuration used should be the operational one
  - the performance measurements should be taken across the entire lifecycle of modeling and cover both data and computational load

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Introduction

- CMIP6: Coordinated experiments designed to understand specific aspects of the model response.
  - The ideal context to create a performance data-base from a multi-model context using different configurations, resolutions, platforms...
- **IS-ENES3 provided a unique opportunity to exploit this new set of metrics**, performing for the first time a complete computational/energy analysis and the creation of a novel data-base based on CMIP6 experiments, using the different models and platforms available all across Europe.
- The outcome of this work was published in the D4.3 deliverable including:
  - The possibilities for collaboration with other groups (ES-DOC, HPC-TF and Carbon Footprint G.)
  - The analysis illustrating some practical examples, and proving the usefulness of the metrics to the community.
  - Main difficulties encountered in the coordination of the collection, including general recommendations on how to solve these problems for future collections and analyzes.

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CPMIP metrics (1, 2)

Metric	used to evaluate ...
Simulation Year Per Day (SYPD)	how efficient is your sim job per each year of the simulation
Core-hours Per Year (CHPY)	how efficient is your sim job with respect to the number of parallel resources used
Complexity	the number of prognostic variables per component
Actual SYPD	how affect queue time and interruptions to the complete experiment
Parallelization	total number of cores allocated for the run
Energy Cost Per Year (JCPY)	how much energy is needed per each year of simulation
Memory Bloat	the ratio between actual and ideal memory size
Data Output Cost	how much time and resources are used performing I/O
Data Intensity	the amount of data produced per compute-hour
Coupling Cost	how much time and resources are used in the cost of the coupling algorithm as well as load imbalance

(1) Balaji et al. 2017, CPMIP: measurements of real computational performance of Earth system models in CMIP6
(2) Mario Acosta et al. 2021, ISENES3 D4.3: CPMIP performance metrics evaluation for CMIP6 and community advice

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CPMIP: Community List

Model / Institution	People Involved
CNRM-CM6	Sophie Valcke, Marie Pierre Moine
IPSL-CM	Arnaud Caubel
EC-Earth	Mario Acosta, Uwe Fladrich, Philippe Le Sager
MetO	Harry Shepherd, JC Rioual
CMCC	Italo Epicoco, Silvia Mocavero
MPI-M-DKRZ	Maria Moreno, Reinhard Budich, Joachim B.
U. Read	Grenville Lister, Bryan Lawrence
Nor-ESM	Alok Kumar Gupta
TOPAZ/MOM5	Paulo Nobre
GFDL	Niki Zadeh

Include 11 models with 32 CMIP6 configurations (AMIP, OCE, Coupled, different resolutions…)

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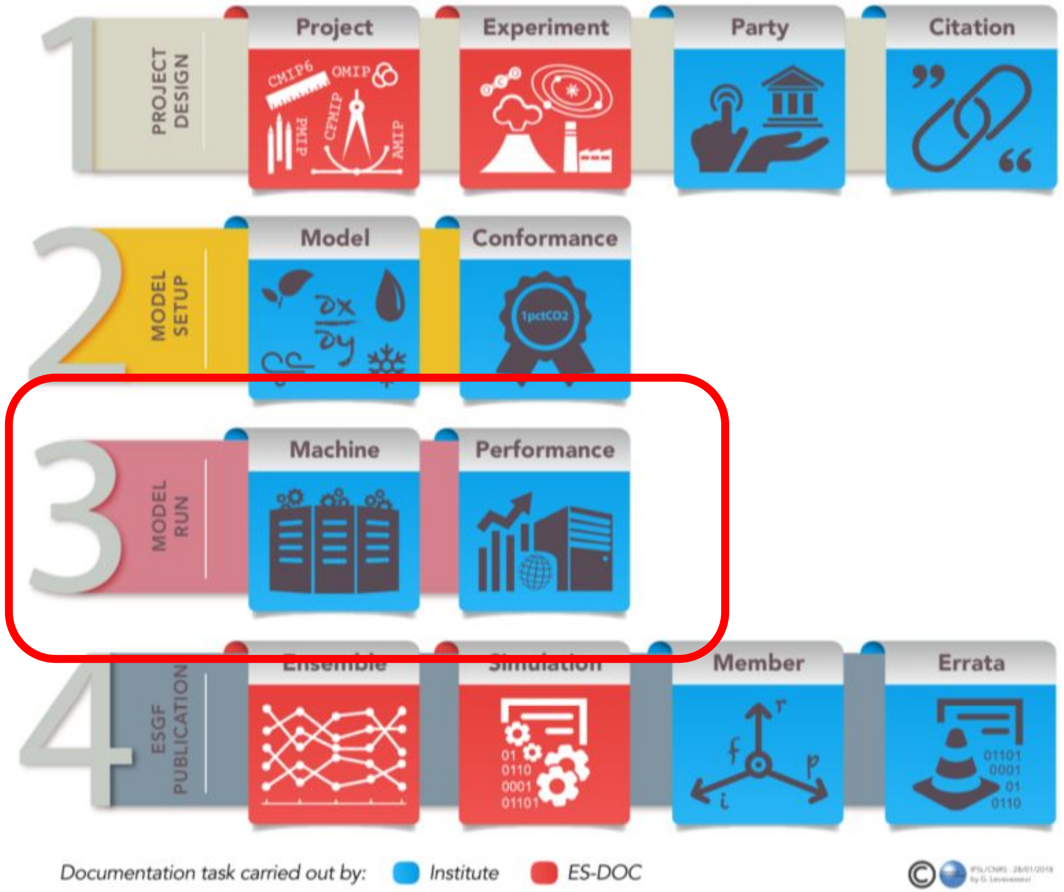
CPMIP:Community numbers

- The CPMIP collection is available through ES-DOC.
- ES-DOC will be improved to include more features in the future, such as metrics per components of a coupled model.



University of Reading

es-doc Earth System Documentation

Provided by Sadie Bartholomew

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HPC-TF work: a CMIP6 Summary

CMIP6 Experiments: Institutions/Models	Useful SY	Total SY	Useful Data Produced (PB)	Total Data Produced (PB)	Useful CH (Mh)	Total CH (Mh)
EC-Earth	28,105	38,854	0.80	1.405	31.3	46.8
CNRM-CERFACS	47,000	84,112	1.35	2.48	160	365
IPSL	75,000	165,000	1.8	7.6	150	320
CMCC	965	1,804	0.965	0.28	1.99	4.34
UKMO	37.237	69,602	10.4	30.23	683	1491
DKRZ	1,276	1,321	0.606	1.76	5.52	5.90
NCC-NORESM2	23,096	43,170	0.596	1.73	27.23	80
NERC	640	1,164	0.460	1.34	55.497	121.2
MPI	24,175	35,000	1.925	5.60	16.32	2114

* We have also Useful SY, Useful Data and Useful CH per CMIP6 experiment

*** Data in red is estimated by Jean-Claude Andre (HPC-TF)**

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Carbon footprint collaboration

CMIP6 Experiments: Institutions/Models	Useful SY	Useful CH (Mh)	Total Energy Cost (Joules)	PUE	CF (g CO2/kWh)	Total Carbon Footprint (CO2)
EC-Earth	28,105	31.3	1.24E+12	1.35	357	165t
CNRM-CERFACS	47,000	160	6.18E+12	1.43	40	97t
IPSL	75,000	150	8.72E+12	1.43	50	172t
CMCC	965	1.99	1.61E+12	1.84	408	329t
UKMO	37.237	683	2.67E+13	1.35	87	868t
DKRZ	1,276	5.52	4.09E+11	1.19	184	24t
NCC-NORESM2	23,096	27.23	1.69E+12			
NERC	640	55.497	2.17E+12	1.10	0*	
MPI	24,175	16.32	7.10E+11	1.19	184	42t

*Green tariff according to NERC

Carbon Footprint = Total Energy Cost (MWh) * Conversion Factor (CF) * Power Usage Effectiveness (PUE) 1.554616×10^{14}

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Conclusion 1

- **The possibilities for collaboration with other groups (ES-DOC, HPC-TF and Carbon Footprint G.)**
  - The coordinated collection is not only useful for dissemination and computational analysis. The collection create a data-base which could be used in the future in several ways, such as innovation and the communication with vendors when the new machines are on deployment.
    - About the amount of resources necessary to run the CMIP6 simulations (Jean-Claude Andre)
    - Invited talk: Towards minimising carbon footprint of climate modelling, WCRP Workshop on Future of Climate Modelling (Mario Acosta, March 2022).

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Introduction

- The analysis illustrated some practical examples, and proving the usefulness of the metrics to the community.
  - Resolution impact
  - Complexity impact
  - Data output impact
  - ASYPD: Queue time and interruptions impact
  - Coupling impact

- In a previous work, we also studied a specific model (EC-Earth) to evaluate the computational efficiency on different machines or configurations
  - Complexity Impact: Identify which component is the bottleneck of the coupled version
  - ASYPD: Queue time could differ between machines, due to the different set-up of the queue systems
  - Comparison through machines: Detect bottlenecks according to the limitations of each hardware

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  - **Coupling impact**

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CPMIP Results

- **If we consider ASYPD_OH as the percentage decreased compared to SYPD**
- ASYPD_OH is around 10-50% for the most of the cases.
- ASYPD_OH can be classified in two clear groups

Institutions reporting a ASYPD_OH < 15% included only queue time

Institutions reporting a ASYPD_OH > 15% included additionally interruptions and/or workflow management

- The results could support that queue time represents around 10-15% and adding interruptions and workflow management around 40-50%
- BSC results using the same configuration prove that the percentage could change between two different platforms. A finer granularity could be needed.

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CPMIP Results

- The increase in Coup C. is not necessarily related to decrease the performance. However, a specific case has been identified and it should be studied:

Resol ↑ → **Coup. C.** ↑ **SYPD** ↓

- It could be a problem in the Coupling phase, maybe because the coupling algorithm is not scaling correctly or maybe simply because the higher resolution configuration is not well-balanced.
- This means also that for high resolutions and not well-balanced cases, institutions should spend more resources to find the balanced version using the trial and error approach… and not always it is trivial.
- A finer granularity and new ways to achieve a well-balanced configuration could be needed

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Conclusion 2

- **The analysis illustrating some practical examples, and proving the usefulness of the metrics to the community.**
  - CPMIP collection is not only a dissemination process. It is a very powerful tool to analyze the computational efficiency of a model across platforms, configurations; find bottlenecks…or even for the multi-model comparison.

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Lessons learned about the collection (I)

- Although the CPMIP collection is important, it is secondary during the CMIP execution.
  - During the execution of the experiments, the ~~main~~ (single) goal is to finish the experiments.
  - Some metrics can be collected after CMIP6 experiments, re-running a complete chunk...but be careful, some institutions have reported that re-run experiments (even partially) is too much expensive. Moreover, they delay the collection and the machine is changed.
  - Even though some institutions have shown interest from the beginning, only ISENES partners and GFDL have provided complete metrics

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- We have some gaps in our numbers and they are not going to be updated
- We made up to three attempts to collect these last values but it was impossible
- Some external partners said YES and show interest but they did not provide numbers at the end.
- We noticed that for some partners the collection is trivial and for others is a real headache

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Lessons learned about the collection (I)

- Collect CPMIP metrics before or during the CMIP experiment
  - Coordinated collections proved to be useful and critical to get the performance results.
  - Facilitate portable and automatic processes to ensure the collection for all institutions, such as the integration with workflow managers.
  - Creation of tools which make easier the collection of some metrics (as the Load balancing tool for OASIS), scripts for automatic collections or the integration of a standard (Energy).
  - Collect and analyze CPMIP metrics during the deployment/tuning/Spinup should help to increase the throughput before the operational runs

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Lessons learned about the collection (I)

- Collect CPMIP metrics before or during the CMIP experiment
  - Coordinated collections
    - **Include new collections for future activities/projects (EERIE, ESiWACE3, ENES-RI)**
  - Facilitate portable and automatic processes
    - **The collection will be integrated through Autosubmit workflow manager, transparent to the user, providing all the numbers automatically for any experiment.**
  - Creation of tools which make easier the collection
    - **Know more about the new Load balancing tool for OASIS from CERFACS and BSC or the work in progress from CMCC to achieve a portable approach to measure Energy**
  - Collect and analyze CPMIP metrics during the deployment/tuning/Spinup
    - **Apply the new approaches during the appropriate stage to ensure the collection**

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Lessons learned about the collection (II)

- CPMIP collection is not only a dissemination process. It is a very powerful tool to analyze the computational efficiency of a model or multi-model but…
  - Specific details for each component and configuration of a model will facilitate the analysis.
  - Some HPC expertise could be needed to interpret the results
  - The limitations of the hardware could be a handicap for the analysis itself
  - The collection requires an extra effort which does not compensate

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- For a coupled model, we could conclude some issues that actually are related to one specific component or machine dependent.
- Even though we detect some issues in a model, is it valuable to review the algorithmic part or simply use a better hardware?
- Is the effort in the collection compensated?

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Lessons learned about the collection (II)

- Develop new approaches to analyze the results.
  - New approaches to include some metrics per component
  - The bigger is the data-base collection, the easier will be to follow recommendations for the analysis of your model.
  - The integration of CPMIP metrics in dwarfs (i.e.ESCAPE2) could identify limitations of the platform before the real executions.

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Lessons learned about the collection (II)

- Develop new approaches to analyze the results.
  - New approaches to include some metrics per component
    - **ES-DOC will be updated to include information per component**
    - **The load balancing tool updated from BSC and CERFACS should provide the rest of metrics needed.**
  - Creation of a data-base and analysis examples
    - **Autosubmit will save in a real data-base the CPMIP for any experiment**
    - **Disseminate the papers in progress with the community to provide examples about how to interpret the results.**
  - The integration of CPMIP metrics in benchmarks
    - **Integrate CPMIP in HPCW dwarfs, a benchmarking using a set of real models and portable through machines (ESiWACE3).**

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Lessons learned about the collection (III)

- Inconsistencies in the way that some metrics are collected
  - ASYPD: Many institutions are including queue time and interruptions, but others are including only queue time or adding data movement, cleaning…
  - JPSY: The value is taken from different sources, usually provided by the operational department of the machine
  - Post-processing/data management could affect to ASYPD for some specific configurations. Should it be studied independently? Could they affect the critical path of the execution?

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- ASYPD could be not totally comparable among models and what is worse, some institutions could think that their ASYPD is fine, where the issue is how it was measured.
- We find discrepancies in the Total Energy cost/Core-Hours for ~~MPI~~ and CMCC
- Measure only simulation job is not a proper approach to analyze the complete workflow of a climate experiment, we are missing information.

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Lessons learned about the collection (III)

- Normalize some metrics could help for future analysis
  - Standardize for all the institutions the approach to collect each metric
  - Provide new approaches to collect metrics which could be comparable across platforms
  - Integrate the collection through workflow managers for long period of simulations

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Lessons learned about the collection (III)

- Normalize some metrics could help for future analysis
  - Standardize the approach to collect each metric
    - **The coordinated collection task should provide guidelines about how to collect critical metrics**
  - Provide new approaches to collect metrics which could be comparable across platforms
    - **The new approach from CMCC could solve the problem for the energy cost**
    - **Using common tools as OASIS will ensure a common approach**
  - Integrate the collection through workflow managers for long period of simulations
    - **Autosubmit will collect the metrics automatically in the same way, independently of the machine or model. The scripts could be ported to other workflow managers.**

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Lessons learned about the collection (III-2)

- Even though some metrics point out to a bottleneck. How much does each of the components affect to the coupled set?
  - CC: Is coming from the coupling algorithm itself or simply a load imbalance issue? Should I waste resources using a trial and error approach to minimize CC?
  - ASYPD: Is coming from the queue time or the interruptions? Could affect the other parts of the workflow to ASYPD? Could the problem change among configurations?

- Create a finer granularity for some metrics

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- Create a finer granularity for some metrics
  - Creation of sub-metrics per component collected by the workflow or new tools as the Load balancing tool of OASIS
  - Evaluate queue time and run time separately, simulate longer runs for the timestamp evaluation
  - Measure the complete workflow of an experiment in different stages (initialization, simulation, postprocessing, data movement and cleaning).

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The Consortium

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

CNRS with CEA, Sorbonne Université

National Centre for Atmospheric Science – Natural Environment Research Council

Met Office

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 – Universidad de Cantabria

DLR

netherlands eScience

Norwegian Meteorological Institute

METEO FRANCE – Toujours un temps d'avance

MANCHESTER 1824 – The University of Manchester

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CHARLES UNIVERSITY

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LiU – LINKÖPING UNIVERSITY

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