

HPC for climate modelling in Europe: ENES, IS-ENES and the OASIS coupler

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Part I:

- The European Network for Earth System modelling ENES
- The IS-ENES EU project: infrastructure for ENES
- 2012-2022 Infrastructure Strategy for ENES: HPC, data, models

Part II

- Code coupling strategies in climate modelling
- OASIS: historical overview, user community
- OASIS3-MCT: use, communication, performances
- Conclusions and perspectives



A network of European groups in climate/Earth system modelling launched in 2001 (MoU) gathering ~50 groups from academic, public and industrial world

<http://enes.org>

- discuss strategy to accelerate progress in climate modelling and understanding

IS-ENES EU projects : InfraStructure for ENES <http://is.enes.org>

Phase1 (7.6 M€) 2009-13: 18 partners;

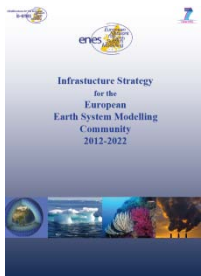
Phase2 (8 M€) 2013-17: 23 partners



FP7 project « Integrating Activities » networking, service & joint research activities

- Integrate the European Earth System Model community
 - Develop ESMs and their environment
 - Foster high-end simulations (interface with PRACE)
 - Disseminate model results to climate research and impact communities via international databases (CMIP5 & CORDEX)
 - Establish a strategy for the European Earth System Modelling Community for 2012-2022 (*computing, models, data*)
-

2012-2022 Infrastructure Strategy for the European Earth System Modelling Community



Drivers : Science & Society
From understanding to development of “Climate Services”

Key science questions

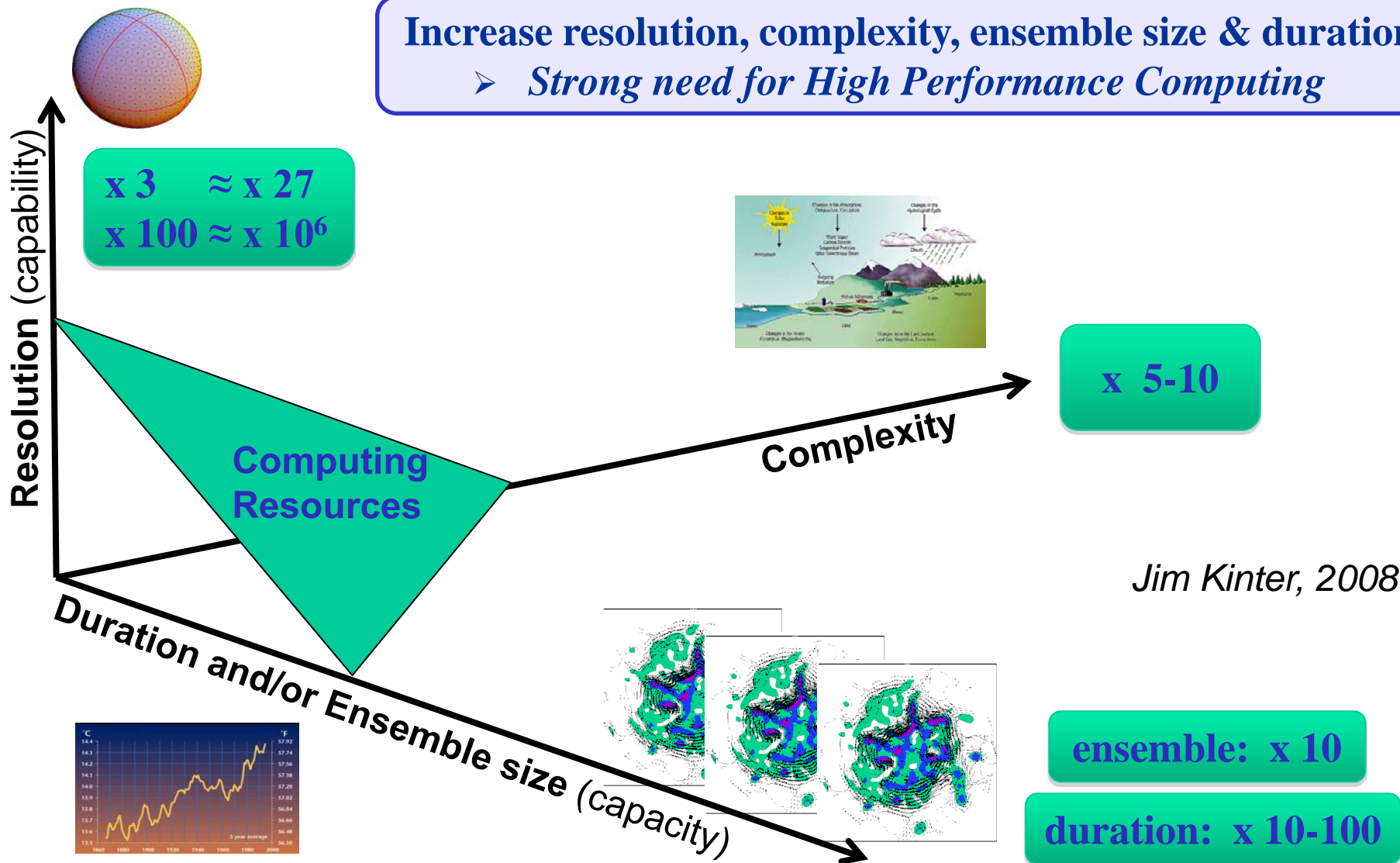
- Q1. How predictable is climate on a range of timescales ?
- Q2. What is the sensitivity of climate and how can we reduce uncertainties ?
- Q3. What is needed to provide reliable predictions of regional climate changes ?
- Q4. Can we model and understand glacial-interglacial cycles ?
- Q5. Can we attribute observed signals to understand processes ?

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52 contributors from BE, CZ, DE, DK, FI, FR, IT, NO, SE, SP, UK

2012-2022 Infrastructure Strategy for the European Earth System Modelling Community

Increase resolution, complexity, ensemble size & duration

➤ *Strong need for High Performance Computing*



Jim Kinter, 2008

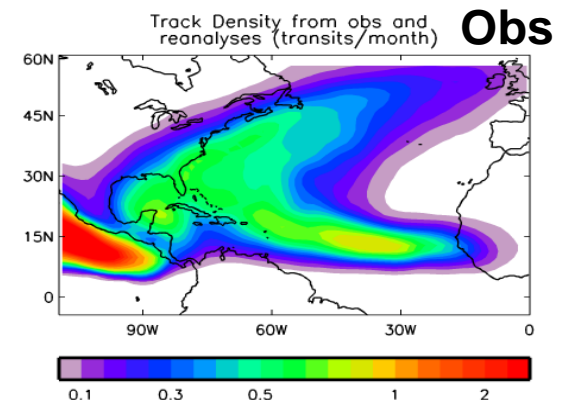
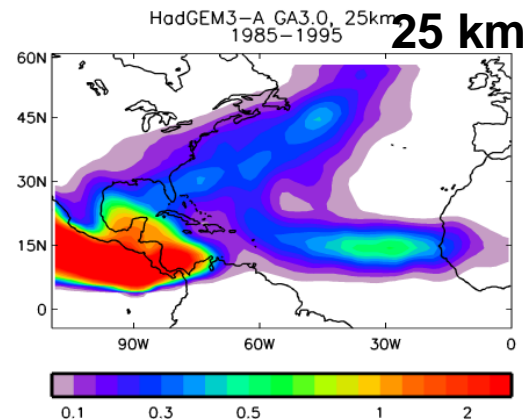
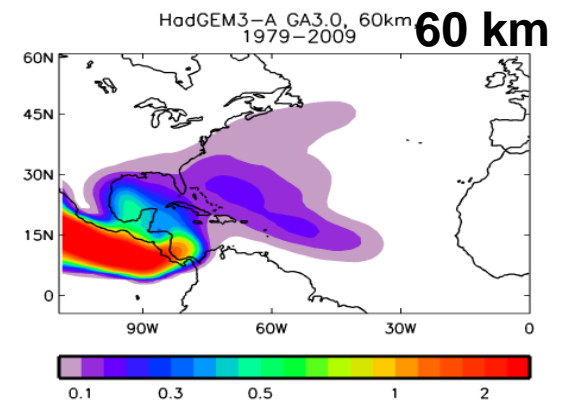
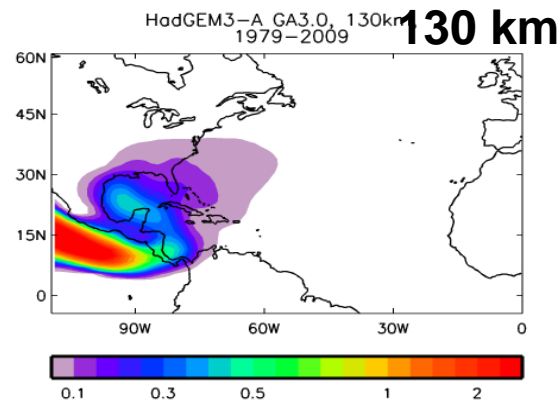


2012-2022 Infrastructure Strategy for the European Earth System Modelling Community

Increase resolution: grand challenge : ~1 km scale for resolving deep convective clouds in global climate models

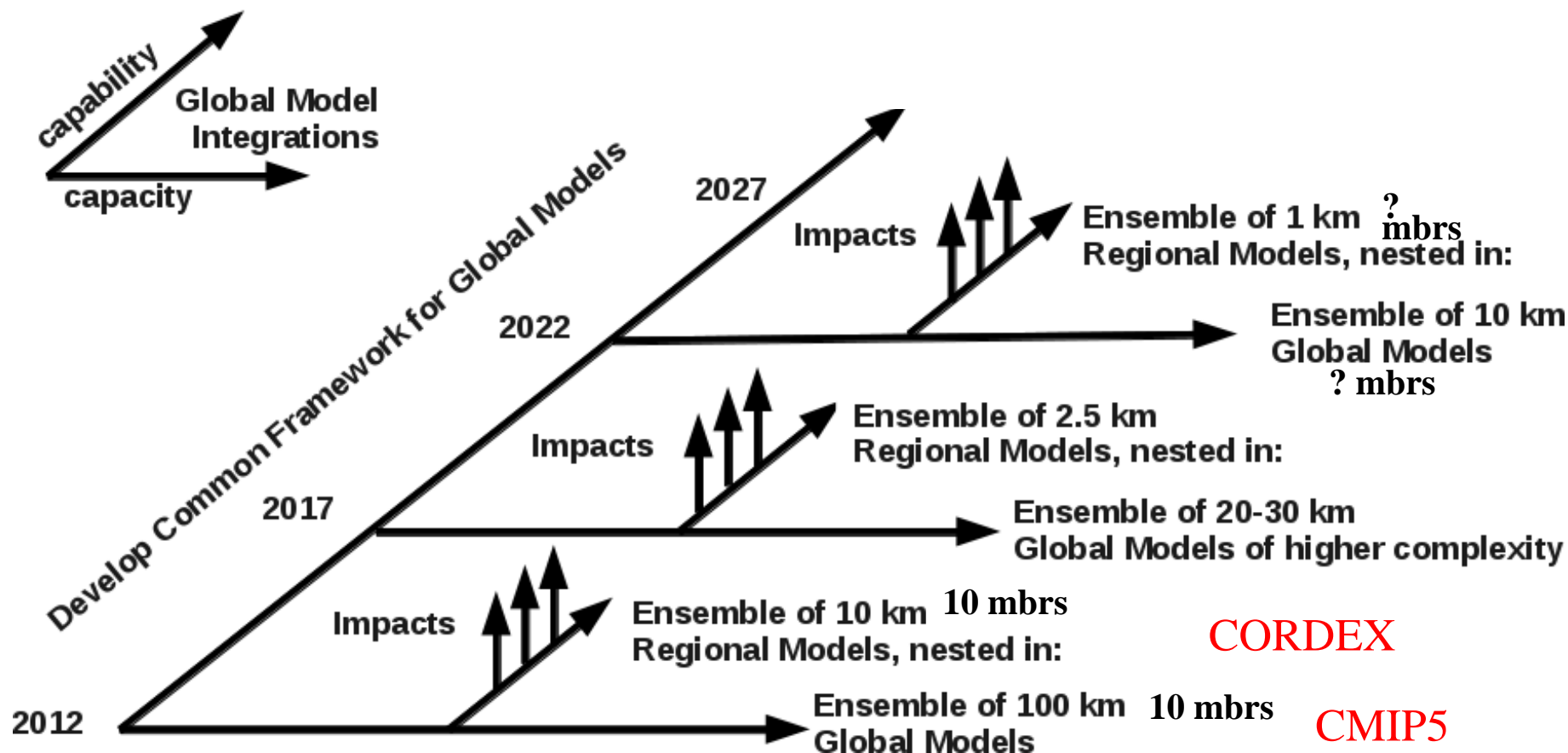
UPSCALE results:
increased resolution
essential to better
simulate extreme events,
e.g tropical cyclones

PL Vidale (NCAS)
M. Roberts (MO/HC)



2012-2022 Infrastructure Strategy for the European Earth System Modelling Community

Increase resolution in ensemble simulations



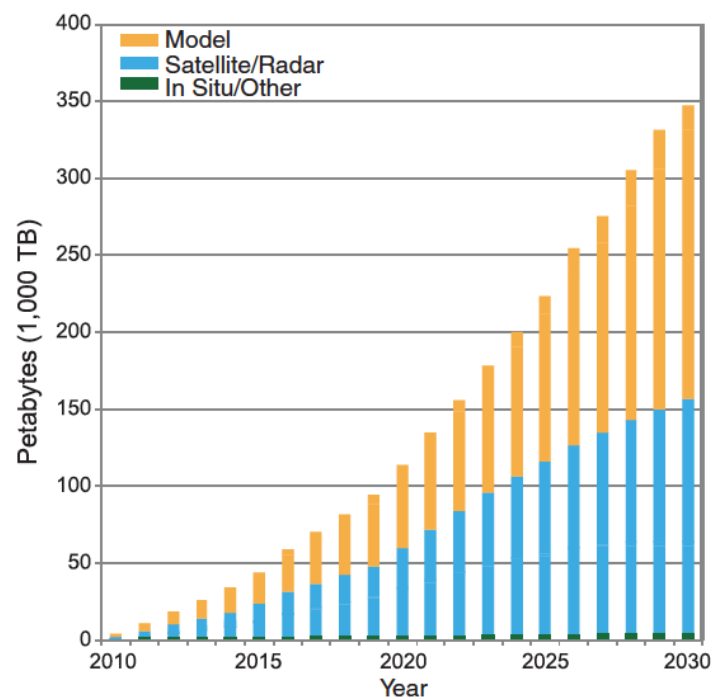
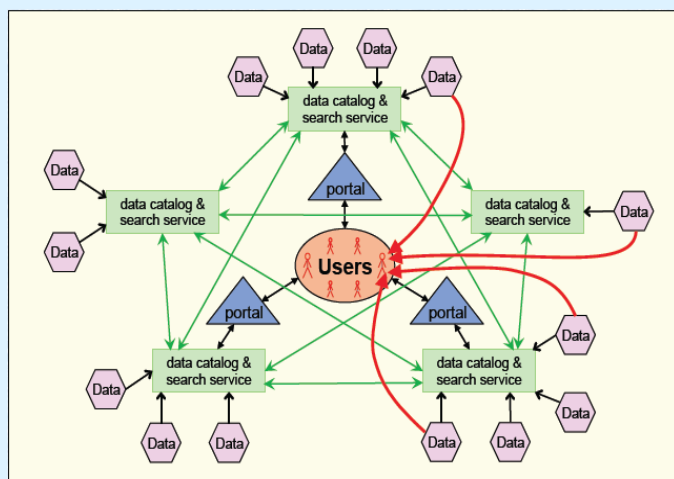
2012-2022 Infrastructure Strategy for the European Earth System Modelling Community

Data: Strong demand from society (climate services) for model data, expected to grow exponentially

CMIP5: 2 to 3 PB

CMIP6: x 30 ?

Earth System Grid Federation



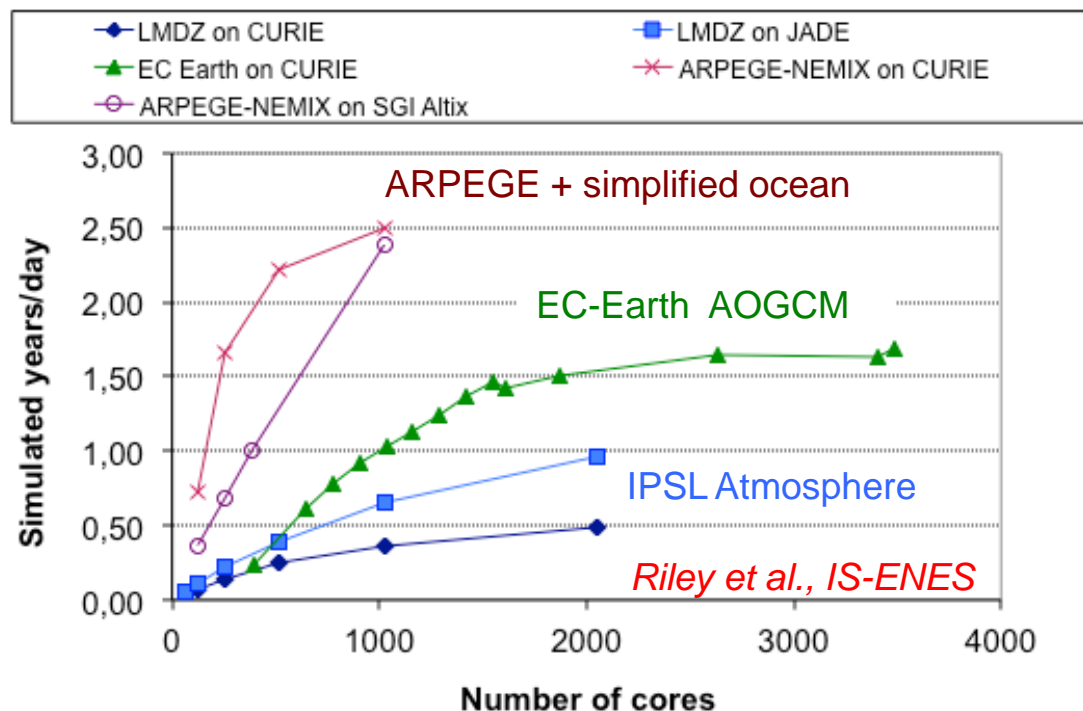
Overpeck et al. (Science 2011)

⇒ **Sébastien Denvil's talk tomorrow**

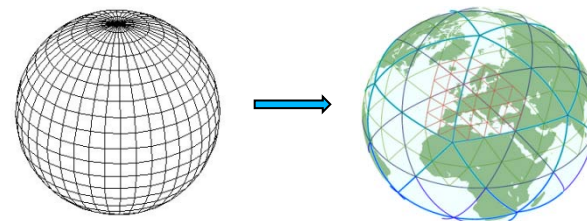
2012-2022 Infrastructure Strategy for the European Earth System Modelling Community

Models:

- Maintain scientific diversity but harmonise technical developments (coupling strategy, I/O, ...)
- Improve model parameterisations
- Prepare models for future highly parallel HPC architectures



Scalability issue
=> need to revisit
dynamical cores &
I/O library



Icosahedral grids

Court. Dubos & Meurdesoif
(IPSL)

HPC for climate modelling in Europe: ENES, IS-ENES and the OASIS coupler

Part II

- Coupling strategies in climate modelling
- OASIS: historical overview, user community
- OASIS3-MCT: use, communication, performances
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Coupling strategies in climate modelling

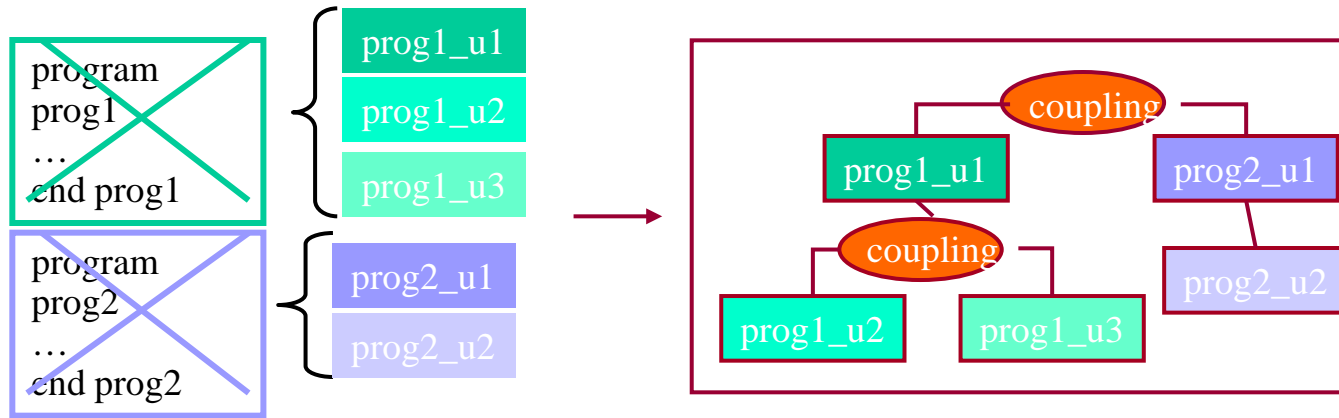
1. use integrated coupling framework

ESMF

CESM (NCAR)

FMS (GFDL)

- Split code into elemental units
- Write or use coupling units
- Use the library to build a **hierarchical merged code**
- Adapt code data structure and calling interface



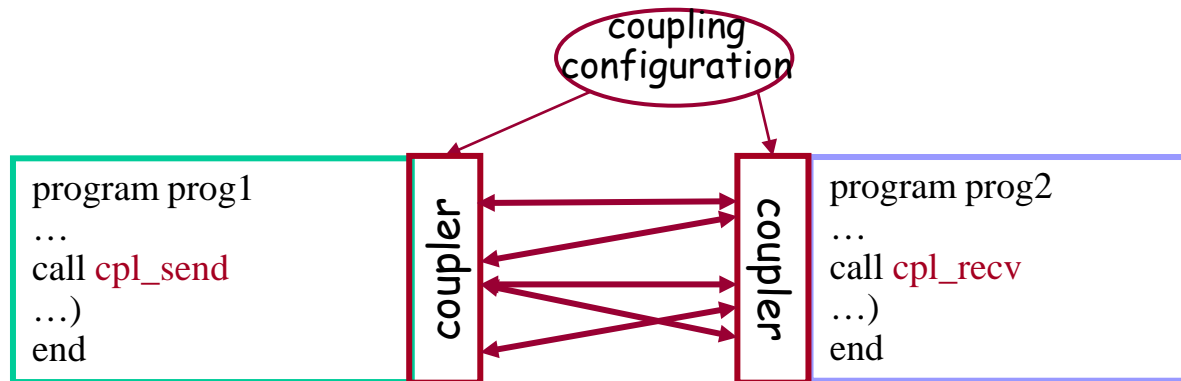
- 😊 efficient,
- 😊 sequential and concurrent components
- 😊 use of generic utilities (parallelisation, regridding, time management, etc.)

- ☹ existing codes
- ☹ (easy)

→ **probably best solution in controlled development environment**

Coupling strategies in climate modelling

2. use a coupler or coupling library

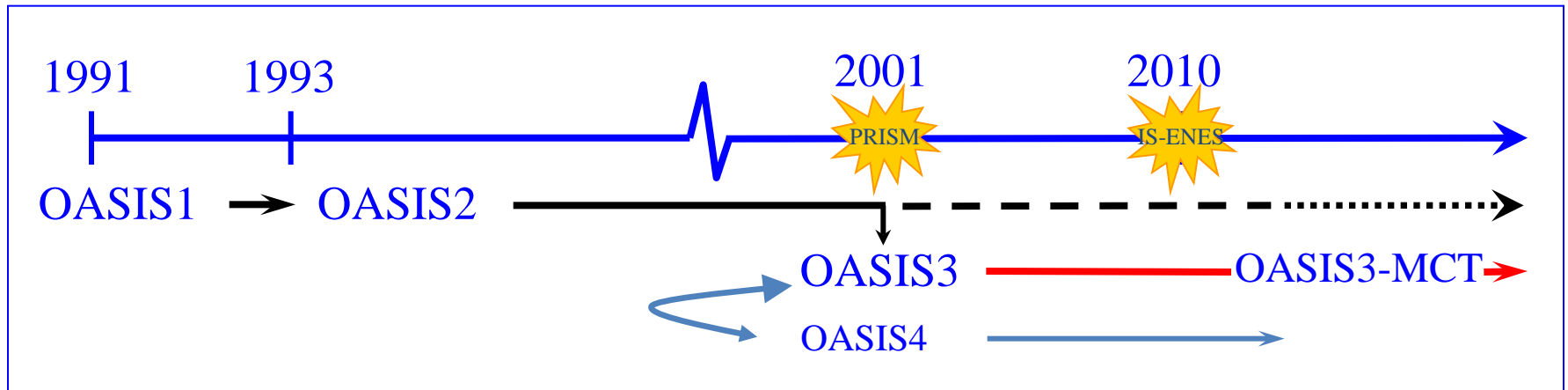


- 😊 existing codes
- 😊 use of generic transformations/regridding
- 😊 concurrent coupling (parallelism)

- 😞 multi-executable: possible waste of resources if sequential execution of the components is enforced
- 😞 multi-executable: more difficult to debug; harder to manage for the OS
- 😞 efficient

→ probably best solution to couple independently developed codes

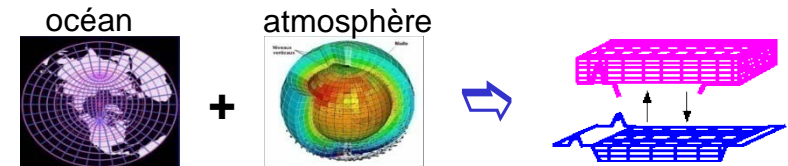
The OASIS coupler: historical overview



• OASIS1 -> OASIS2 -> OASIS3:

2D ocean-atmosphere coupling
low resolution, low frequency

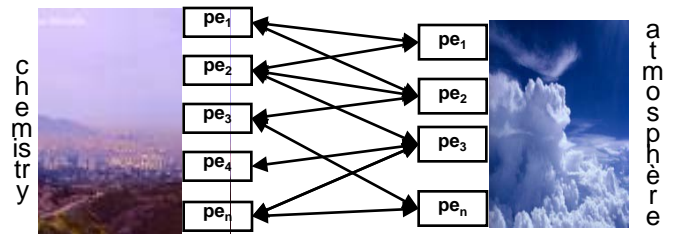
→ flexibility, modularity, 2D interpolations



• OASIS4 / OASIS3-MCT:

2D/3D coupling of high resolution parallel components on massively parallel platforms

→ parallelism, efficiency, performance





The OASIS coupler: user community today

About 40 groups world-wide (climate modelling or operational monthly/seasonal forecasting):

- France: CERFACS, METEO-FRANCE, IPSL (LOCEAN, LMD, LSCE), OMP, LGGE, IFREMER
 - Europe: ECMWF + Ec-Earth community
 - Germany: MPI-M, IFM-GEOMAR, HZG, U. Frankfurt
 - UK: MetOffice, NCAS/U. Reading, ICL
 - Denmark: DMI
 - Norway: U. Bergen
 - Sweden: SMHI, U. Lund
 - Ireland: ICHEC, NUI Galway
 - The Netherlands: KNMI
 - Switzerland: ETH Zurich
 - Italy: INGV, ENEA, CASPUR
 - Czech Republic: CHMI
 - Spain: U. Castilla
 - Tunisia: Inst. Nat. Met
 - Japan: JMA, JAMSTEC
 - China: IAP-CAS, Met. Nat. Centre, SCSIO
 - Korea: KMA
 - Australia: CSIRO
 - New Zealand: NIWA
 - Canada: RPN-Environment Canada, UQAM
 - USA: Oregon State U., Hawaii U., JPL, MIT
 - Peru: IGP + downloads from Belgium, Nigeria, Colombia, Saudi Arabia, Singapore, Russia
- OASIS3 is used in 5 of the 7 European ESMs that participate in IPCC AR5

OASIS3-MCT is a library linked to the component models

OASIS3-MCT API:

- Initialization: `call oasis_init_comp(...)`
- Grid definition: `call oasis_write_grid (...)`
- Local partition definition: `call oasis_def_partition (...)`
- Coupling field declaration: `call oasis_def_var (...)`

• Coupling field exchange:

➤ in model time stepping loop

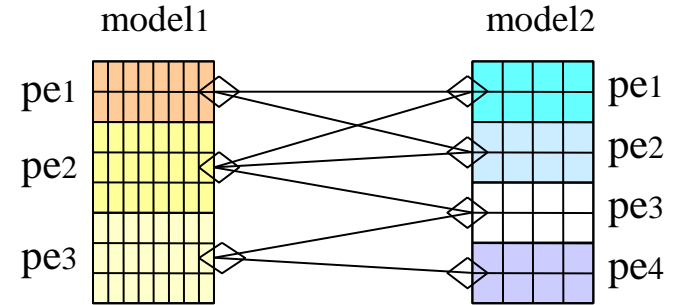
```
call oasis_put (... , date, var_array. ...)  
call oasis_get (... , date, var_array, ...)
```

- user's defined source or target (end-point communication)
- sending or receiving at appropriate time only
- automatic averaging/accumulation if requested
- automatic writing of coupling restart file at end of run

Fully parallel communication between parallel models based on MCT using MPI:

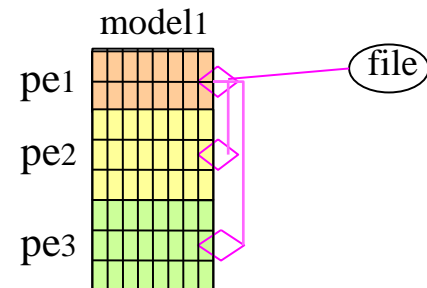


- computation of communication patterns
- matrix multiplication for regridding (on the source or target processes)
- coupling data transfer/redistribution



If specified by the user, the regridding weights and addresses are calculated onto one model process using the LANL SCRIP library (nearest-neighbour, bilinear, bicubic, conservative)

• I/O functionality
(switch between coupled and forced mode):





Some OASIS3-MCT users

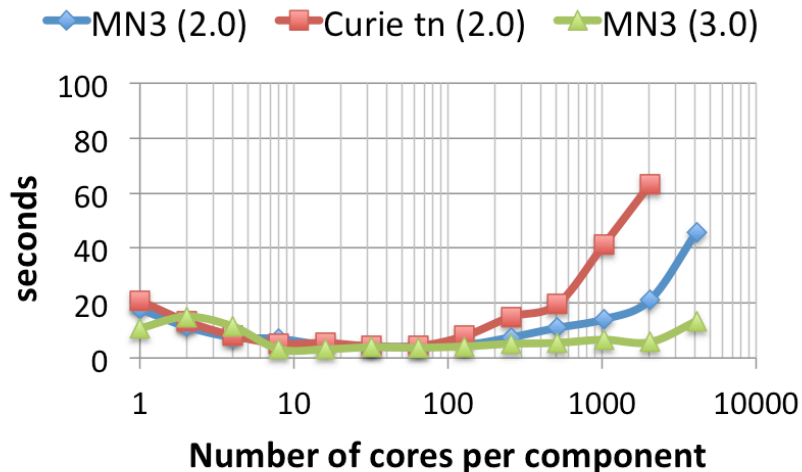
- ◆ CERFACS (France):
 - NEMO ocean (ORCA025, 1021x1442) - ARPEGE atmosphere (Gaussian Red T359 grid, 817240 points).
 - Decadal experiments in HiResClim I & II PRACE project (38 & 50 Mhours on IBM Mare Nostrum at BSC)
 - Seasonal prediction experiments in SPRUCE PRACE project (27 Mhours on tier-0 Bullx Curie at TGCC).
- ◆ IPSL (France):
 - WRF atm - NEMO ocean model, both with two-way nested zooms, resolution from 27 km to 9 km (4322X1248 grid points), 7 coupling fields, 1h coupling period.
 - Used in PULSATION project funded by the French ANR, 22 Mhours on PRACE tiers-0 Bullx Curie.
- ◆ MPI-M (Germany):
 - All MPI-ESM versions, in particular MPI-ESM-XR: atmosphere ECHAM6 T255L95 (768x384 grid points, ~50km, 95 vertical levels) - ocean MPIOM TP6ML40 (3602x2394 grid points, ~10km, 40 vertical levels); 17 coupling fields, 1h coupling frequency.
- ◆ MetOffice (UK) :
 - Global ocean-atmosphere coupling between UM global atmosphere (N768, 1536x1152) and NEMO ocean (ORCA012, 4320x3058), 38 coupling fields, 1h-3h coupling frequency
- ◆ BTU-Cottbus (Germany):
 - 3D coupling between COSMO-CLM regional atmosphere (221x111x47, ~2 deg) and ECHAM global atmosphere (T63, 192x96x47), + 2D coupling to MPI-OM ocean (254x220)
 - 6% coupling overhead for exchange of 6 x 3D fields every ECHAM time step
- ◆ ...+ many others ...



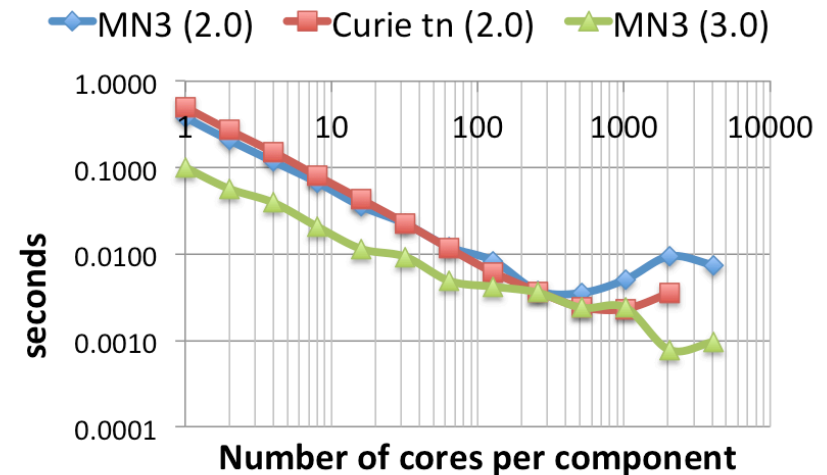
OASIS3-MCT performance

- Toy coupled model: ping-pong exchanges between NEMO ORCA025 grid (1021x1442) and Gaussian Reduced T799 grid (843 000)
- Bullx Curie thin nodes; Intel® procs Sandy Bridge EP; IFort 12.1.7.256, Bullx MPI 1.1.16.5
- IBM MareNostrum3: Intel Sandy Bridge processors, Intel MPI 4.1.0.024

Total initialisation time T799-ORCA025



Time for one ping-pong T799-ORCA025

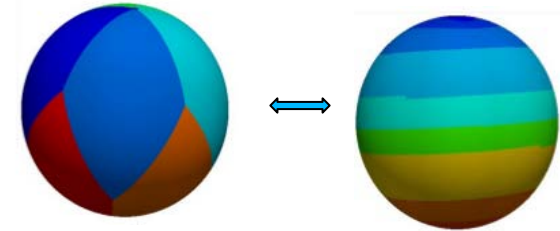


Coupling overhead for one-year long simulation with one 1 coupling exchange every hour in each direction between codes with $O(1 \text{ M})$ grid points running on 4000 cores/component:

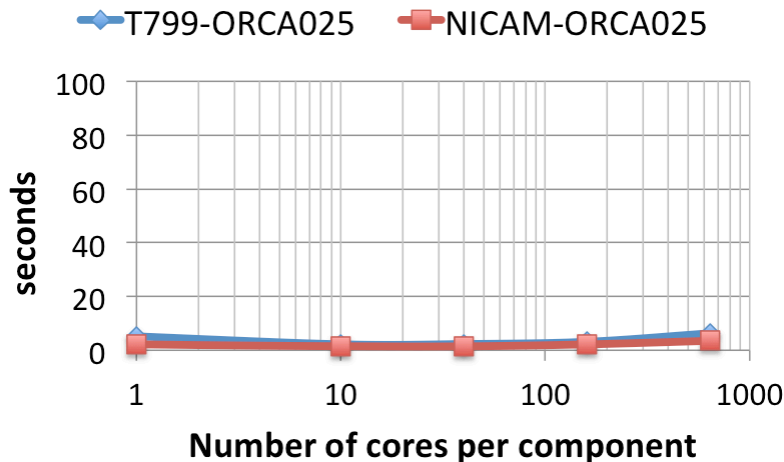
- ~20 seconds for initialisation, ~9 seconds for data exchange

OASIS3-MCT performance

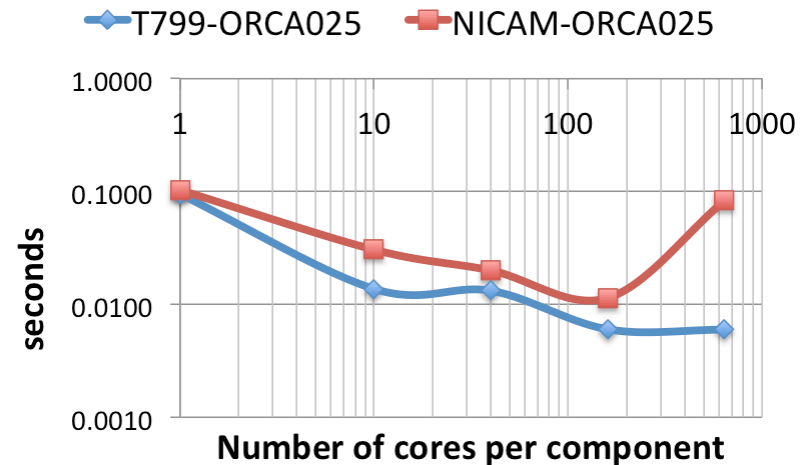
- Ping-pong exchanges between NEMO ORCA025 grid (1021x1442) and **NICAM icosahedral** grid (2621440)
- Bullx Beaufix: ; Intel® Ivy Bridge EP; Ifort, IMPI 4.1.1.036



Total initialisation time on Beaufix



Time for one ping-pong on Beaufix



Coupling overhead for one-year long simulation with one 1 coupling exchange every hour in each direction between codes with $O(1 \text{ M})$ grid points running on 1000 cores/component:

- ~7 seconds for initialisation, ~12 minutes for data exchange

Conclusions and perspectives

ENES & IS-ENES

- IS-ENES: build a long-term European Research Infrastructure for climate:
 - proposal for a "Centre of Excellence for climate and weather"
 - proposal for an ESFRI
- 2012-2022 strategy for the European climate modelling community
 - High Performance **Computing**: strong need for increased resolution, complexity, ensemble size & duration
 - **Data** issue :exponential growth, strong demand from society
 - **Model** scalability: need for new dynamical cores, I/O library
- Climate modelling has long cycles of development/evaluation/production
 - needs HPC facilities adapted to its needs,
 - on-going discussion with PRACE (CMIP6)

The OASIS3-MCT coupler

- Good example of bottom-up approach and shared software benefits
 - Good performance: most likely to provide a satisfactory solution for our climate models for the next ~5 years.
 - Longer term:
 - IS-ENES2 Coupling technology benchmark
 - Should we (Europeans) evolve to the "integrated coupling" approach (e.g. ESMF): more constraints but more opportunities for performance,
-

The end

