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

CERFACS

is-enes
INFRASTRUCTURE FOR THE EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

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ENES : European Network for Earth System modelling

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

CAPACITIES

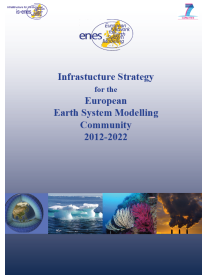
+

IS-ENES : Infrastructure for ENES

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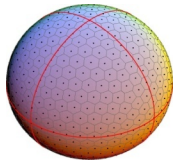
52 contributors from BE, CZ, DE, DK, FI, FR, IT, NO, SE, SP, UK

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

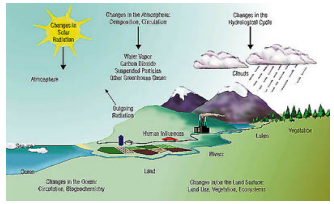
Increase resolution, complexity, ensemble size & duration

➢ ***Strong need for High Performance Computing***



x 3 ≈ x 27

x 100 ≈ x 10^6



x 5-10

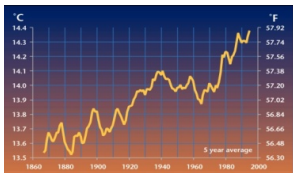
Resolution (capability)

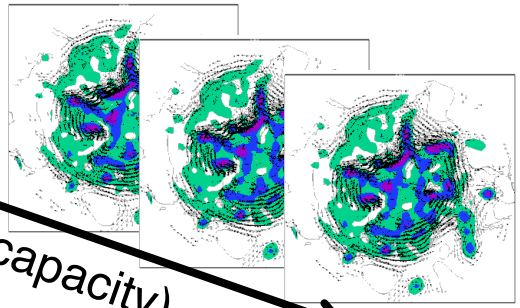
Complexity

Duration and/or Ensemble size (capacity)

Computing Resources

Jim Kinter, 2008



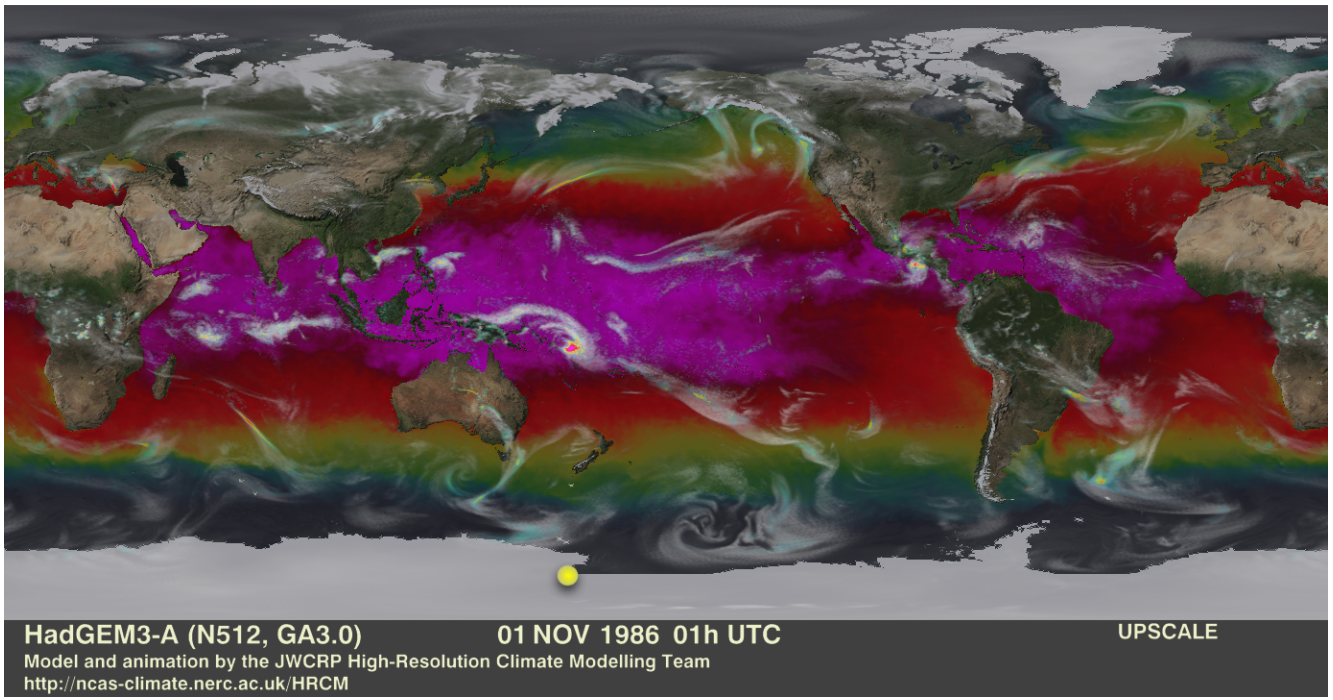


ensemble: x 10

duration: x 10-100

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



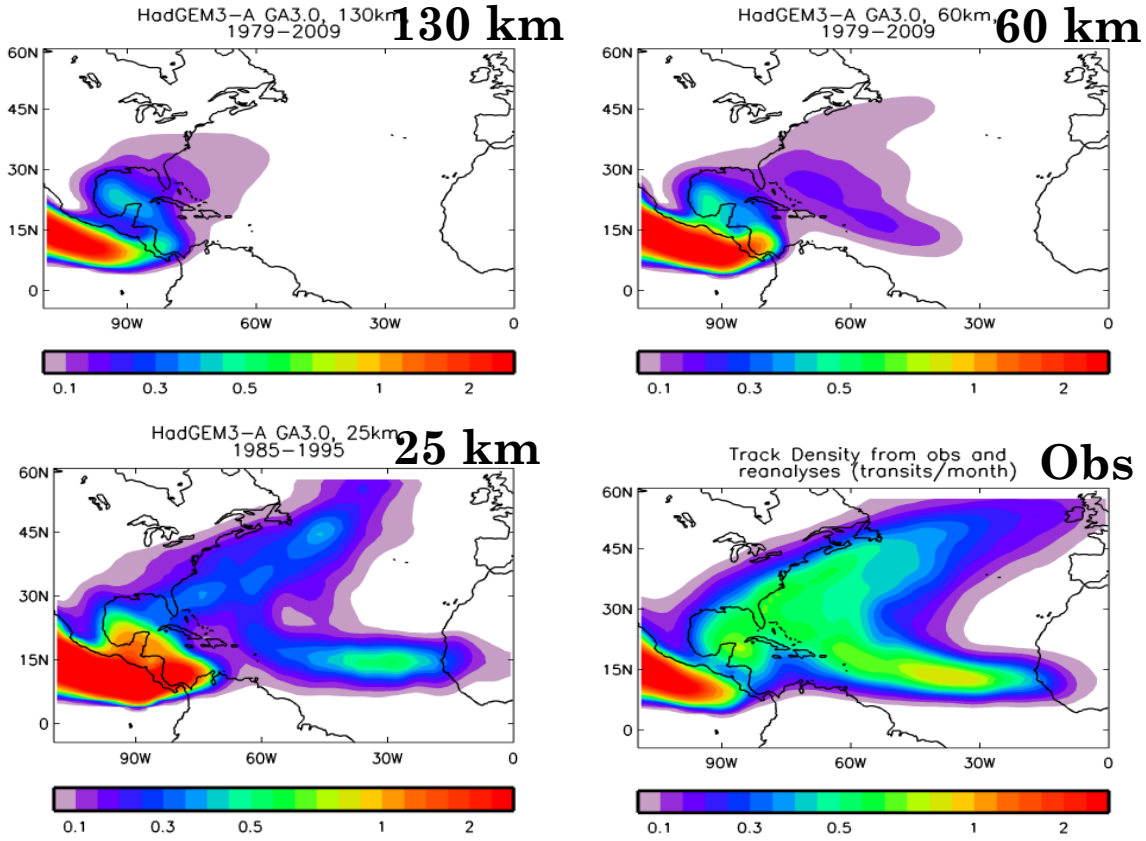
UPSCALE PRACE project, NCAS - High resolution climate group
HiGEM- Atmosphere alone ~25 km, 6000 cores – 140 Mhours for whole project

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)



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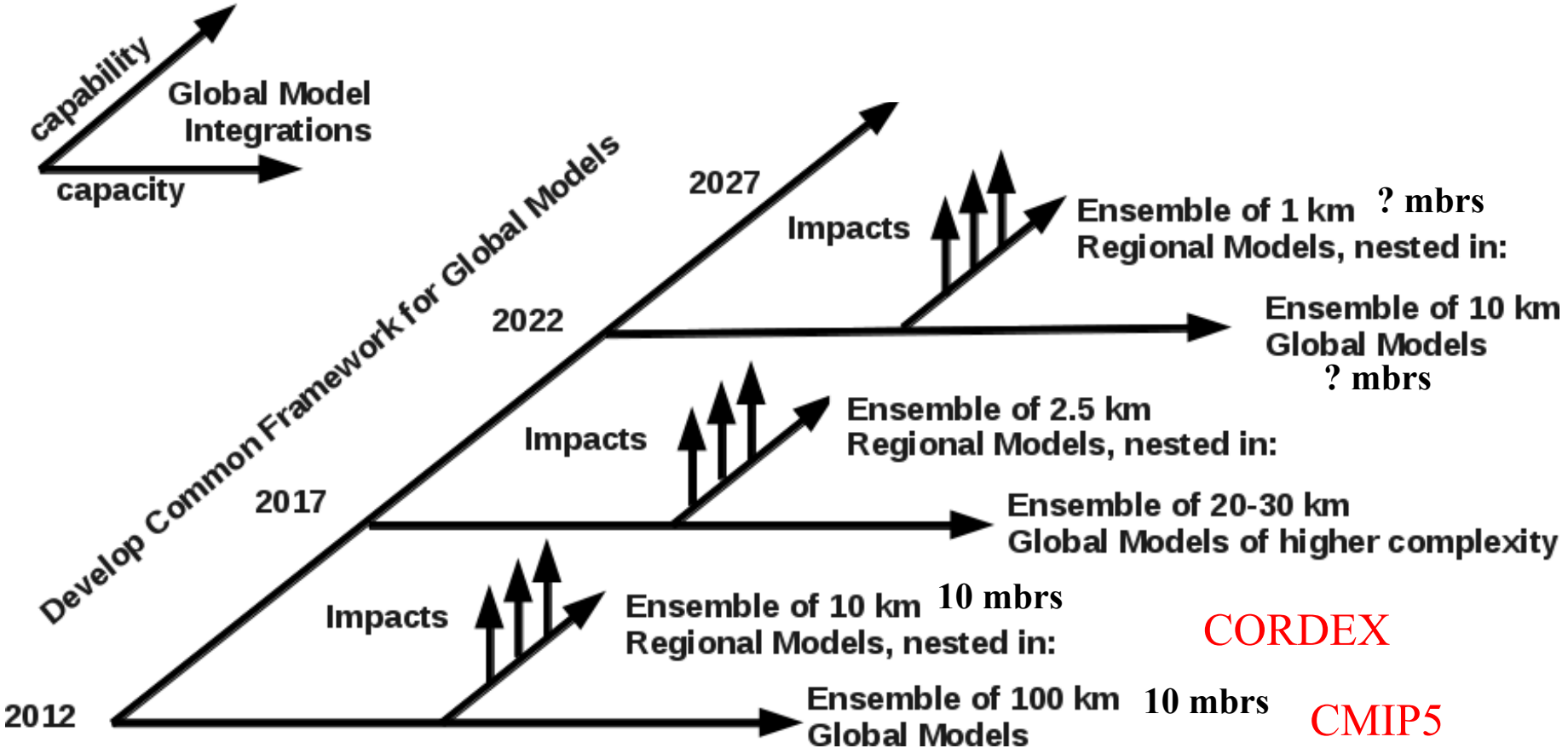
Increase resolution in ensemble simulations



2012-2022 Infrastructure Strategy
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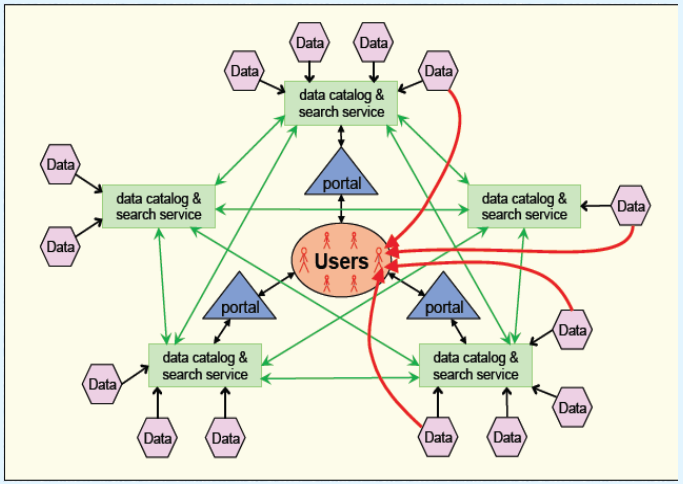
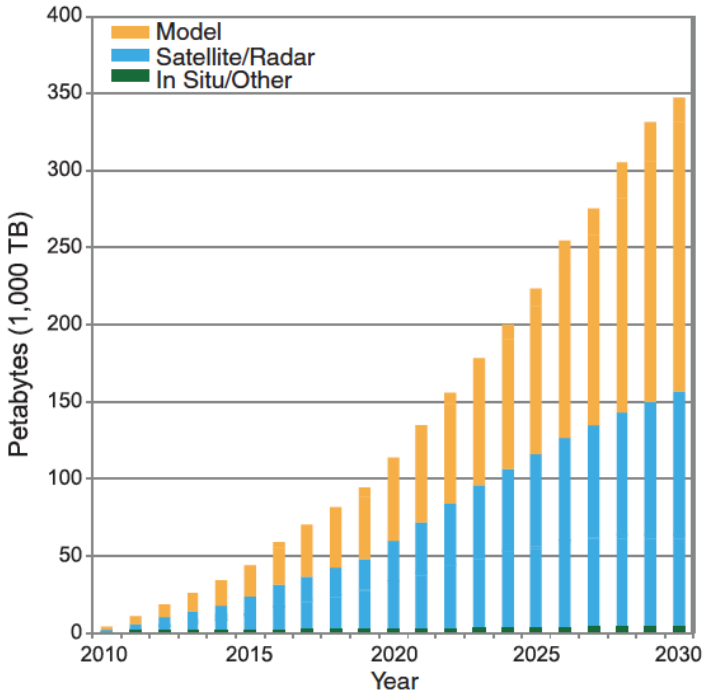
Data: Strong demand from society (climate services) for model data, expected to grow exponentially

CMIP5: 2 to 3 PB
CMIP6: x 30 ?

Earth System Grid Federation





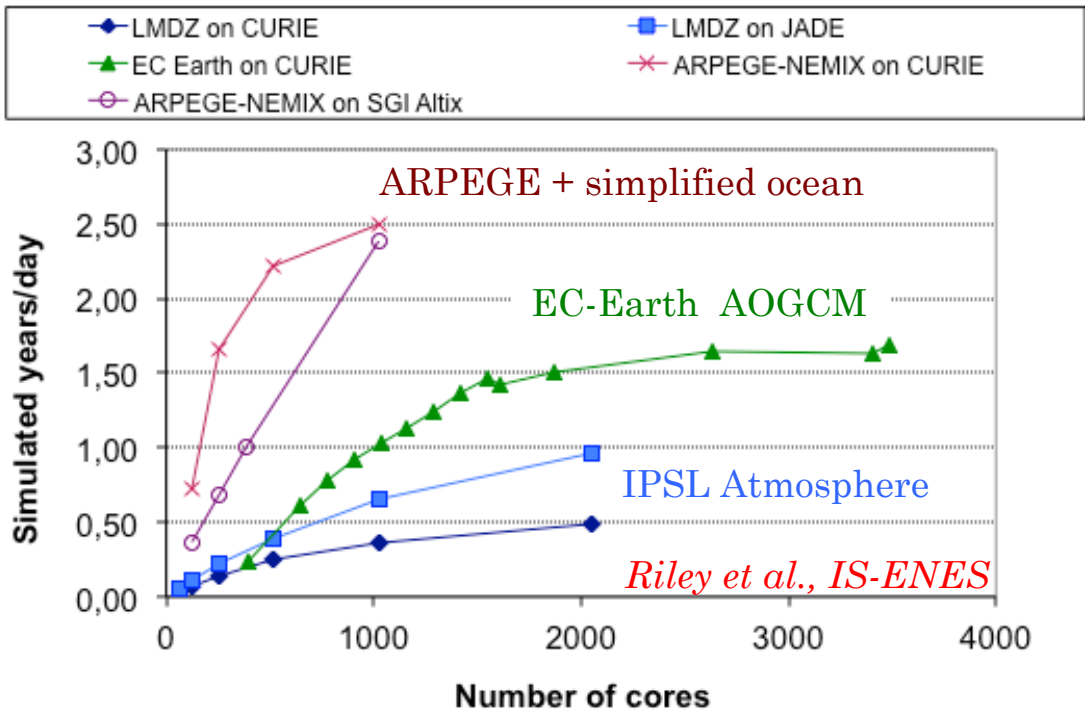
Overpeck et al. (Science 2011)

⇒ **Sébastien Denvil's talk tomorrow**

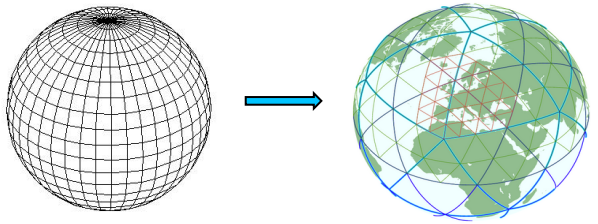
2012-2022 Infrastructure Strategy
for the European Earth System Modelling Community

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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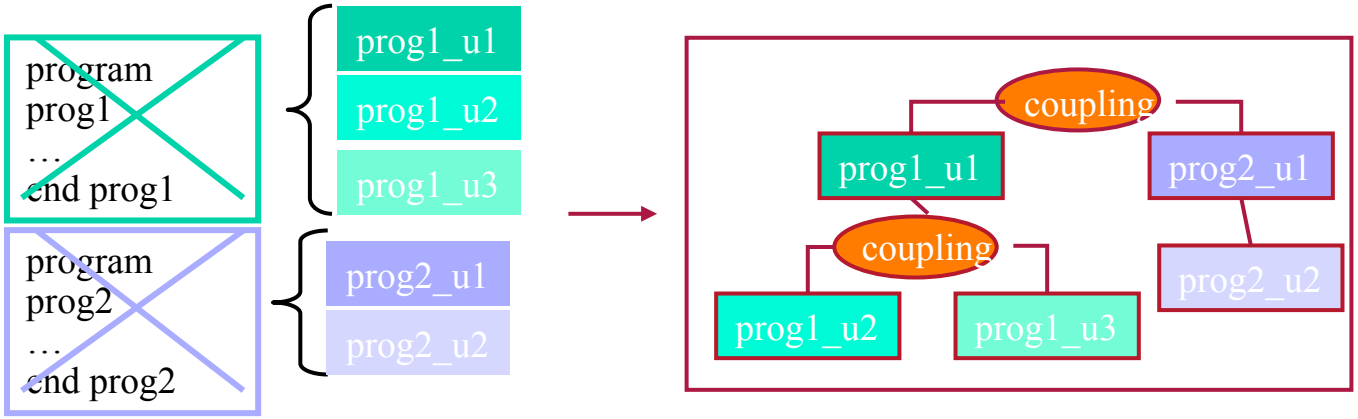
Coupling strategies in climate modelling

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



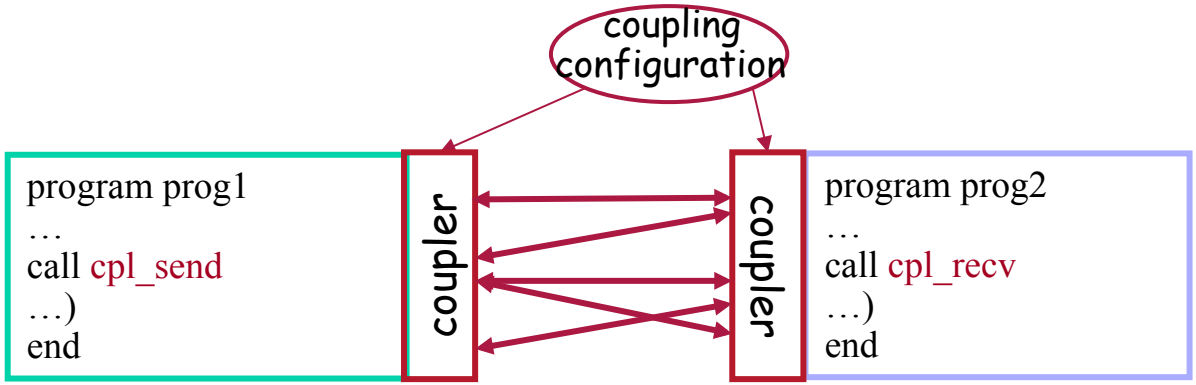
☺ efficient,
☺ sequential and concurrent components
☺ use of generic utilities (parallelisation, regridding, time management, etc.)

☹ existing codes
😐 (easy)

→ probably best solution in controlled development environment

Coupling strategies in climate modelling

2. use a coupler or coupling library

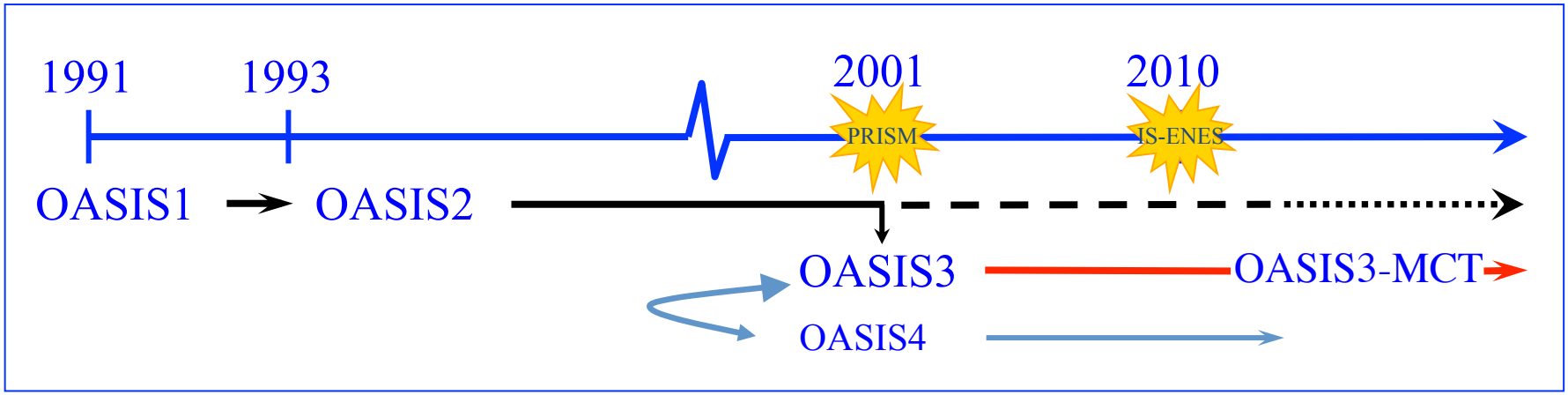


- ☺ existing codes
- ☺ use of generic transformations/ regridding
- ☺ concurrent coupling (parallelism)

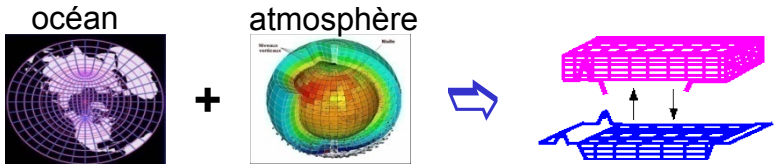
- ☹ multi-executable: possible waste of resources if sequential execution of the components is enforced
- ☹ multi-executable: more difficult to debug; harder to manage for the OS
- 😐 efficient

→ probably best solution to couple independently developed codes

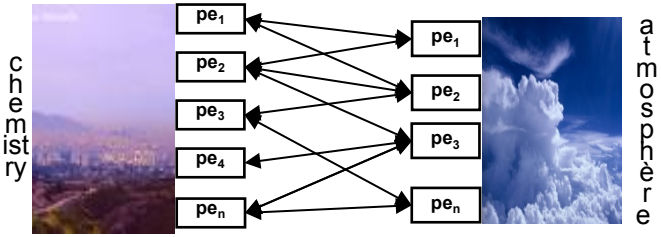
The OASIS coupler: historical overview



- **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 Netherland: 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

Use of OASIS3-MCT

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

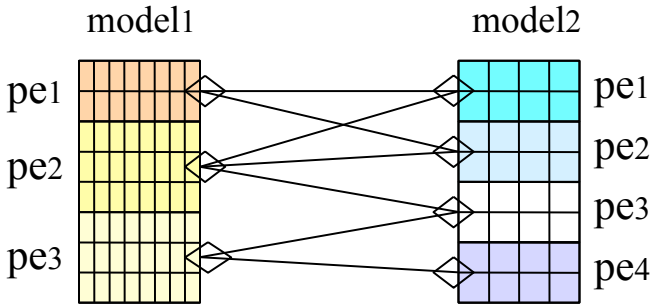
```
call oasis_put (…, date, var_array. …)
call oasis_get (…, date, var_array, …)
```

  - 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

OASIS3-MCT communication

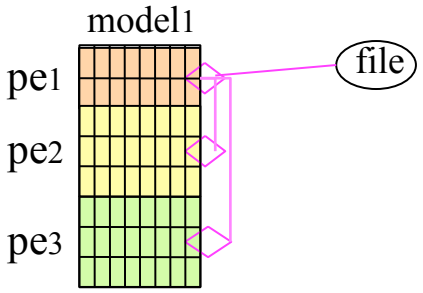
Fully parallel communication between parallel models based on MCT using MPI:

- 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):

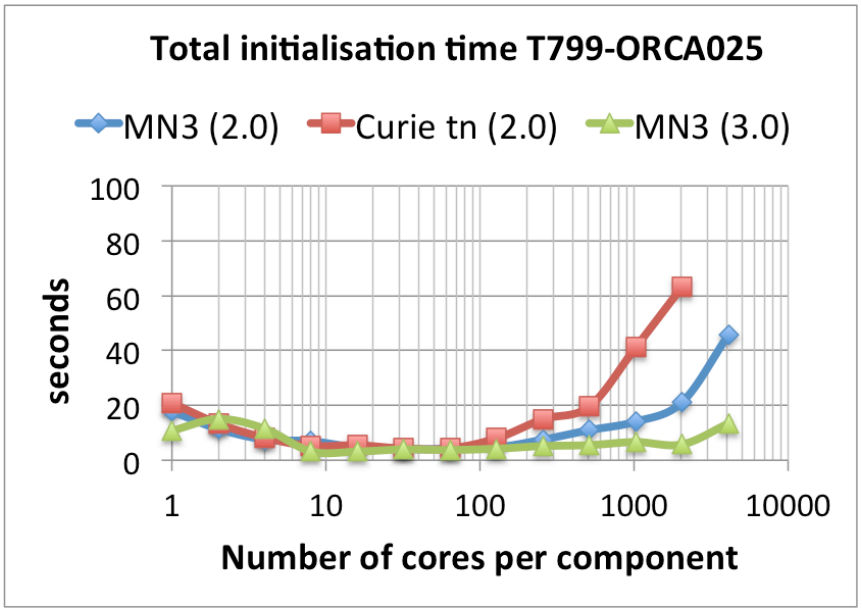


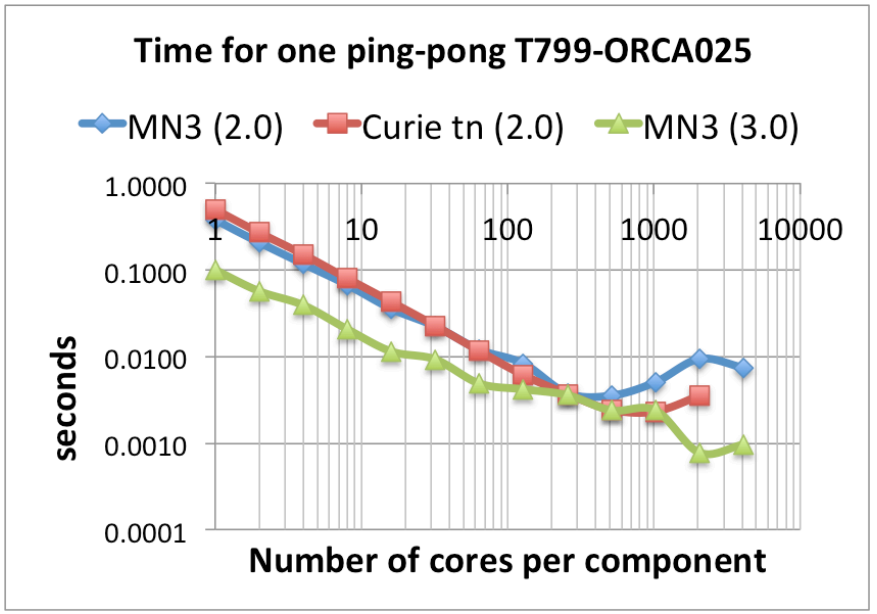
Some OASIS3-MCT users

- 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



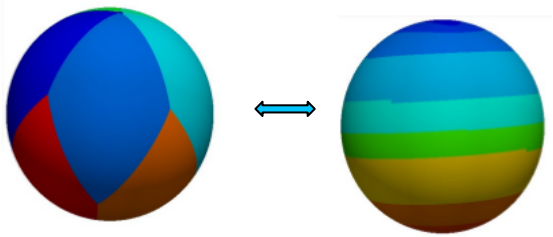


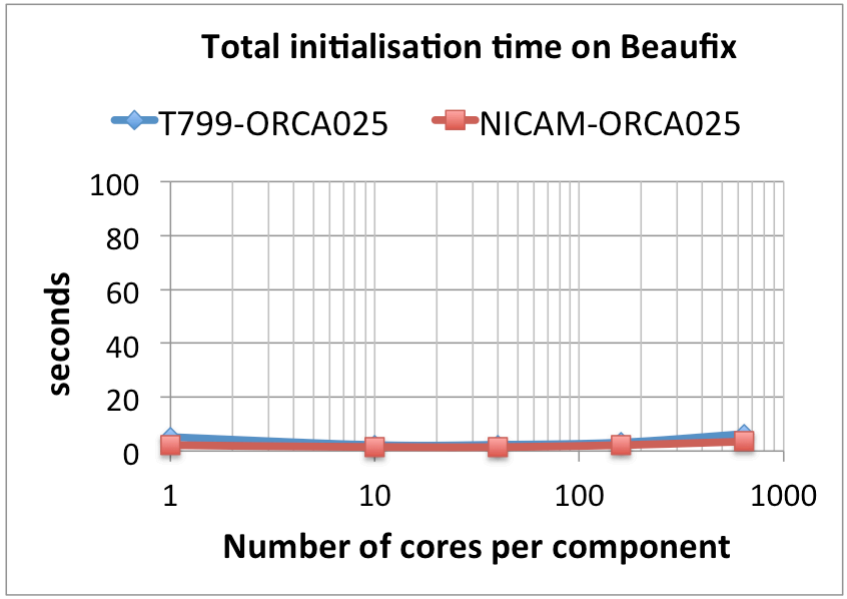
Coupling overhead for one-year long simulation with one 1 coupling exchange every hour in each direction between codes with O(1 M) grid points running on 4000 cores/component:

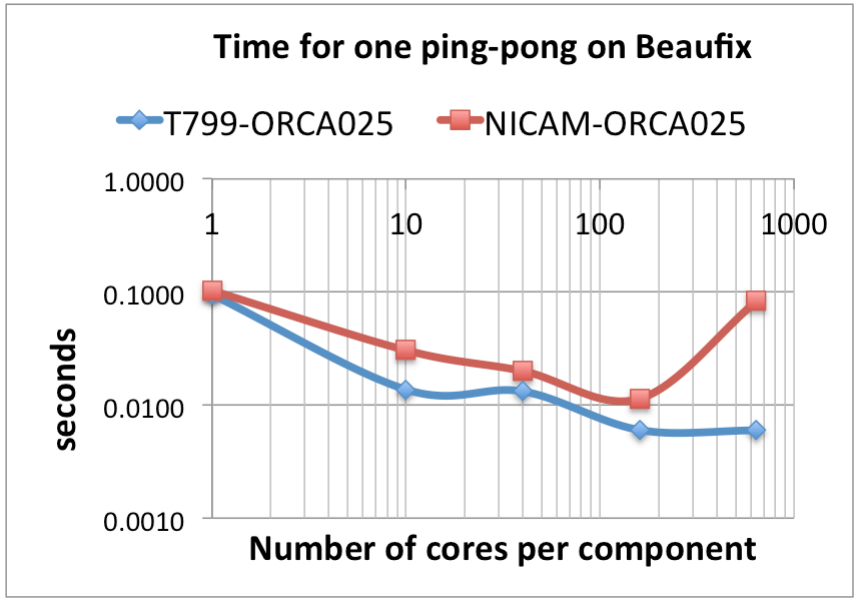
- ~20 seconds for initialisation, ~9 seconds for data exchange

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







Coupling overhead for one-year long simulation with one 1 coupling exchange every hour in each direction between codes with O(1 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