Numerical simulations in Oceanography for climate studies: How HPC can be used ?

Jean-Marc Molines (LGGE/MEOM)

With contributions of T. Penduff, B. Barnier, J.M. Brankart, J. Le Sommer, S. Leroux (LGGE), L. Bessières (Cerfacs)

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PRACE

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iris CINES TGCC

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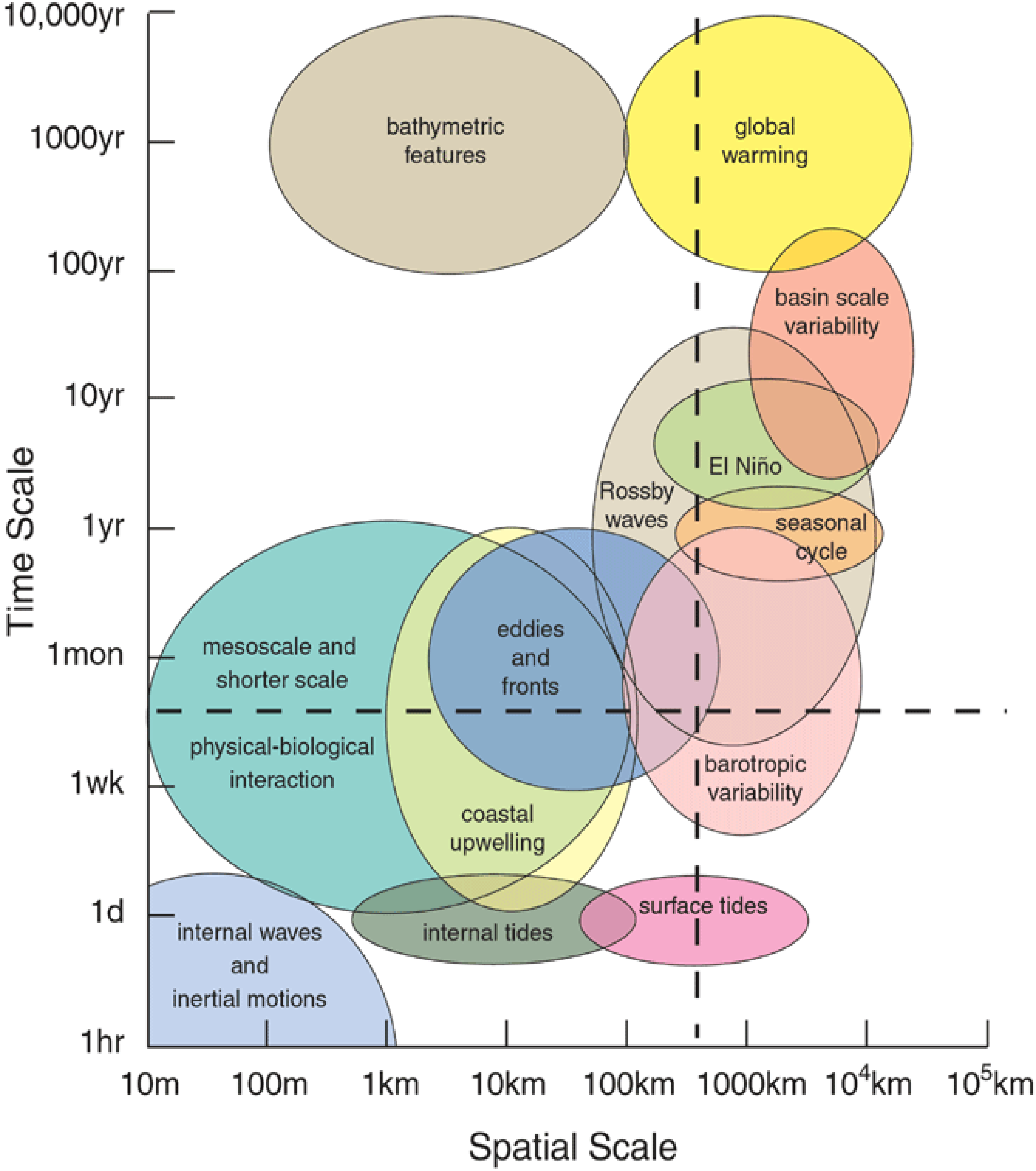
Overview

- Spatio/temporal scales in the ocean (climate focus), computational impacts.
- Numerical model outlook
- Examples of model configurations on HPC

- Summary and discussion

Ocean circulation scales



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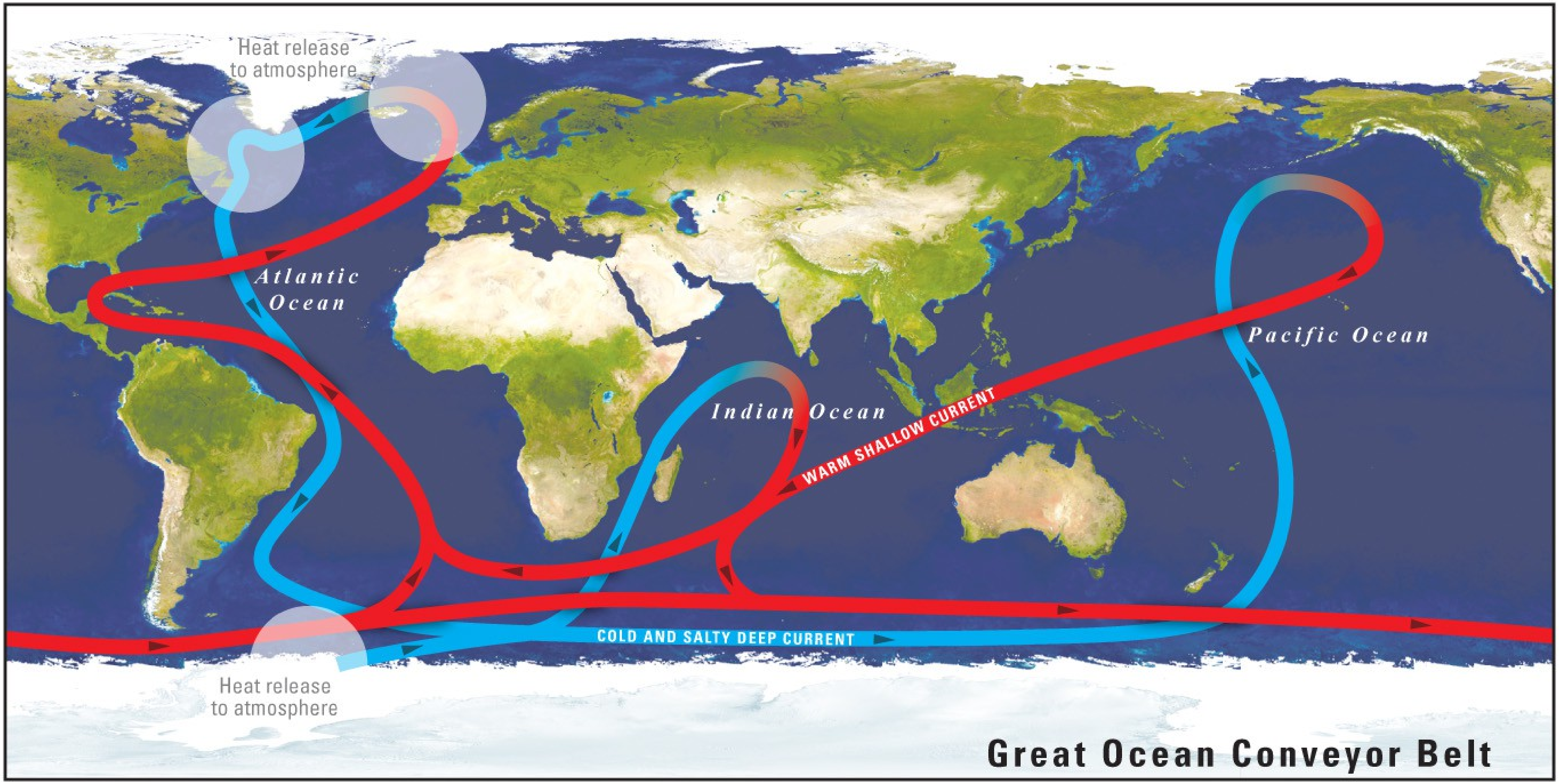
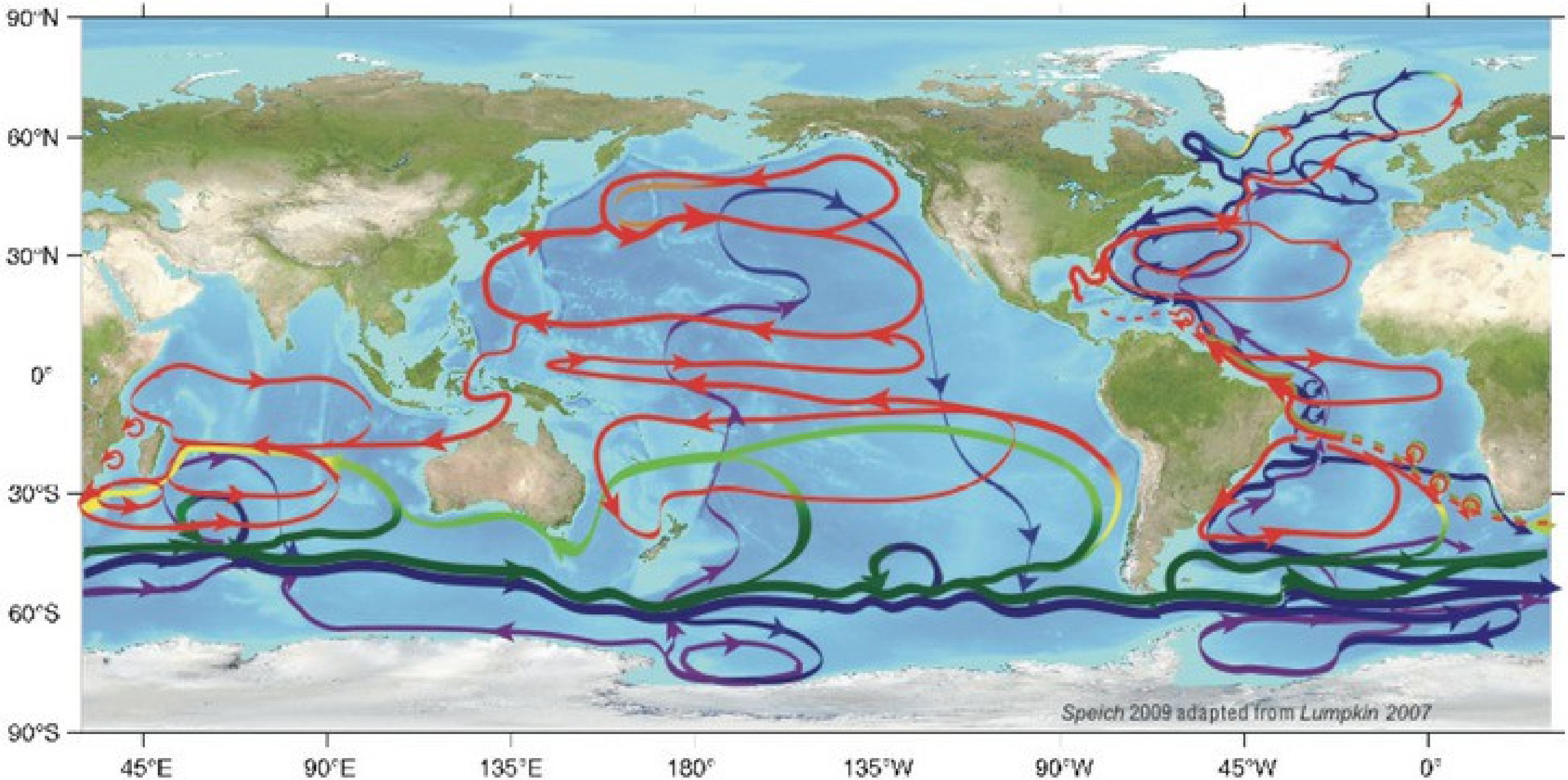
Large scales : Thermohaline circulation



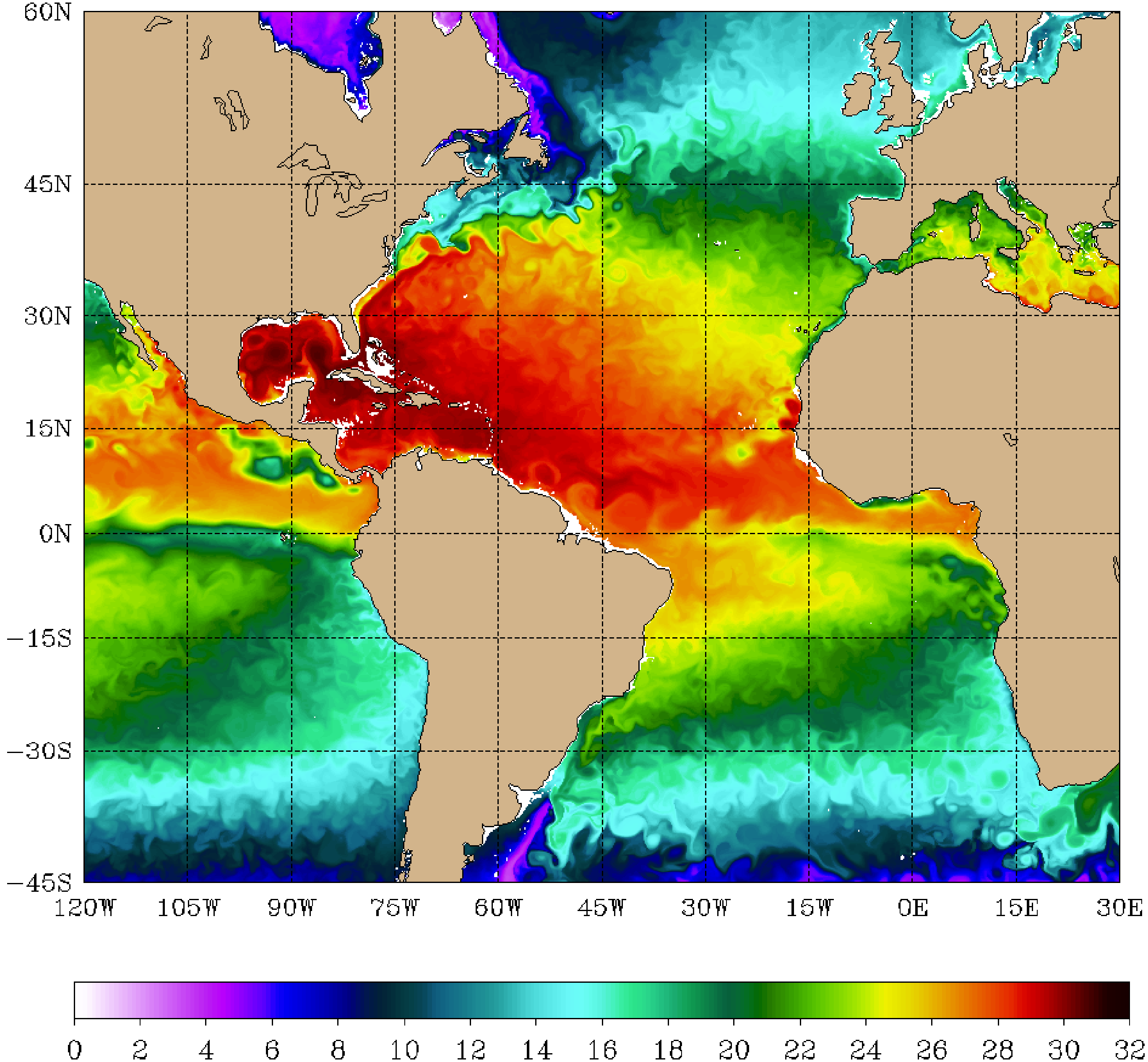
==> 200 to 1000 years time scales

Basin scales : Gyres circulation



==> 2 to 20 years time scales

Mesoscale : Eddies



Sea Surface Temperature

From 1/12° simulation

==> 2 months to few years

Eddies are sources of the chaotic behaviour of the ocean.

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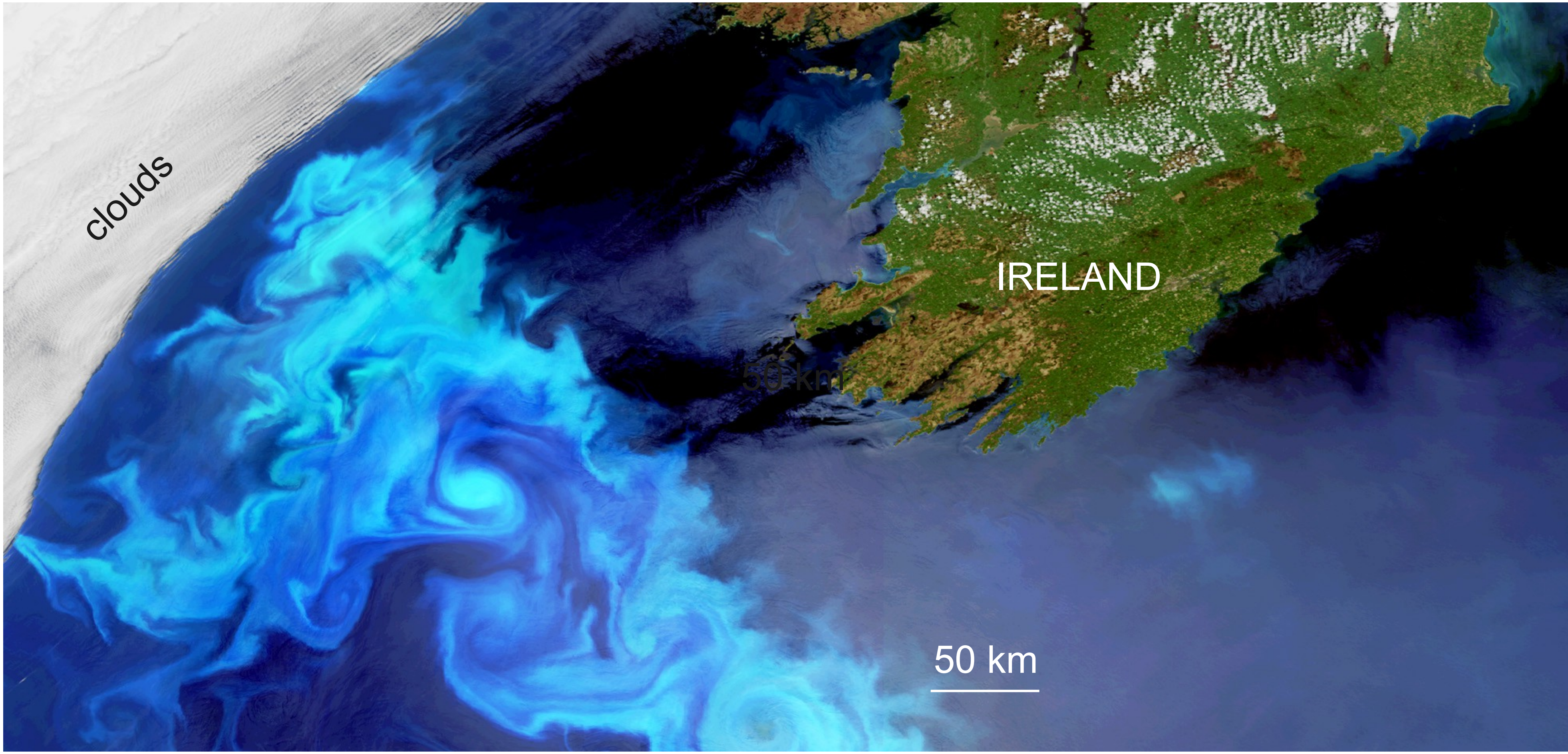
Sub-mesoscale : filaments, fronts



Chlorophyl spring bloom seen by Envisat satellite (ESA)

==> days to month time scale : toward energy dissipation scales

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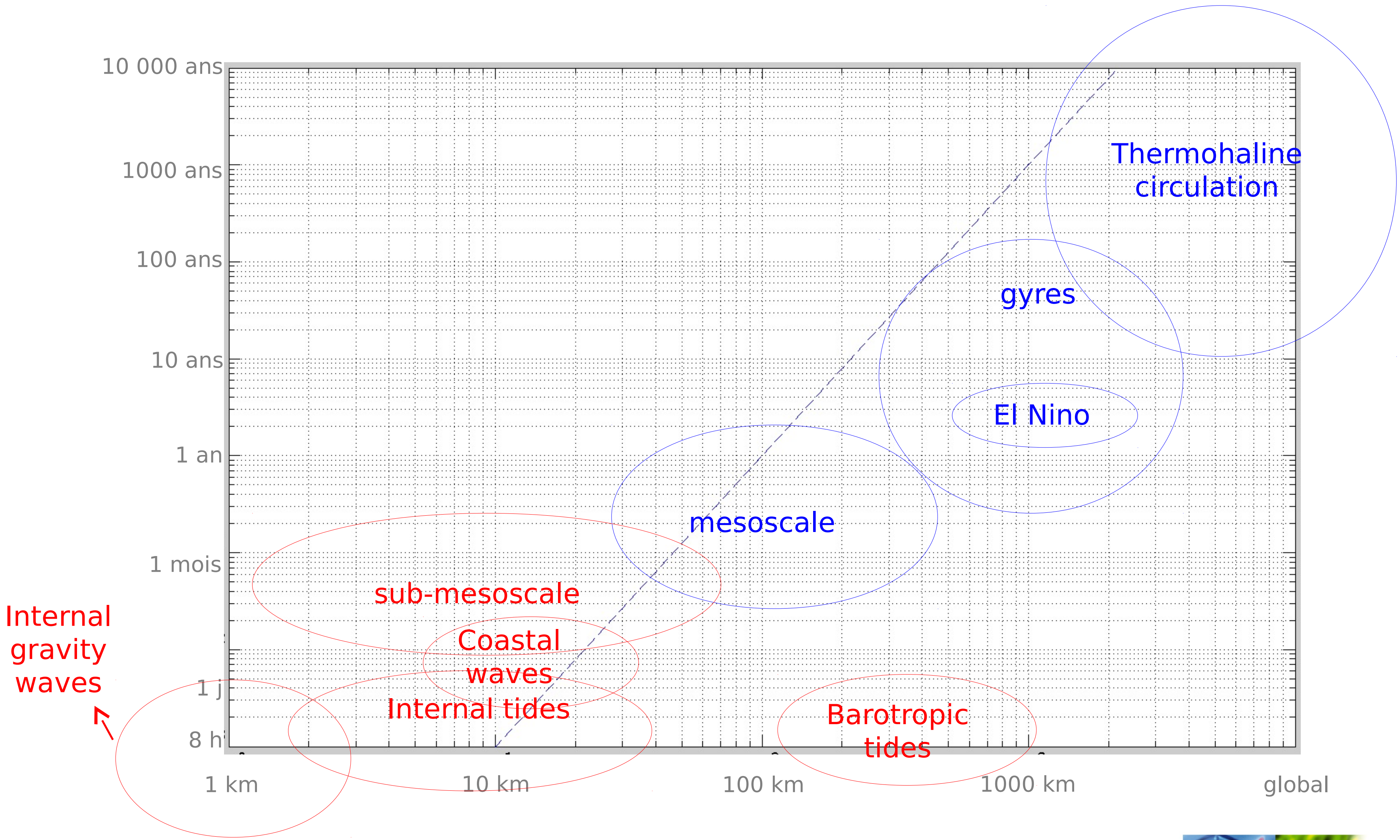
Numerical modelling challenges

- Large domain: planet Earth
- Large time scales: 0(1000 yrs)

- Requires high resolution (time/space): eddies in the ocean impacts/link all scales !

==> HPC is needed for these very CPU intensive and TeraBytes producing computations

Scales and computational cost



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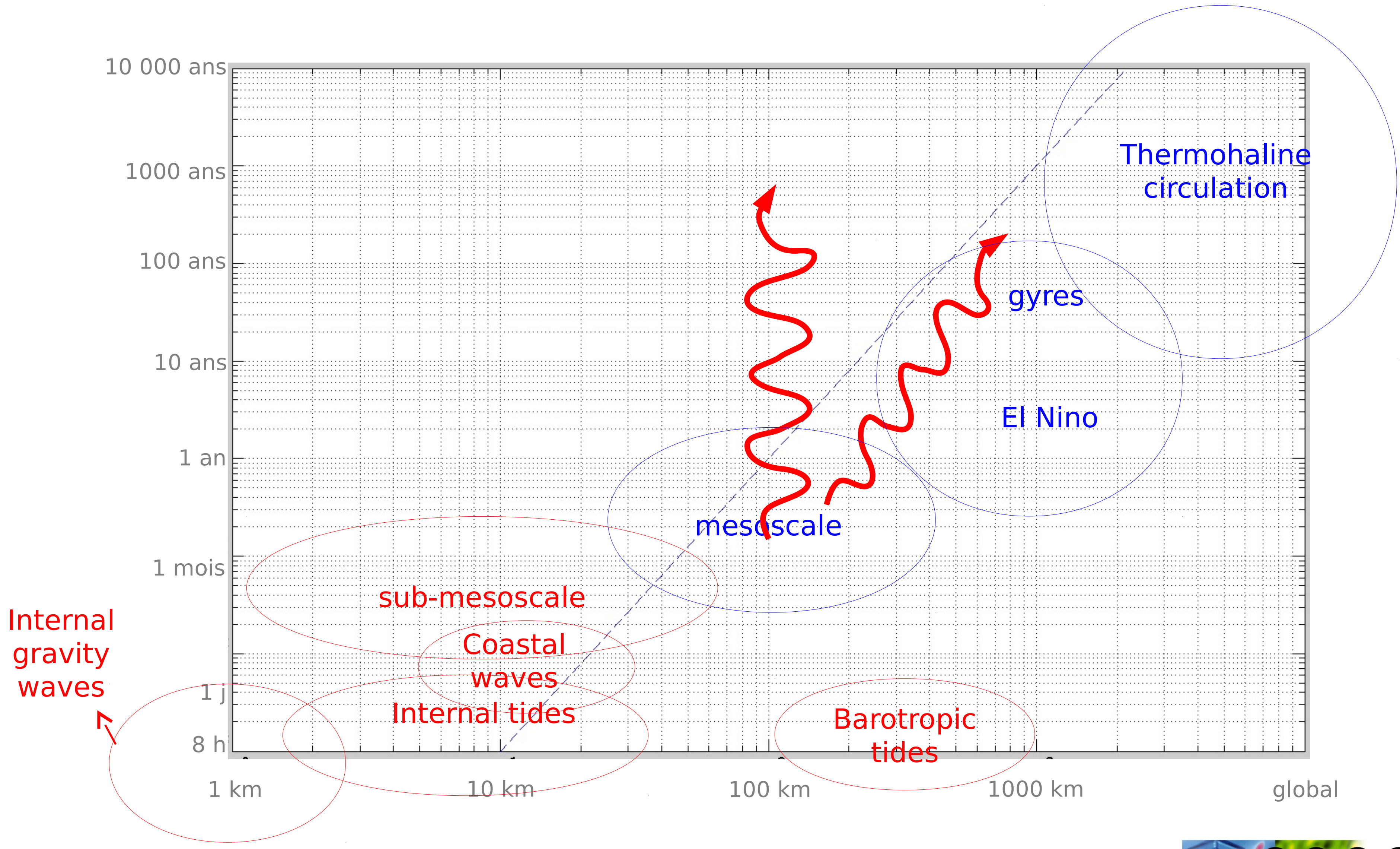
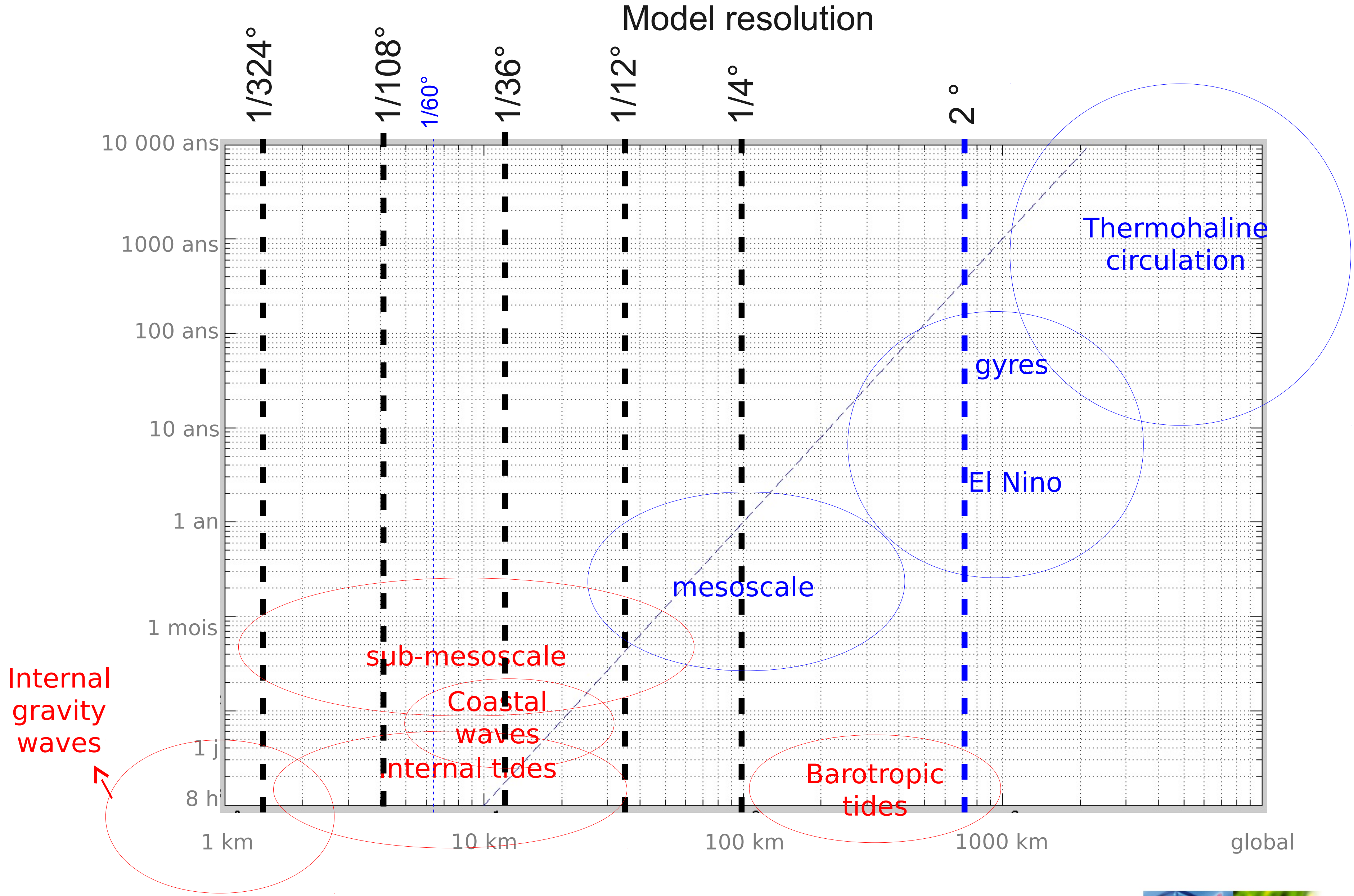
Scales and computational cost

Mesoscale eddies produce large scale (space and time) **intrinsic** variability



Scales and computational cost



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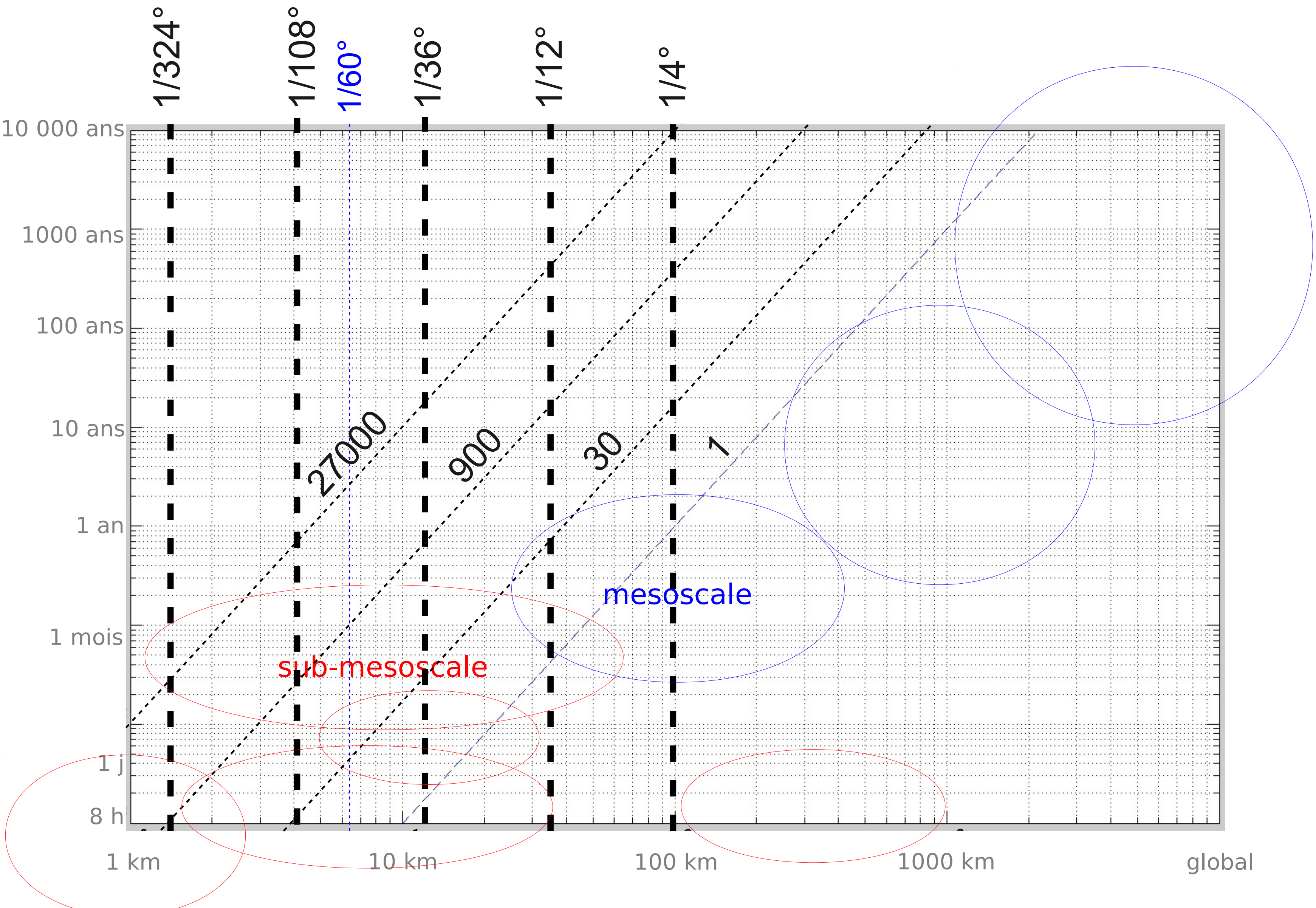
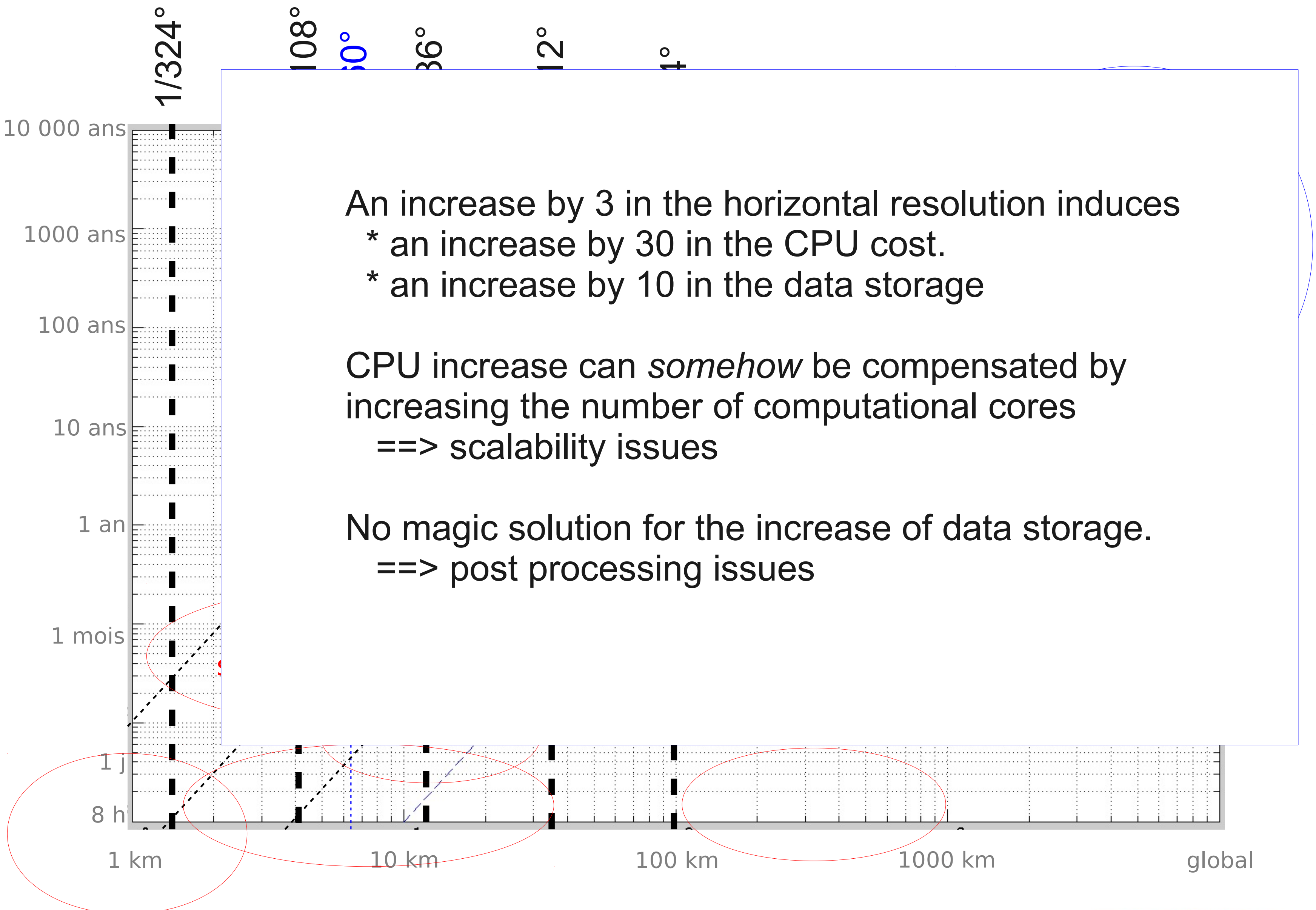
Scales and computational cost



Scales and computational cost



An increase by 3 in the horizontal resolution induces
  * an increase by 30 in the CPU cost.
  * an increase by 10 in the data storage

CPU increase can *somehow* be compensated by increasing the number of computational cores
  ==> scalability issues

No magic solution for the increase of data storage.
  ==> post processing issues

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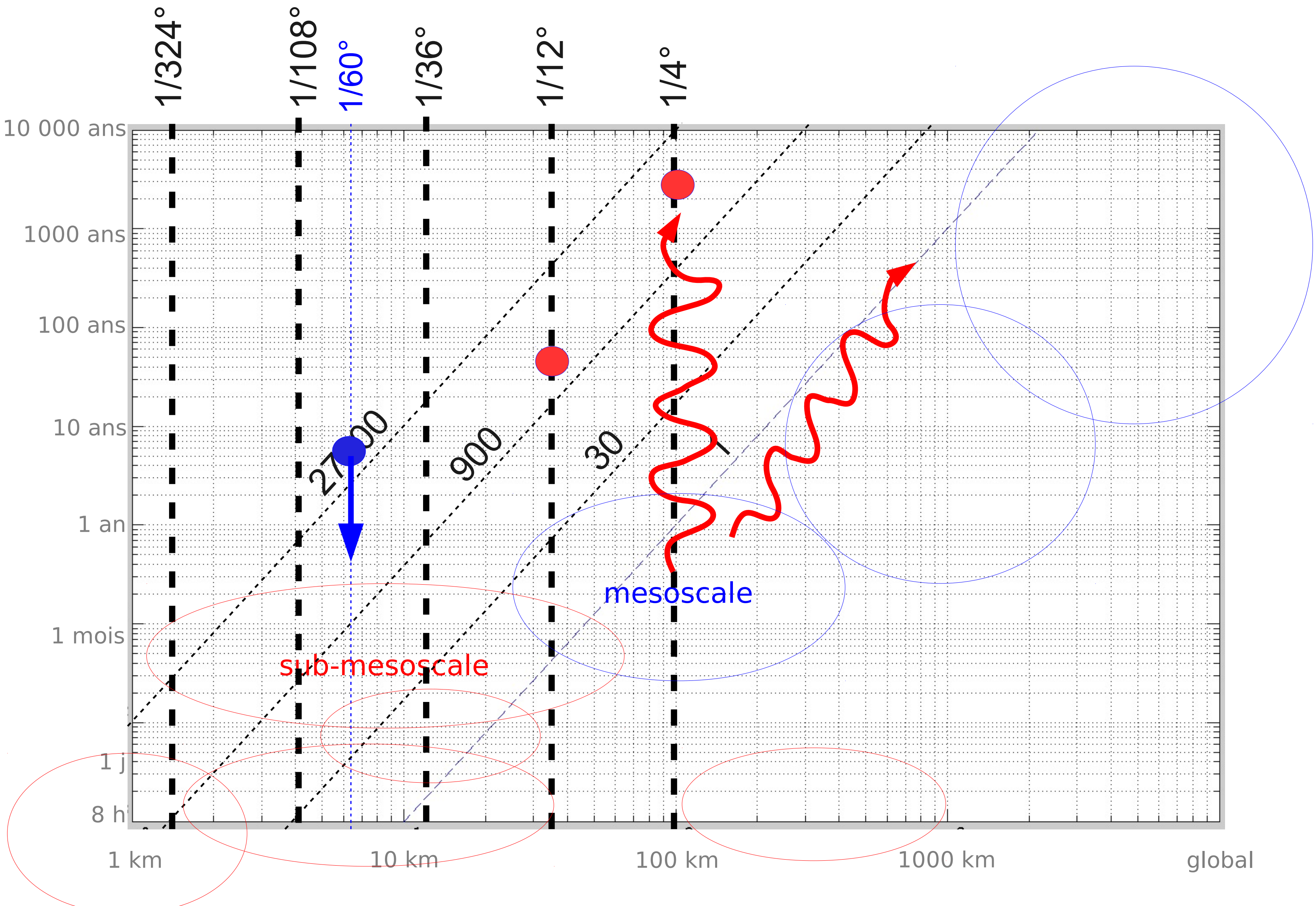
Scales and computational cost



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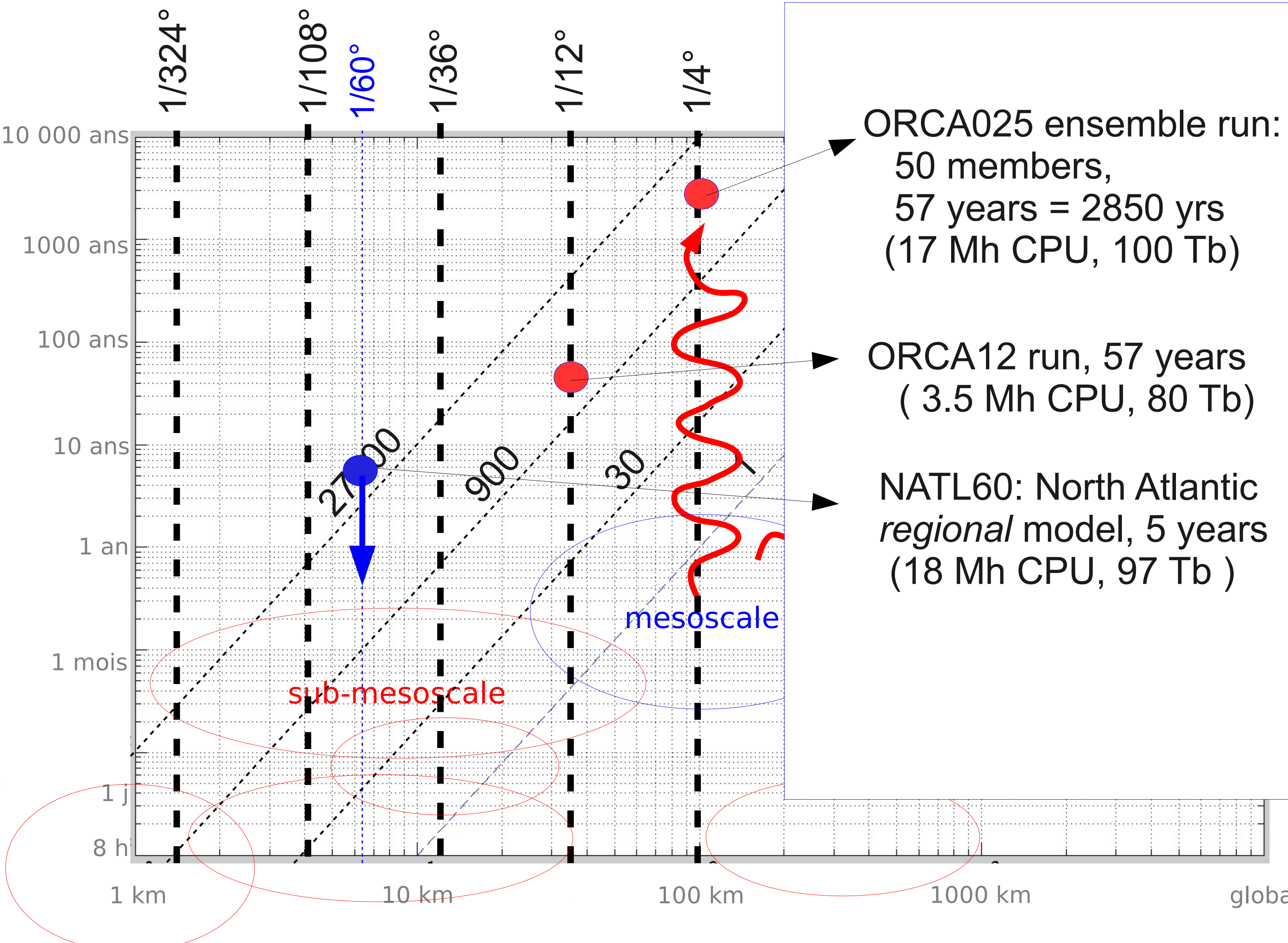
Scales and computational cost



ORCA025 ensemble run:
50 members,
57 years = 2850 yrs
(17 Mh CPU, 100 Tb)

ORCA12 run, 57 years
(3.5 Mh CPU, 80 Tb)

NATL60: North Atlantic
regional model, 5 years
(18 Mh CPU, 97 Tb)

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Numerical tools

Numerical model :

- NEMO:

  Nucleus for **E**uropean **M**odeling of the **O**cean

- model developped by a consortium of 6 European institutions:

- Ocean, Sea-Ice, Bio-Geochemistry components, Tangent and Adjoint Model.

Numerical model :

NEMO also interfaced with third party software

- Adaptative Grid Refinement (AGRIF)
- I/O server (XIOS)
- coupling atmospheric models (OASIS)

Numerical model :

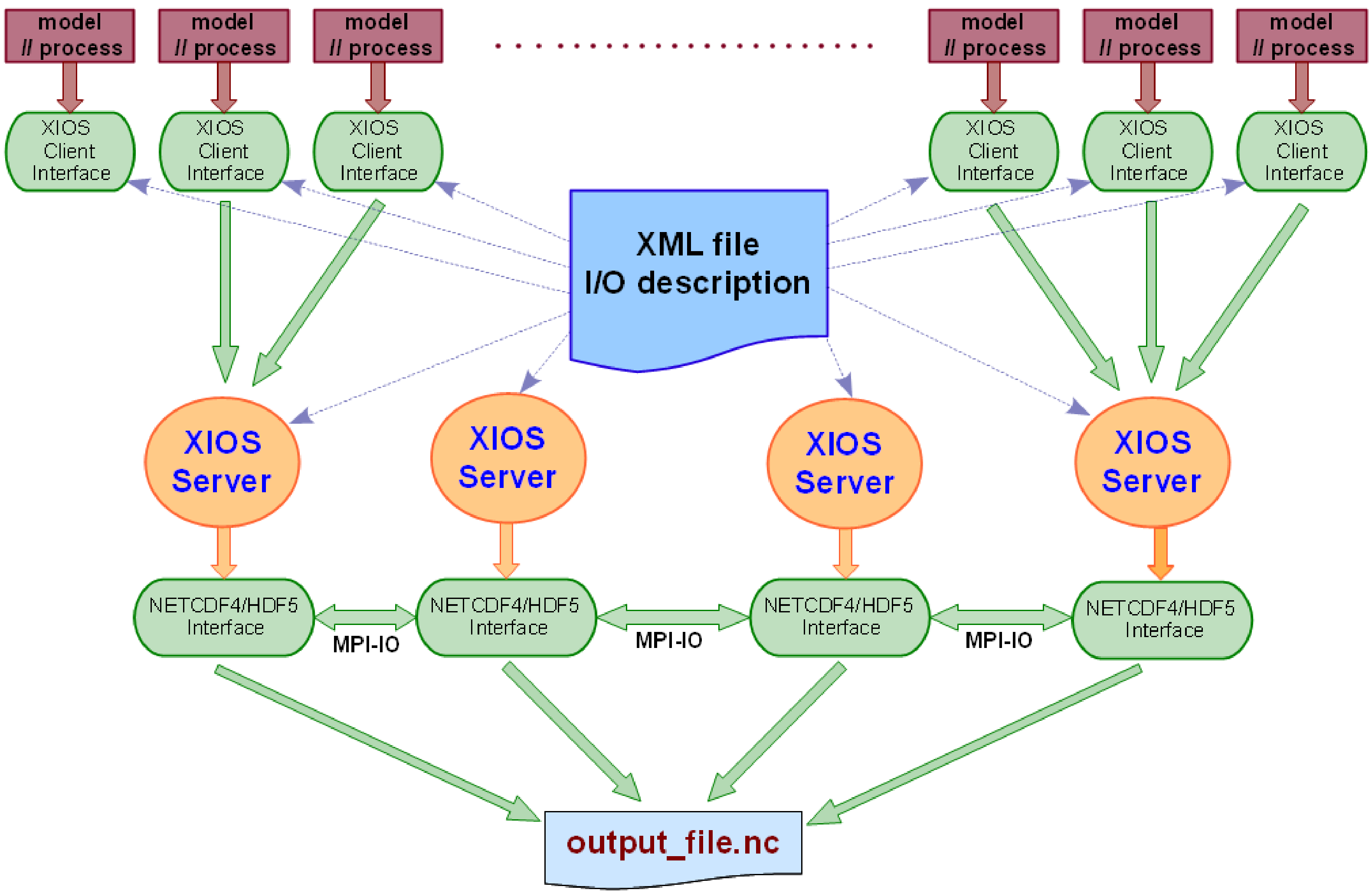
NEMO resolves the primitive equations (dynamics and thermodynamics) of the ocean circulation.

- Finite differences
- Coded in Fortran 90/95

NEMO parallelized with explicit message passing technique (MPI)

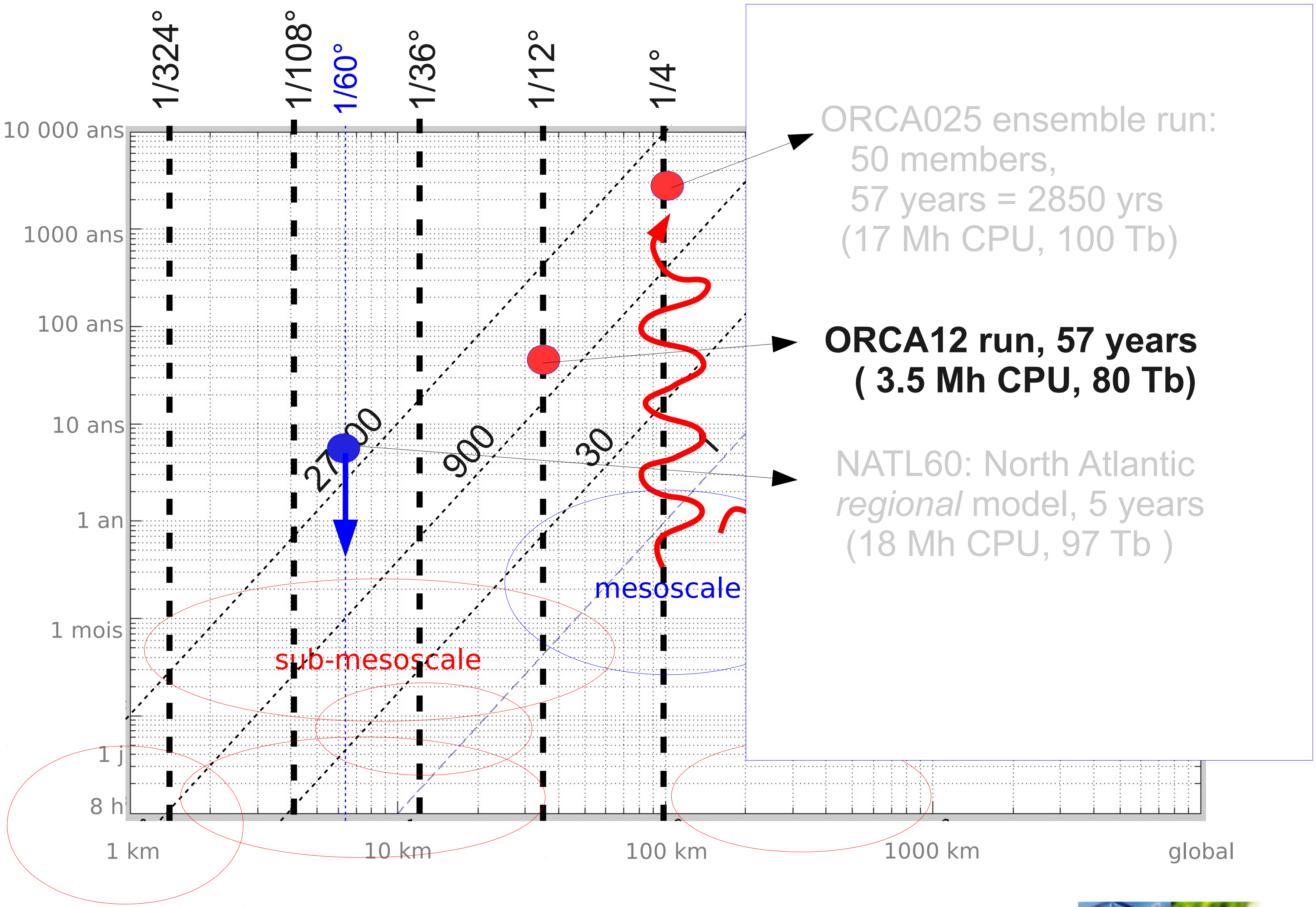
- Domain decomposition : each sub-domain is associated to a computing core.

XIOS I/O server



From J.L Dufresne et al. 2015, colloque MASTODONS

Model configurations



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ORCA12.L46 simulations

DRAKKAR

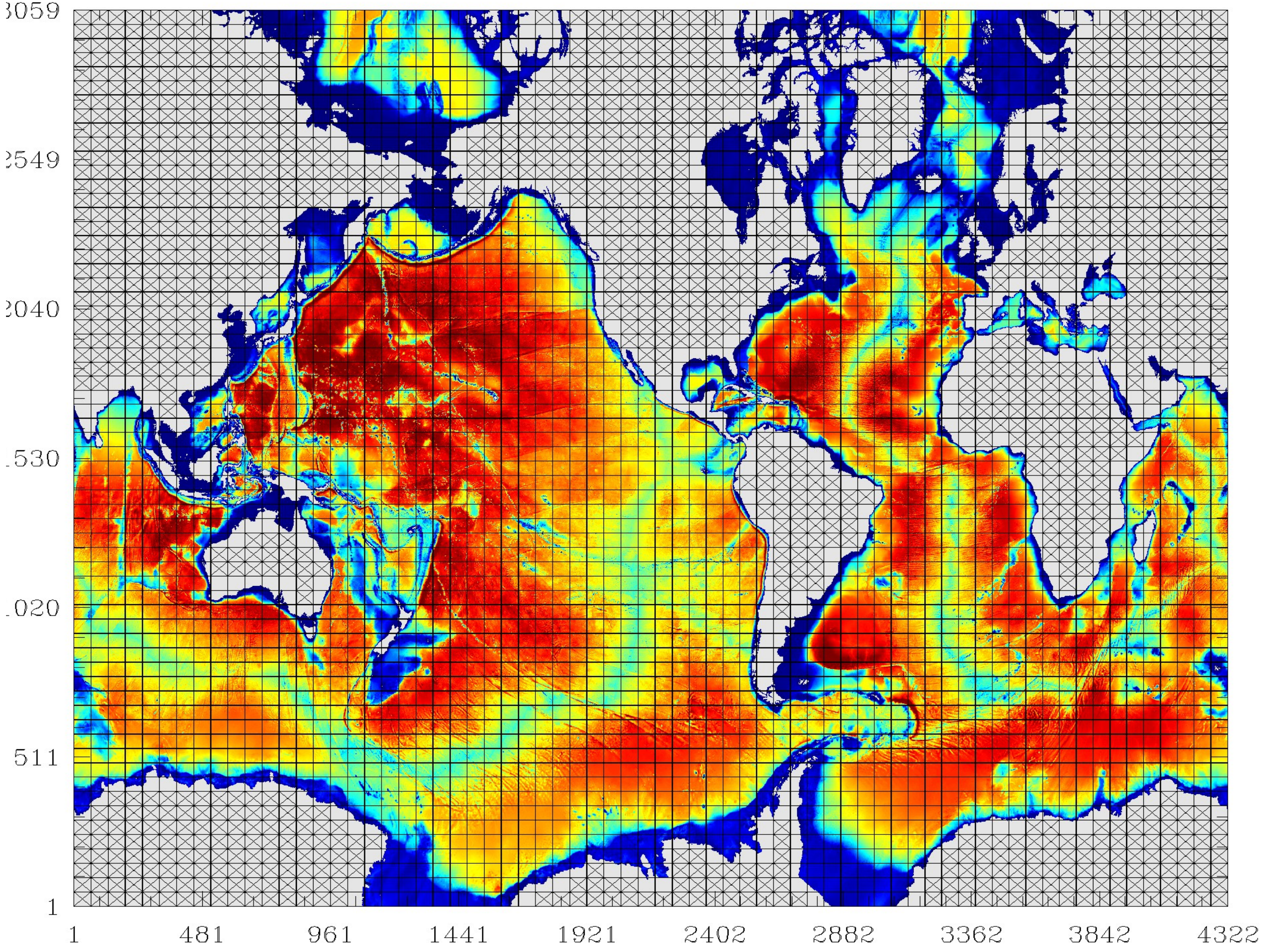
- ORCA12.L46 is a global configuration with a base resolution of 1/12° (ORCA type grid *)
- Mesh size is 4322 x 3059 x 46 (608.10^6 grid points)
- Typical time step is 360 sec (87600 stp/year)
- One year output is 900 Gb (netcdf4 with compression)
- Target machine is OCCIGEN (CINES)

GENCI CINES Centre Informatique National de l'Enseignement Supérieur

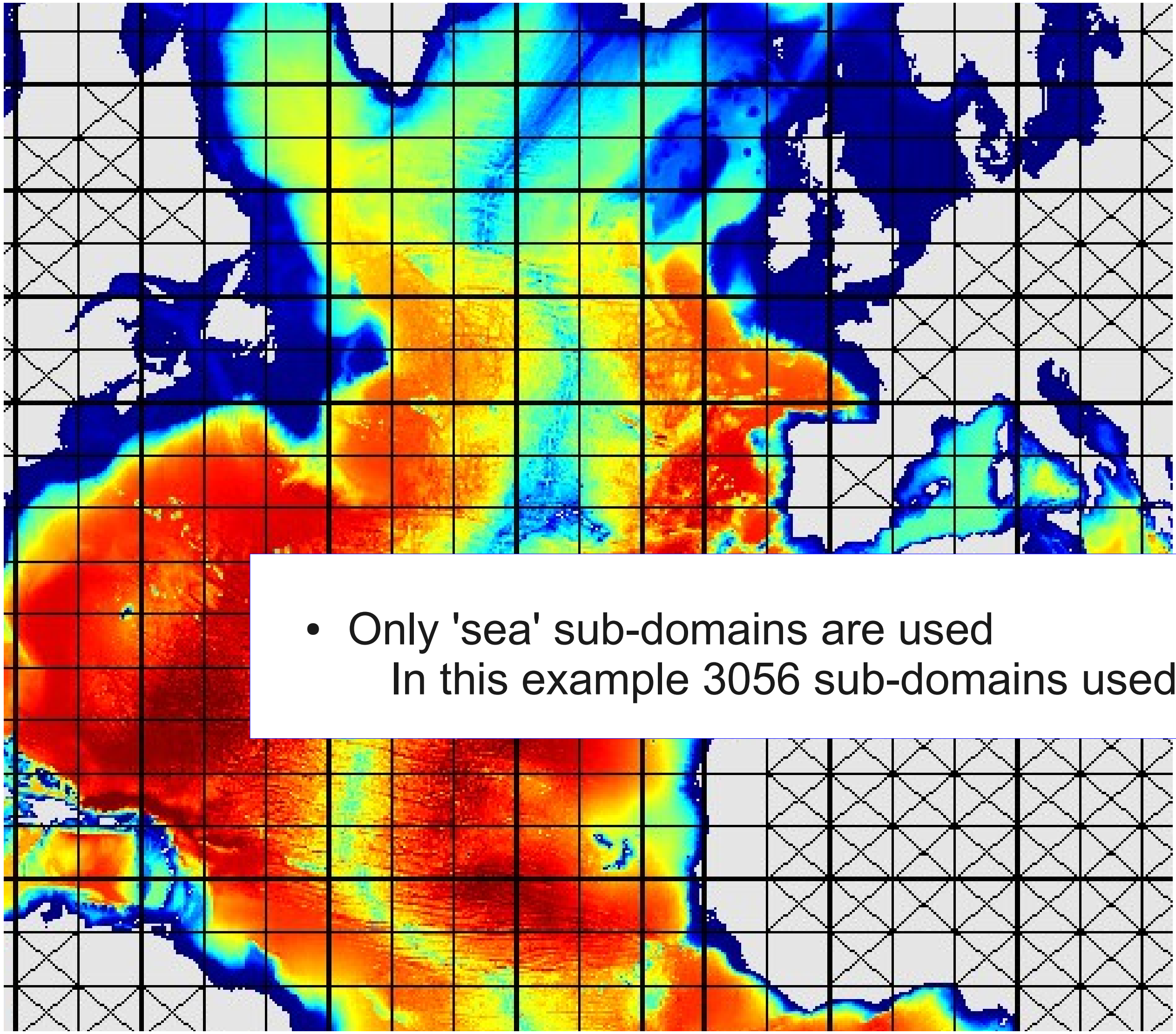
- 41 000 CPU hours per year

  (3500 to 5000 cores can be used)

Domain decomposition



Domain decomposition



- Only 'sea' sub-domains are used
  In this example 3056 sub-domains used

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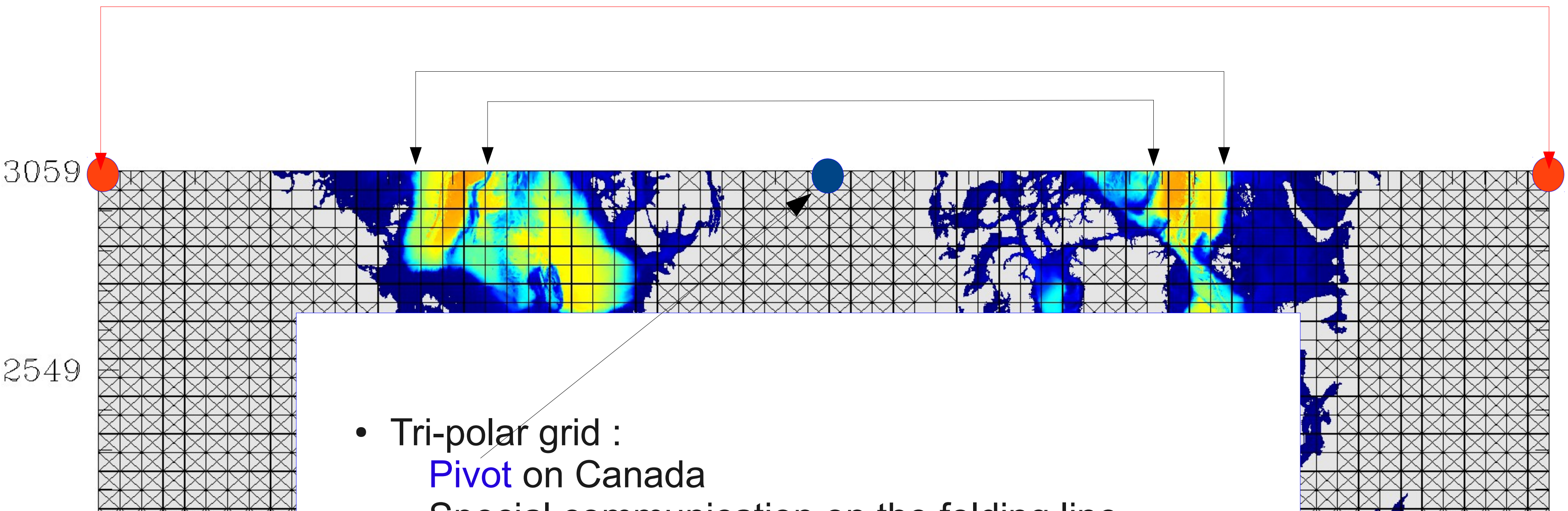
ORCA grid: north fold condition

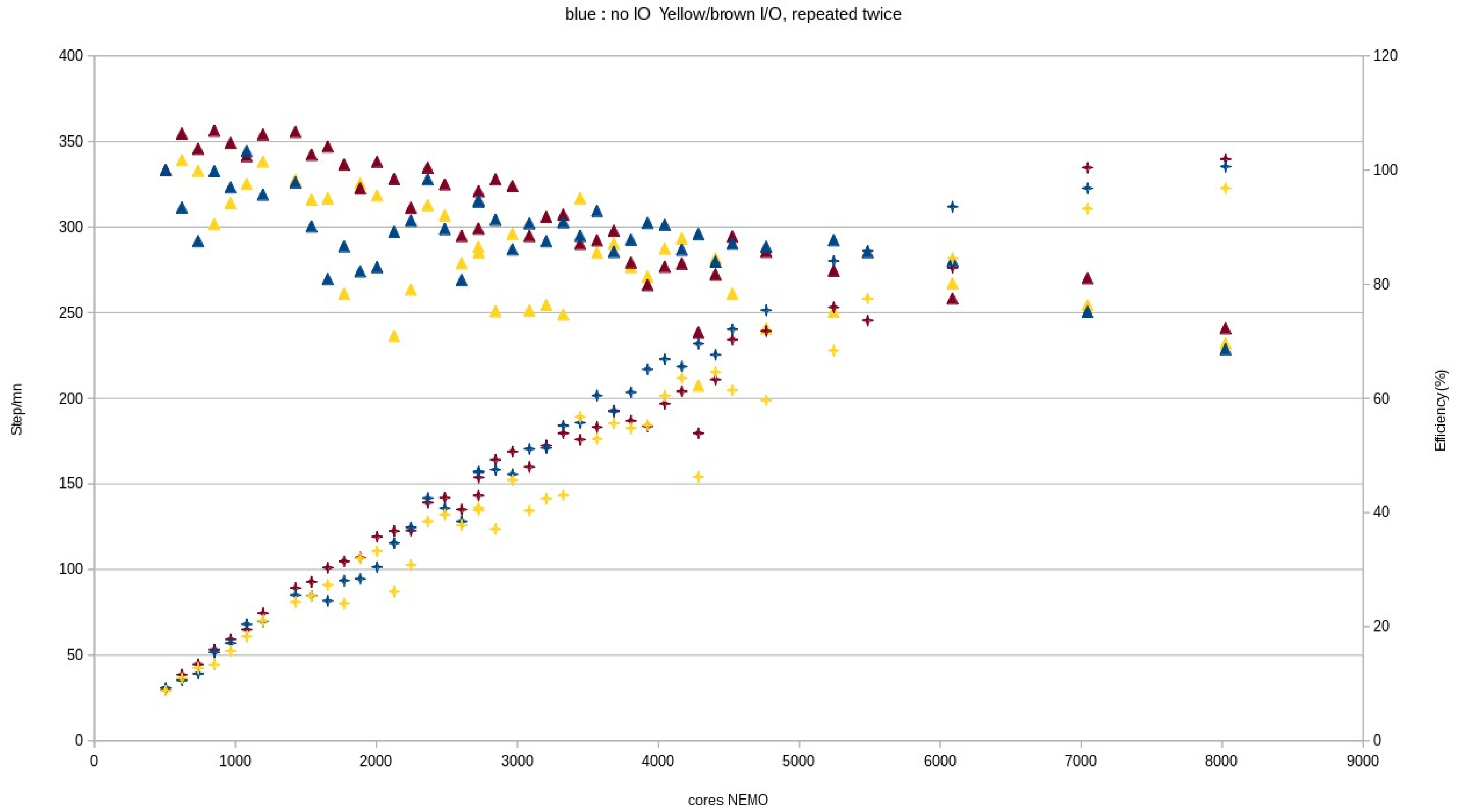


- Tri-polar grid :
  Pivot on Canada
  Special communication on the folding line

- Mercator grid (grid size decreases as cos(Lat))
  base 1/12° ==> max size at equator = 9.2 km
  ==> 4.1 km at 60°
  ==> 2.4 km at 75° (S)
  smooth transition to tripolar grid North of 45°N

==> Stability condition (time step) depend on smaller grid size

ORCA12 Scalability on OCCIGEN



HPC-days Lyon April 2016

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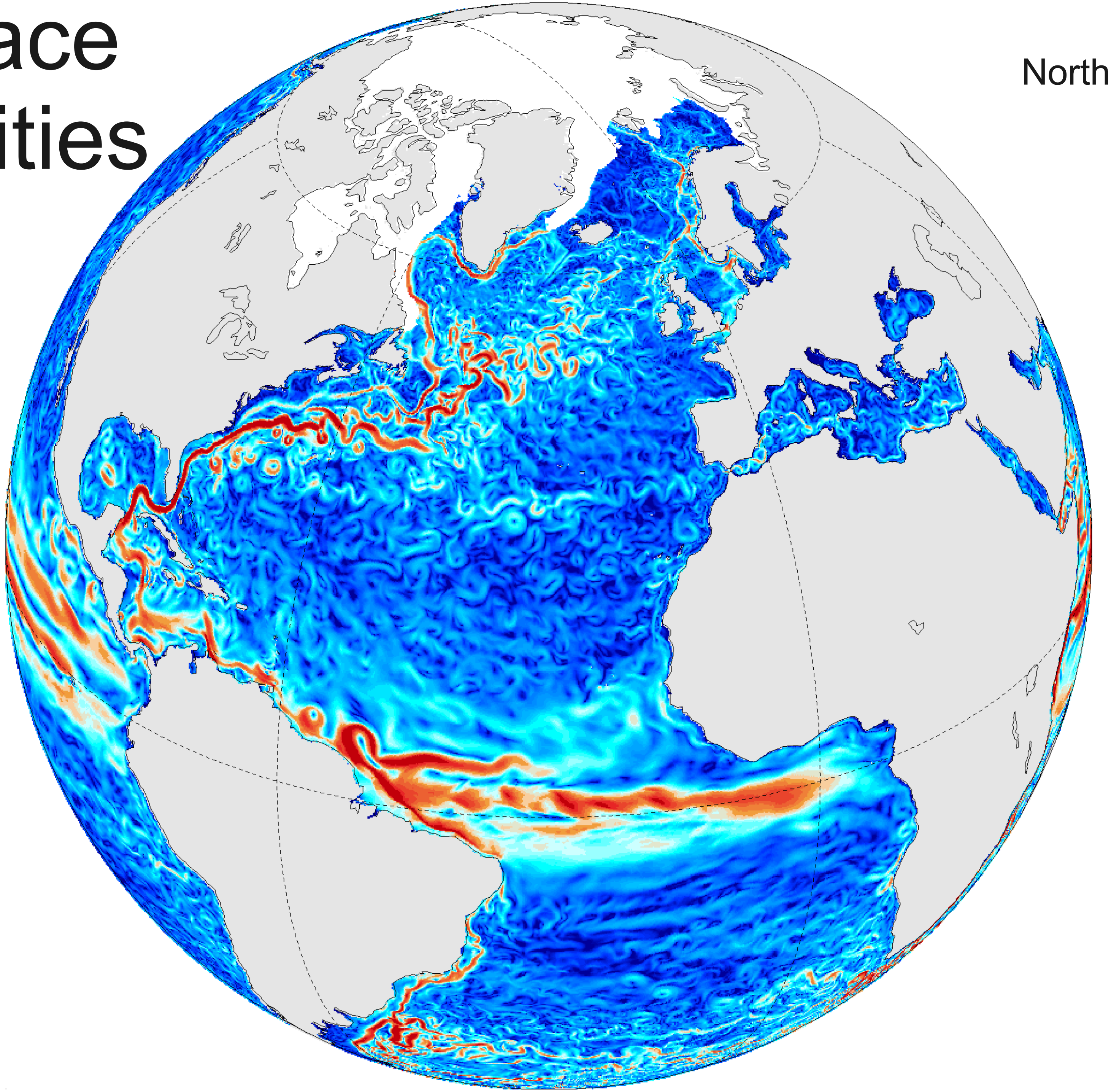
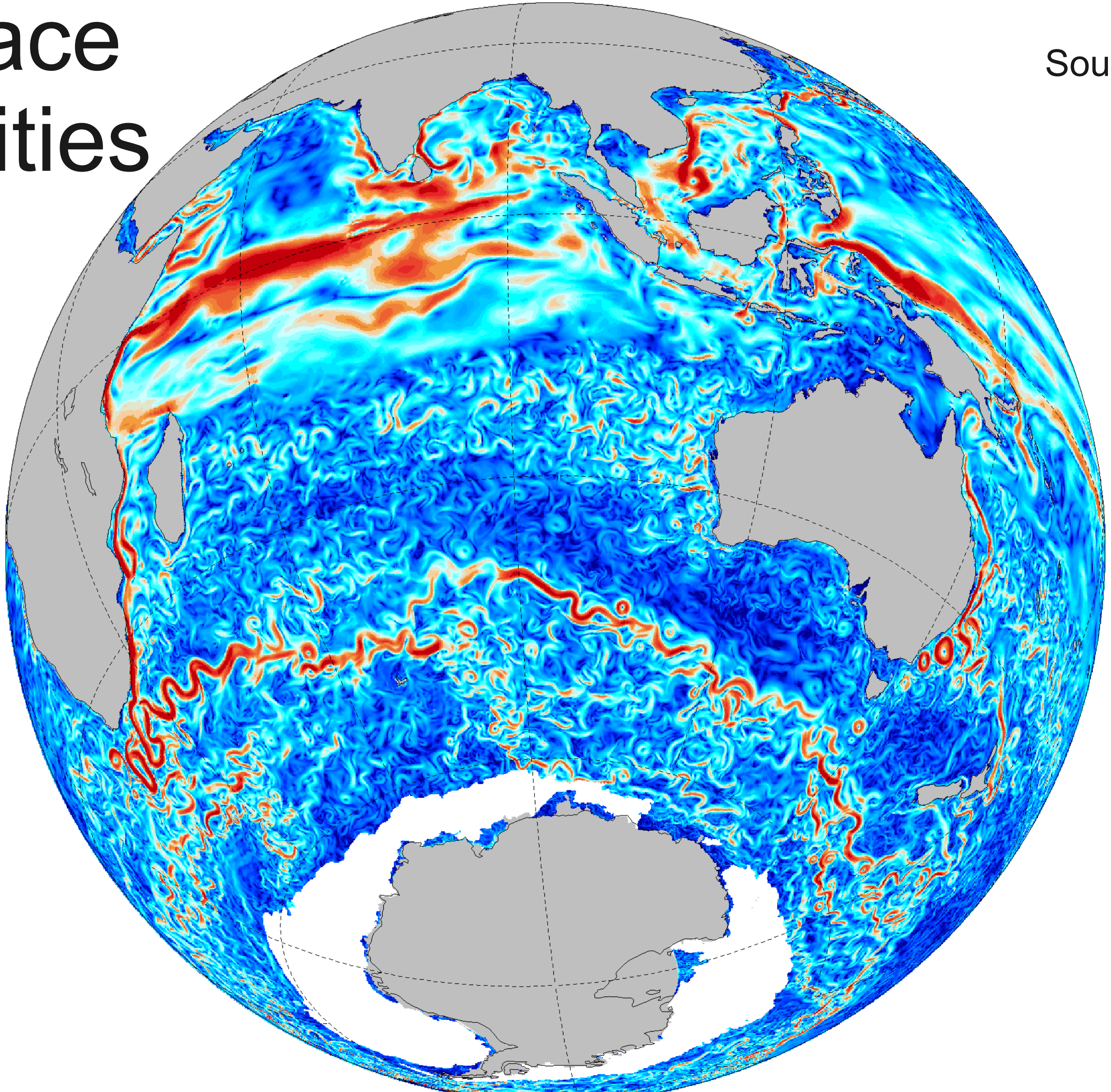
Surface velocities



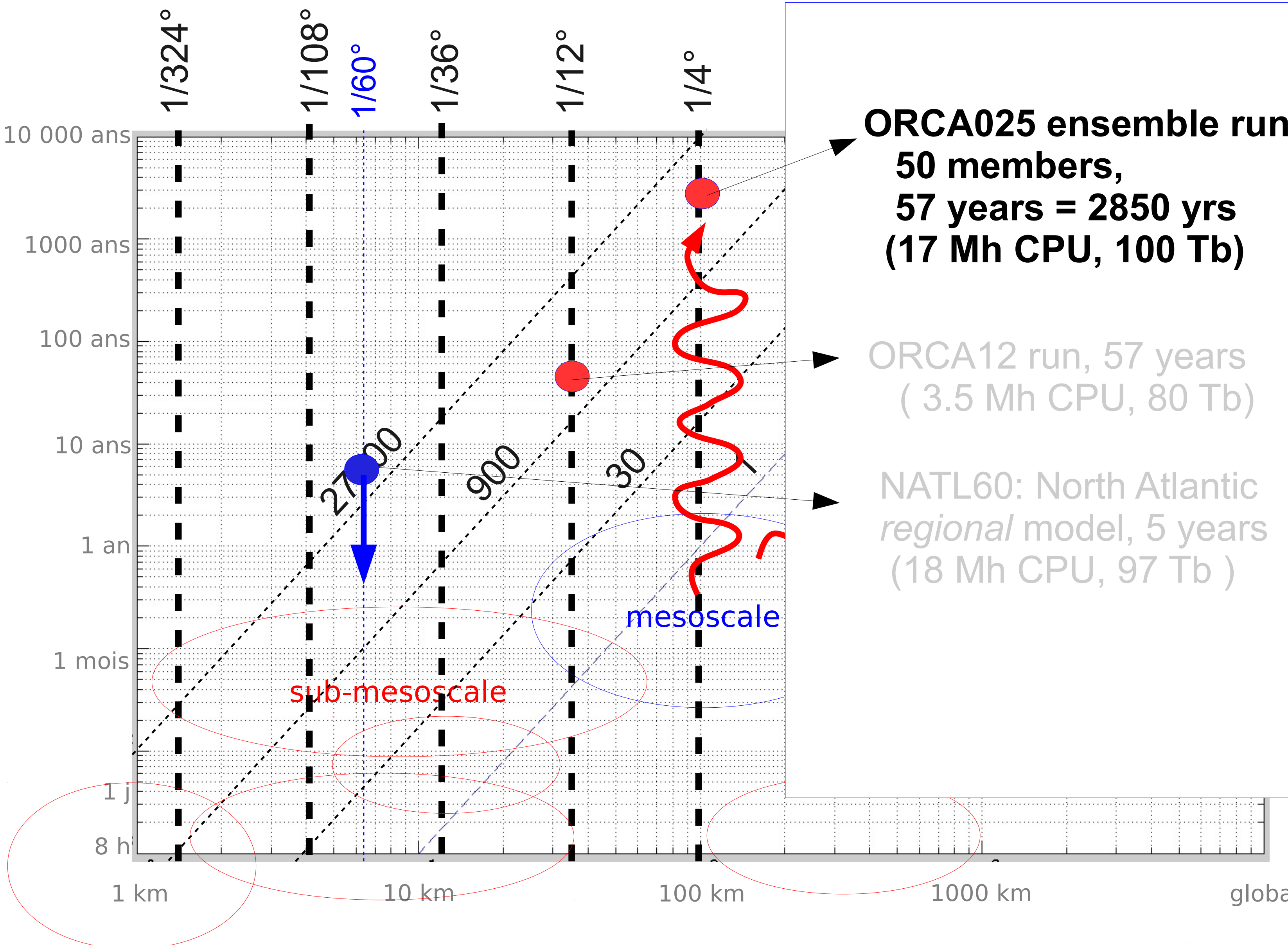
North

Surface velocities

South



Model configurations



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ORCA025.L75 Ensemble simulation

Context: **OCCIPUT**
OceaniC Chaos – ImPacts, strUcture, predicTability

PIs: T. Penduff (LGGE), L.Terray (CERFACS)

Aim : Unravel Intrinsic Low Frequency Variability of the ocean

Method: Use a 50 members ensemble run performed with ORCA025.L75 configuration on the period 1958-2015

ORCA025.L75 configuration

- ORCA025.L75 is a global configuration with a base resolution of 1/4° (ORCA type grid *)
- Mesh size is 1440 x 1021 x 75 (67.10^6 grid points)

    (x 50 members = $3.8\ 10^9$ total grid points)
- Typical time step is 1080 sec (29200 stp/year)
- One year output is 2Tb (netcdf4 with compression)
- Target machine for the ensemble run is CURIE
- CPU cost is 19 Mh (16M PRACE + 3M TGCC)

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NEMO modifications

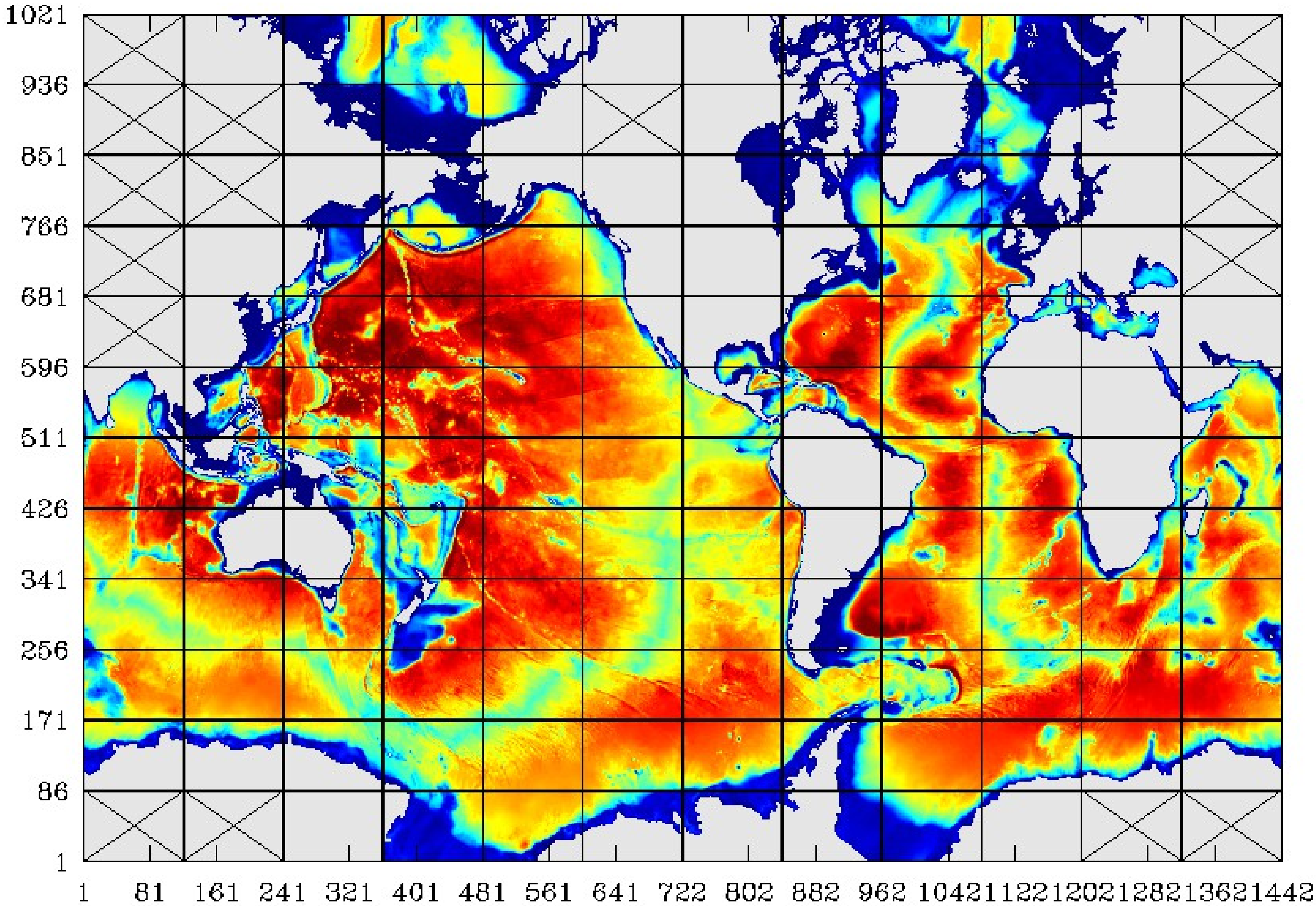
Goal : Running the ensemble with only one nemo executable, in order to perform cross-members diagnostics.

Method: (1) Define an array(dim= n_members) of nemo MPI communicators.

(2) define an array(dim=n_domain) of cross-members MPI communicators. (Each members use the same domain decomposition)

(3) Adjust file names and I/O to deal with different members.

Domain decomposition



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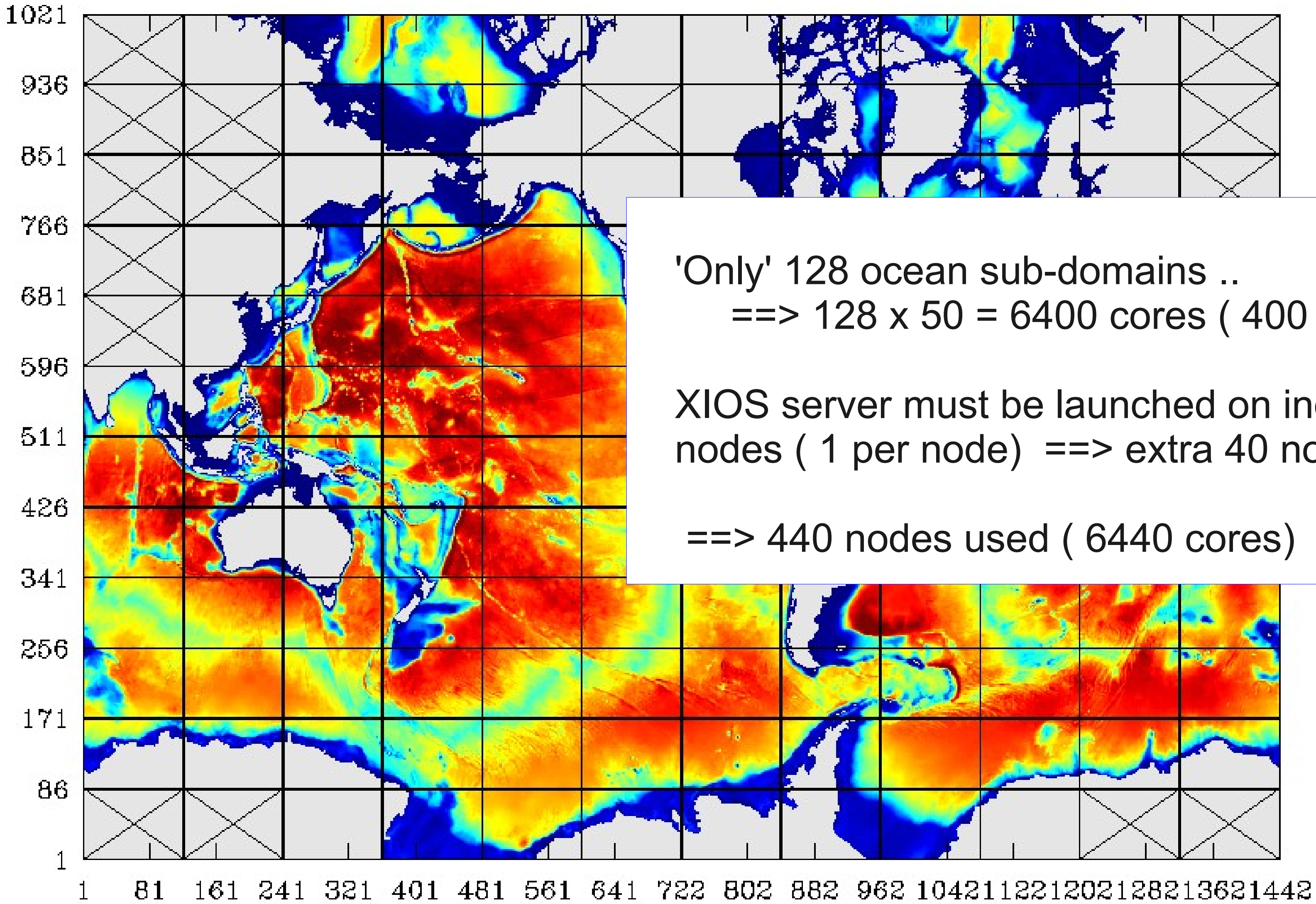
Domain decomposition

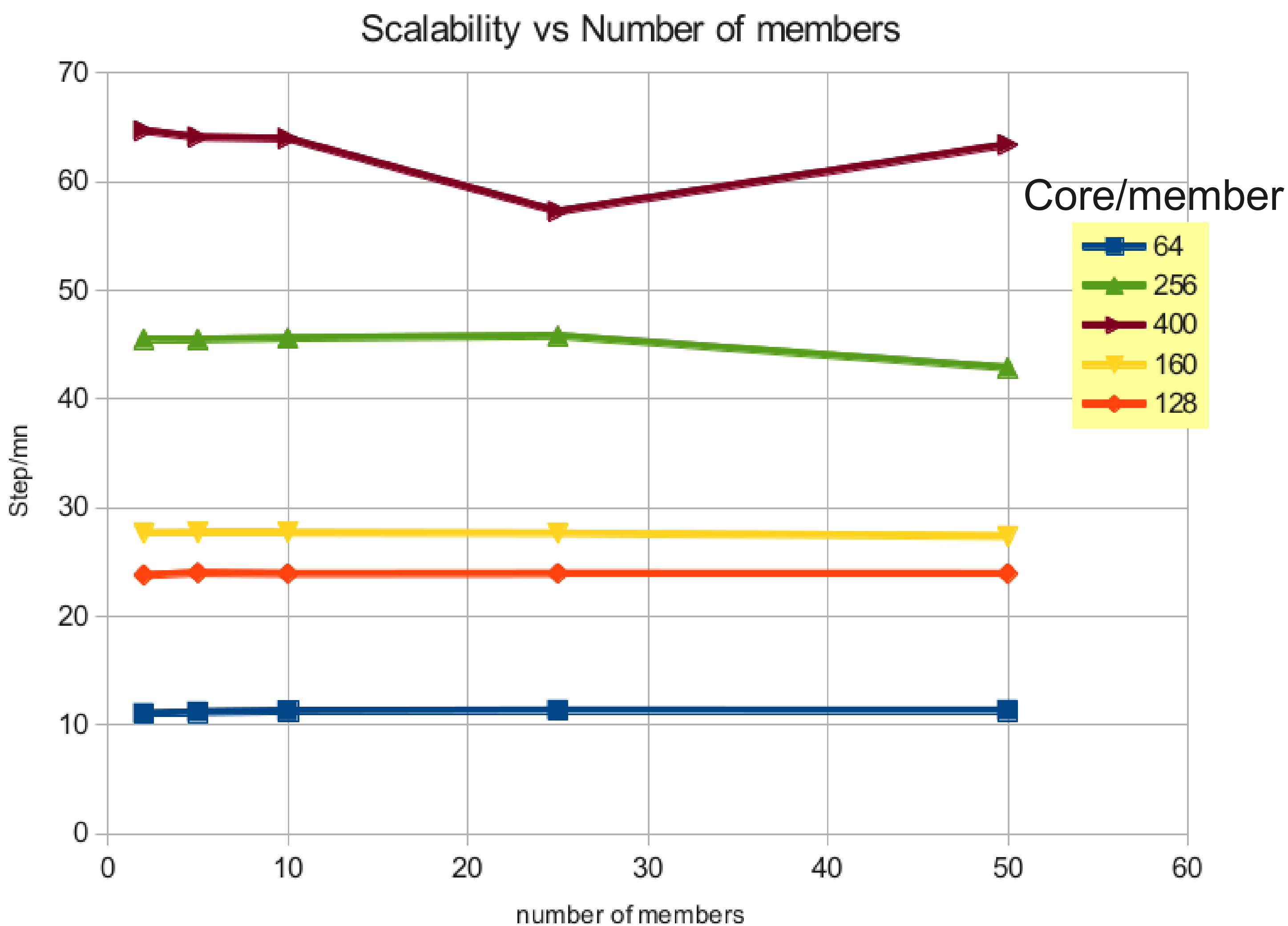


'Only' 128 ocean sub-domains ..
==> 128 x 50 = 6400 cores (400 nodes)

XIOS server must be launched on independent nodes (1 per node) ==> extra 40 nodes.

==> 440 nodes used (6440 cores)

Scalability tests



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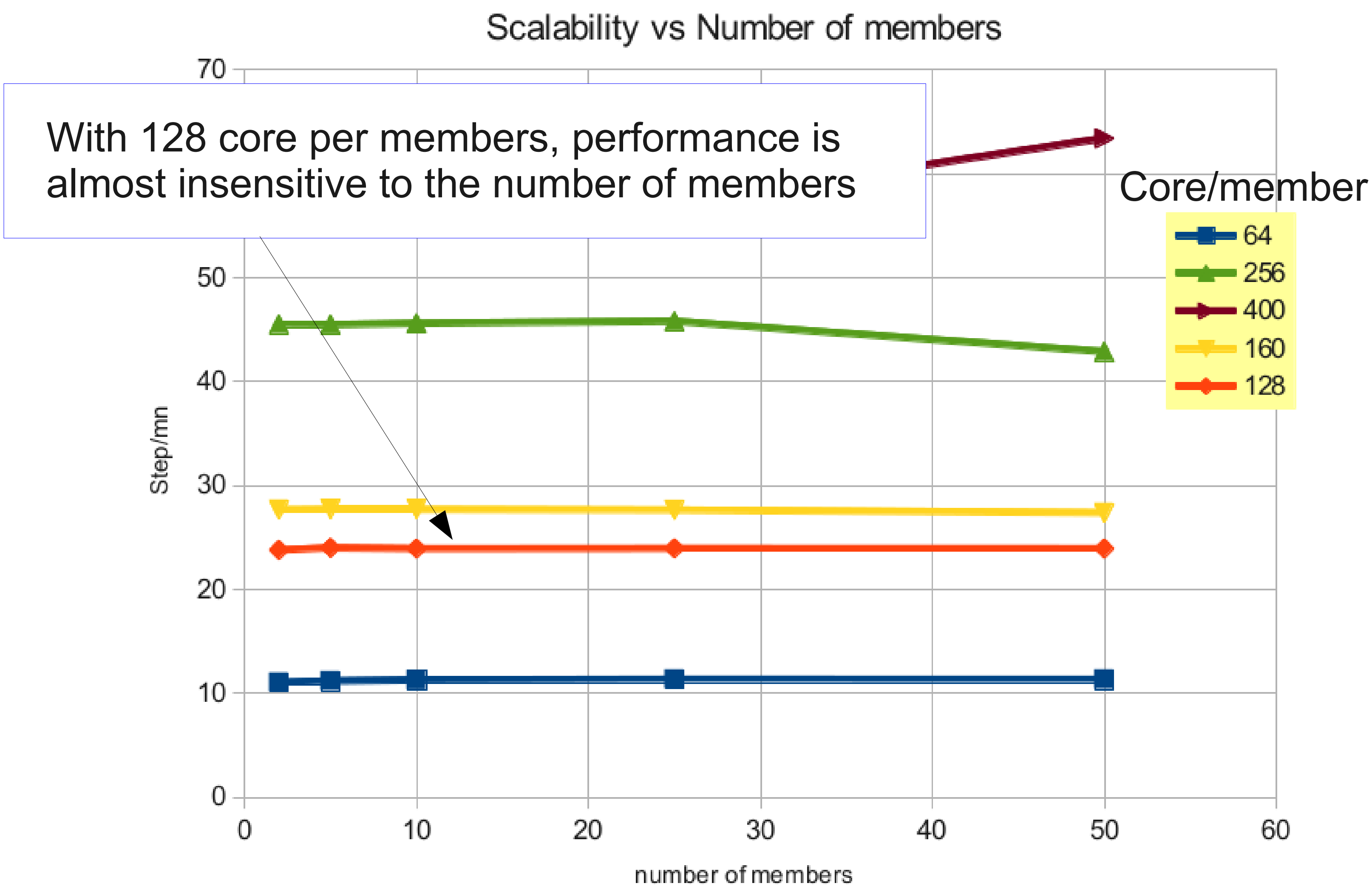
Scalability tests



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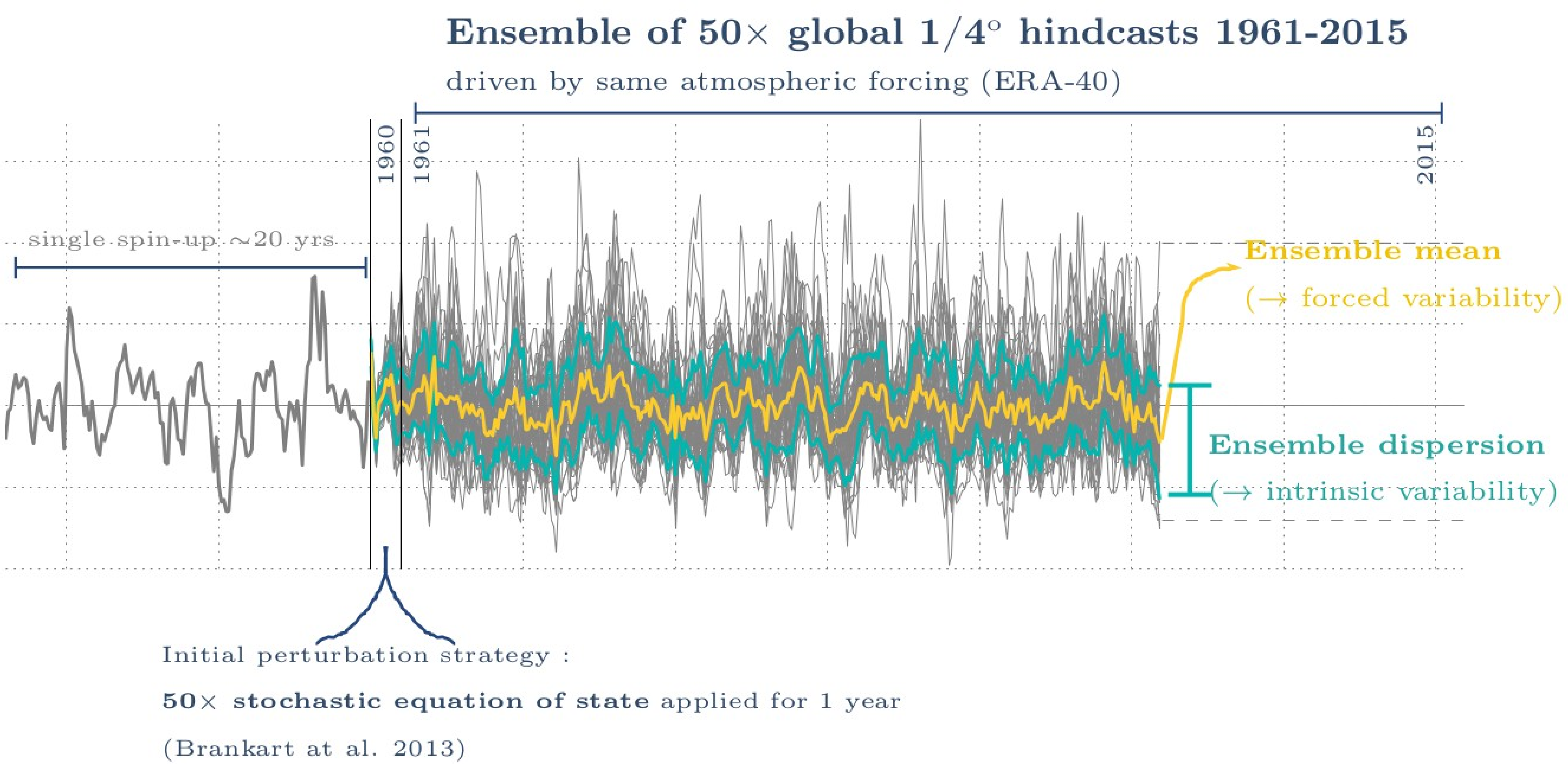
Ensemble run



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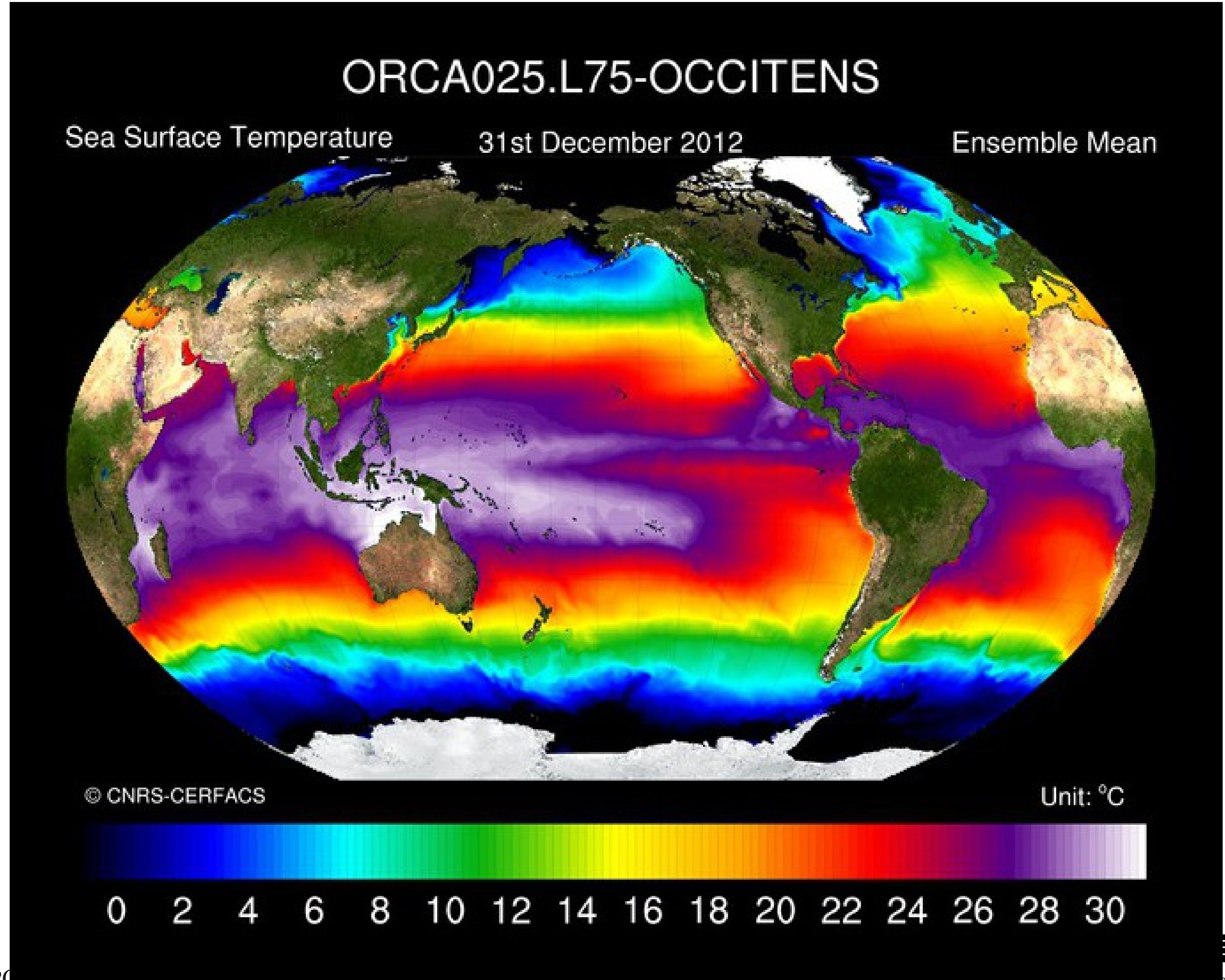
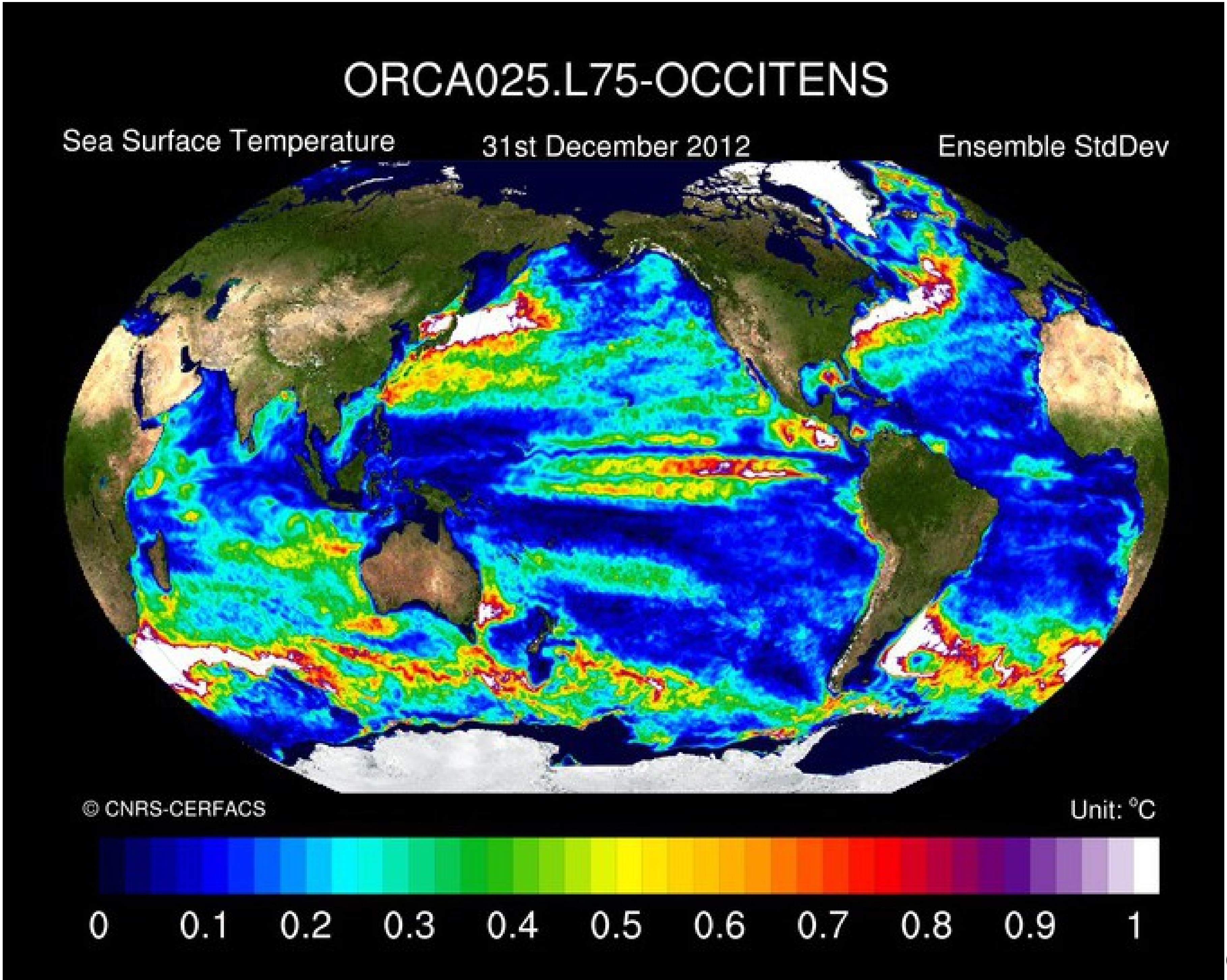
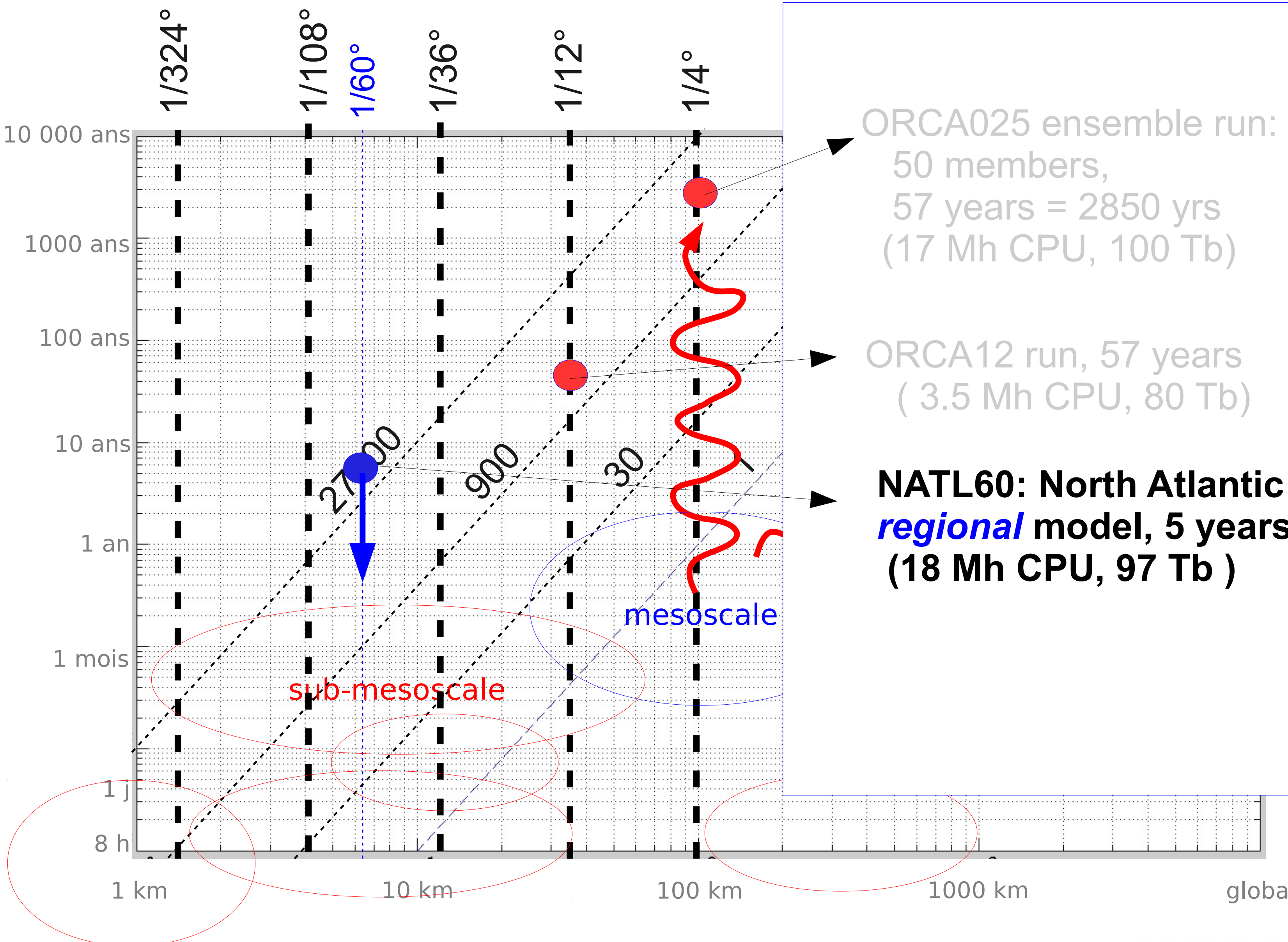

ORCA025.L75-OCCITENS
Sea Surface Temperature
31st December 2012
Ensemble Mean
© CNRS-CERFACS
Unit: °C
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30


ORCA025.L75-OCCITENS
Sea Surface Temperature
31st December 2012
Ensemble StdDev
© CNRS-CERFACS
Unit: °C
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Model configurations



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NATL60: North Atlantic *regional* model, 5 years (18 Mh CPU, 97 Tb)

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NATL60.L300 simulation

Context: Great Challenges GENCI 2014 during the validation phase of OCCIGEN.

Aim: Perform a numerical simulation of the ocean circulation at km scale.

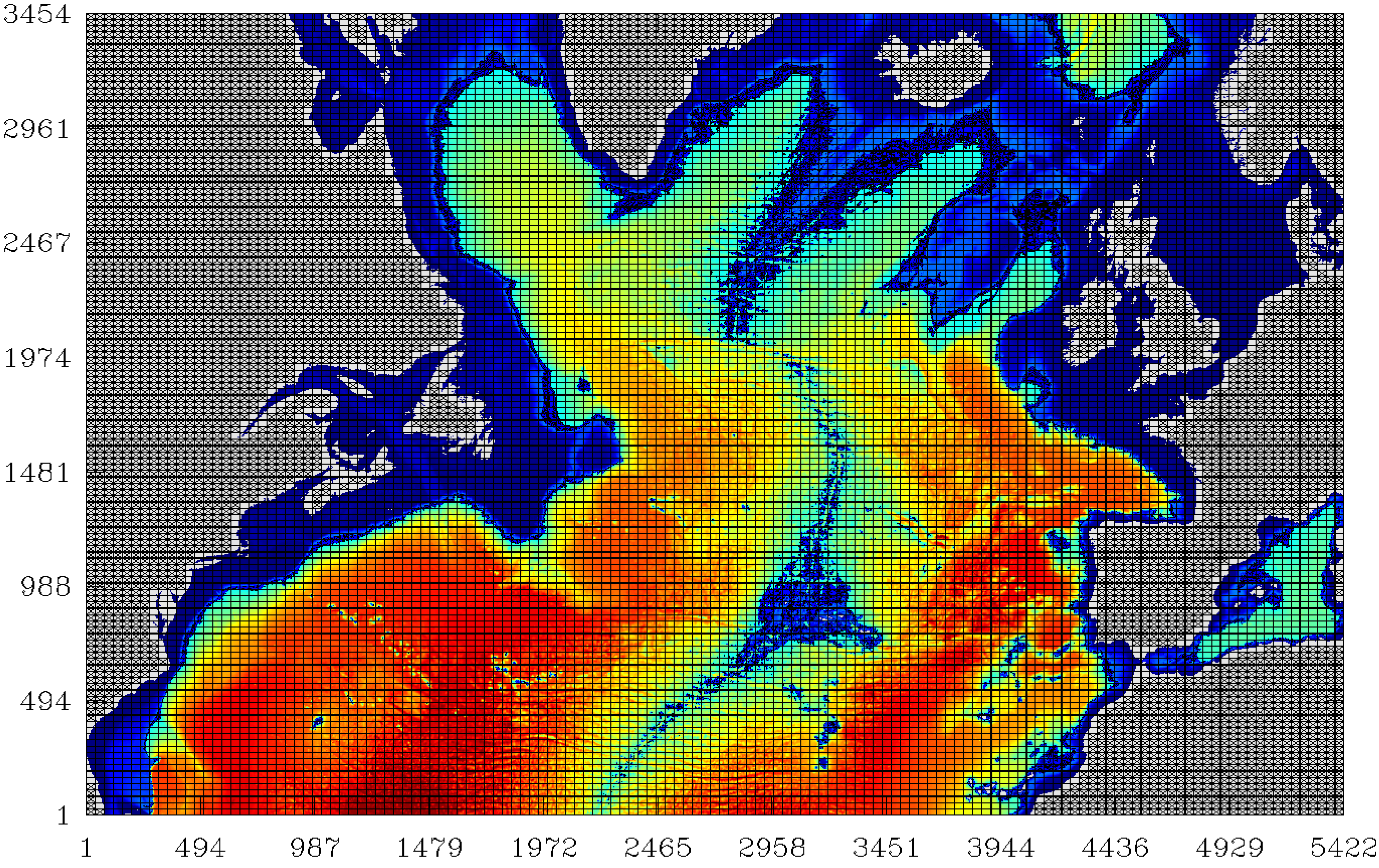
==> link with SWOT satellite project (2020)

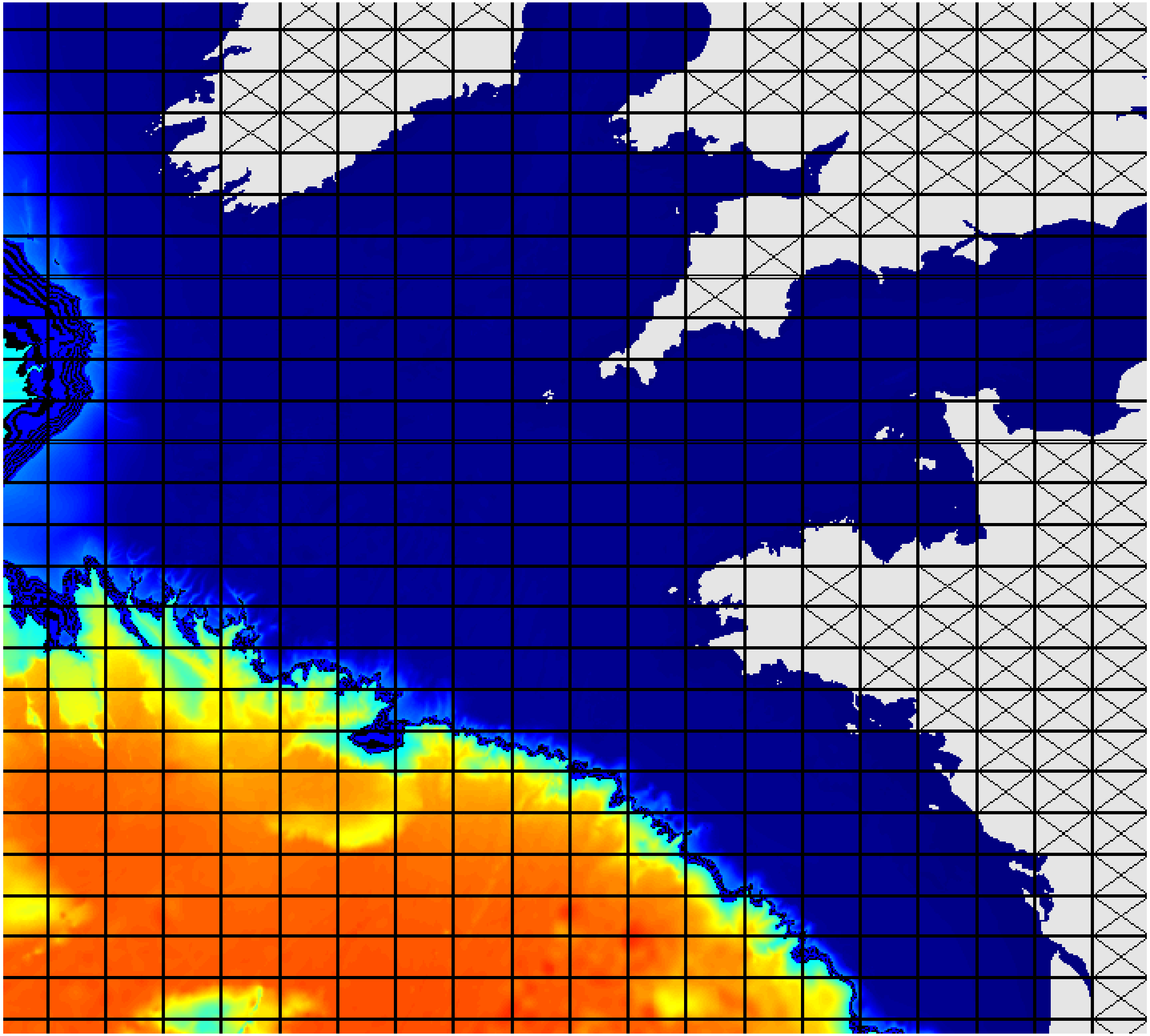
Method : Setup a regional configuration from ORCA12 grid, and a refinement of 5 => 1/60°. A refined vertical resolution of 300 levels is necessary to recover internal wave signals.

NATL60.L300 configuration

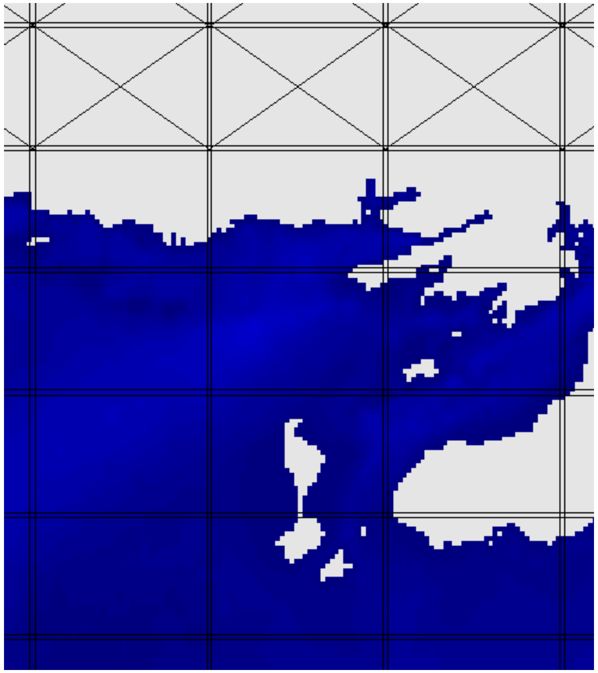
- NATL60.L300 is a *regional* configuration with a base resolution of 1/60° (imbedded in ORCA12) covering the North Atlantic between 26°N and 68°N
- Mesh size is 5422 x 3464 x 300 (5.6 10^9 grid points)
- Typical time step is 60 sec (525500 stp/year)
- One year output is 20 Tb (netcdf4 with compression)
- Target machine for this run is OCCIGEN
- CPU cost is 18 Mh (including fails during the validation phase)

Domain decomposition: 13000 domains





Sub domain size:
41x29x 300 pts



13000 NEMO + 296 XIOS = 13296 cores = 554 nodes / 2106 (26 % of occigen)

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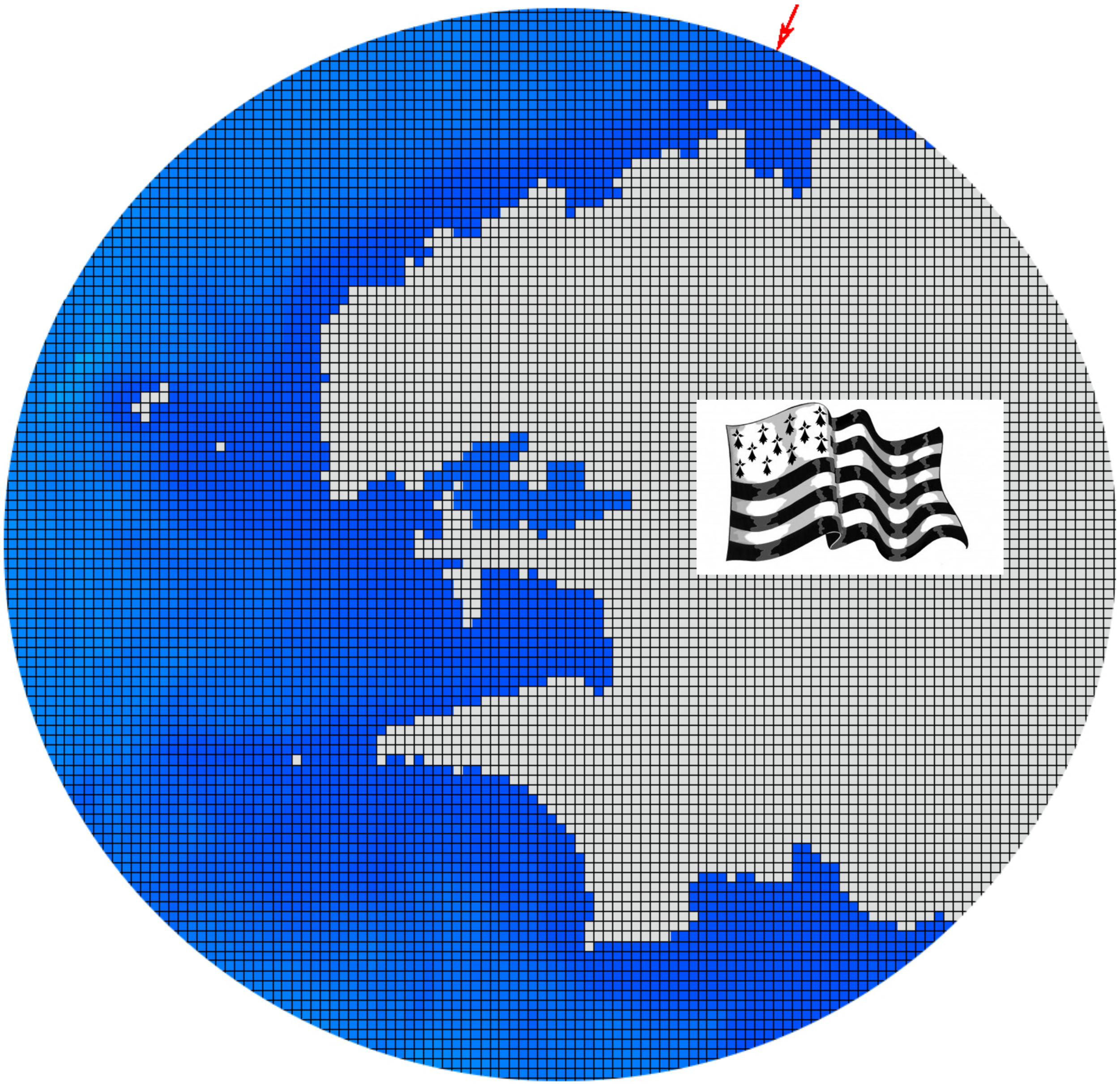
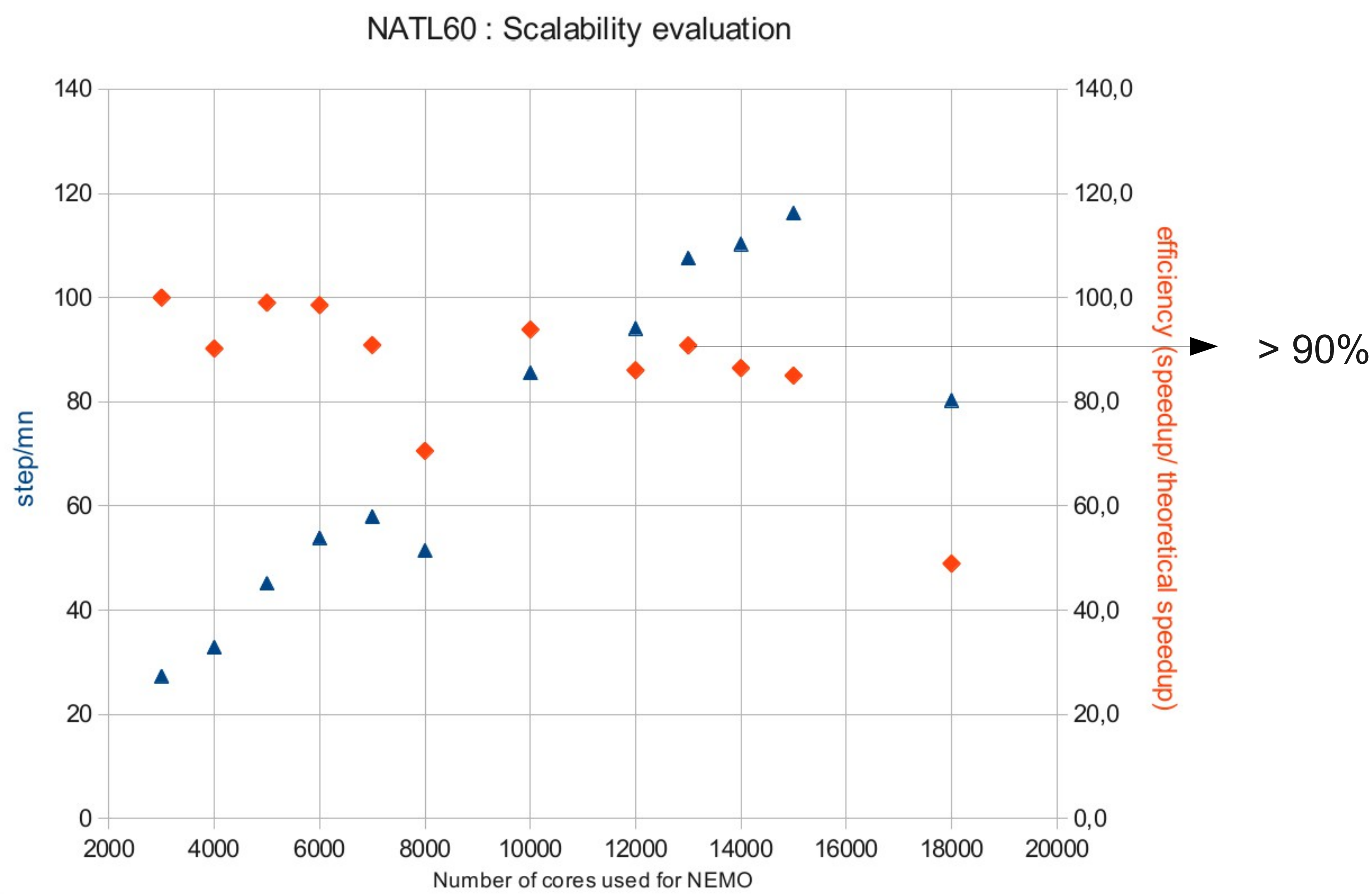


- 1/60° resolution
  → 1.2 km at 50 N.
- Bathymetry builded from global files at 1/120° resolution
  → *manual* (!!) tunning for obvious errors
- Coast lines *manualy* edited
  → 15d full time !

HPC also requires manual skill, sometimes …. !

NATL60 Scalabilité on OCCIGEN



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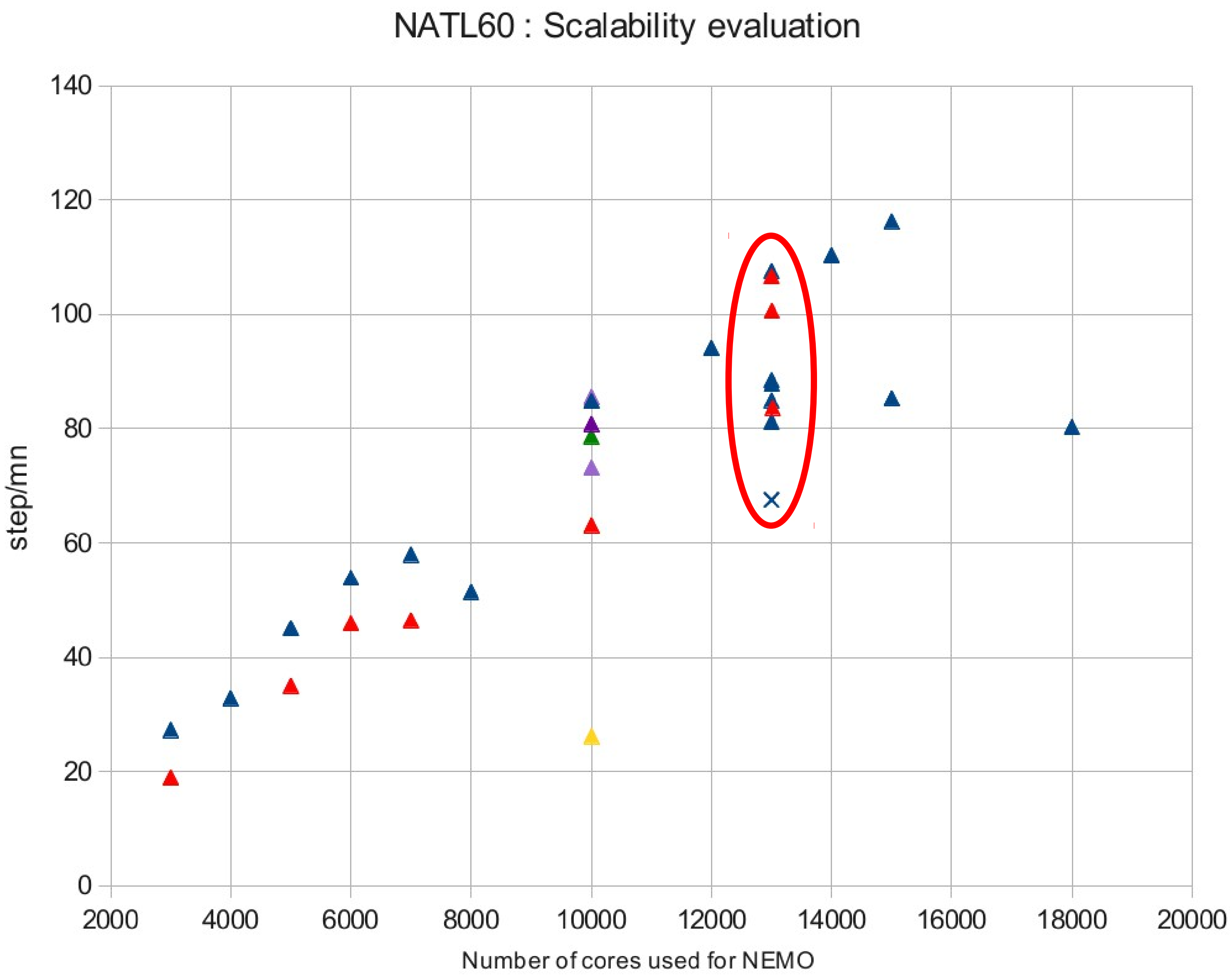
Influence de XIOS/placement



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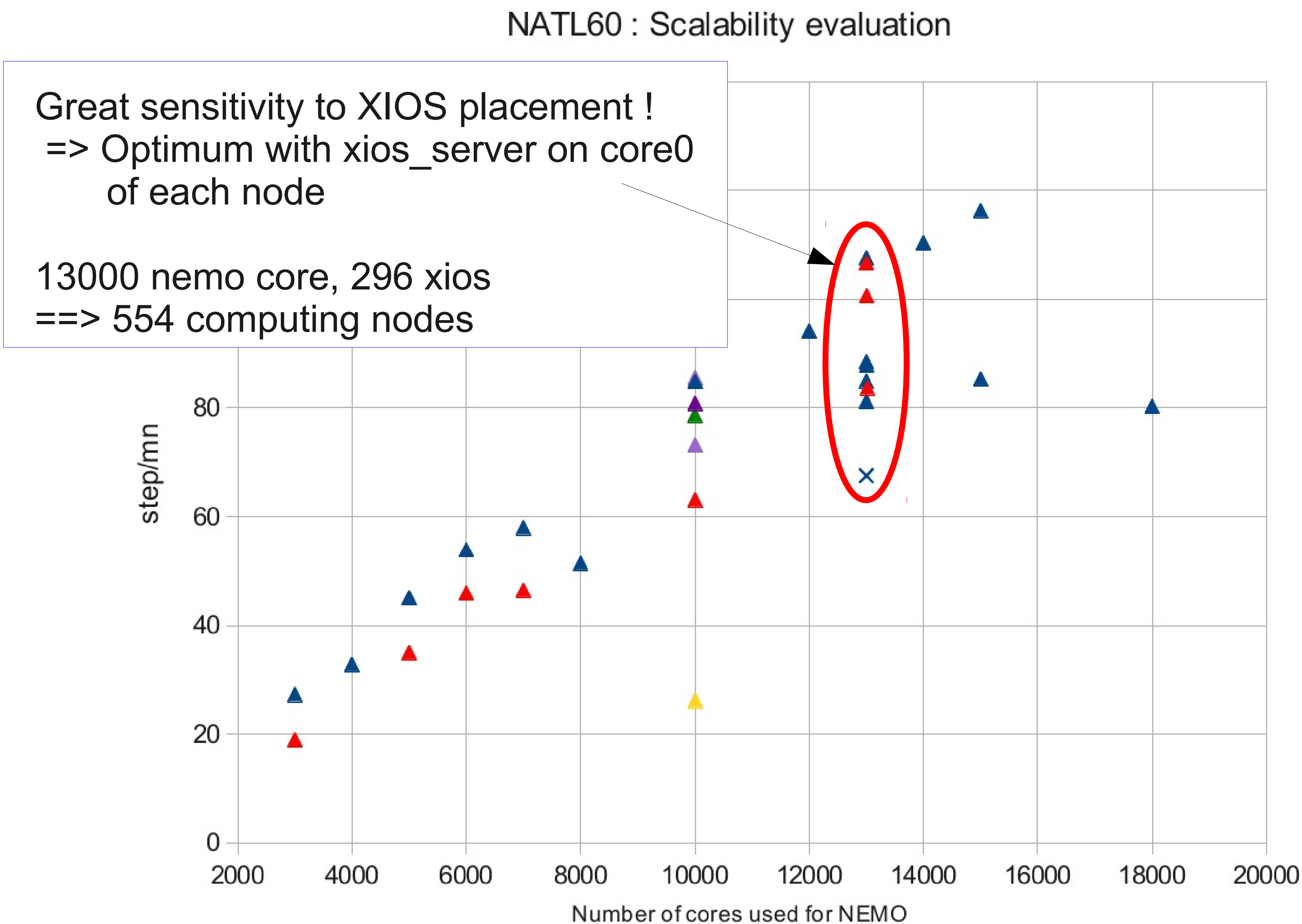
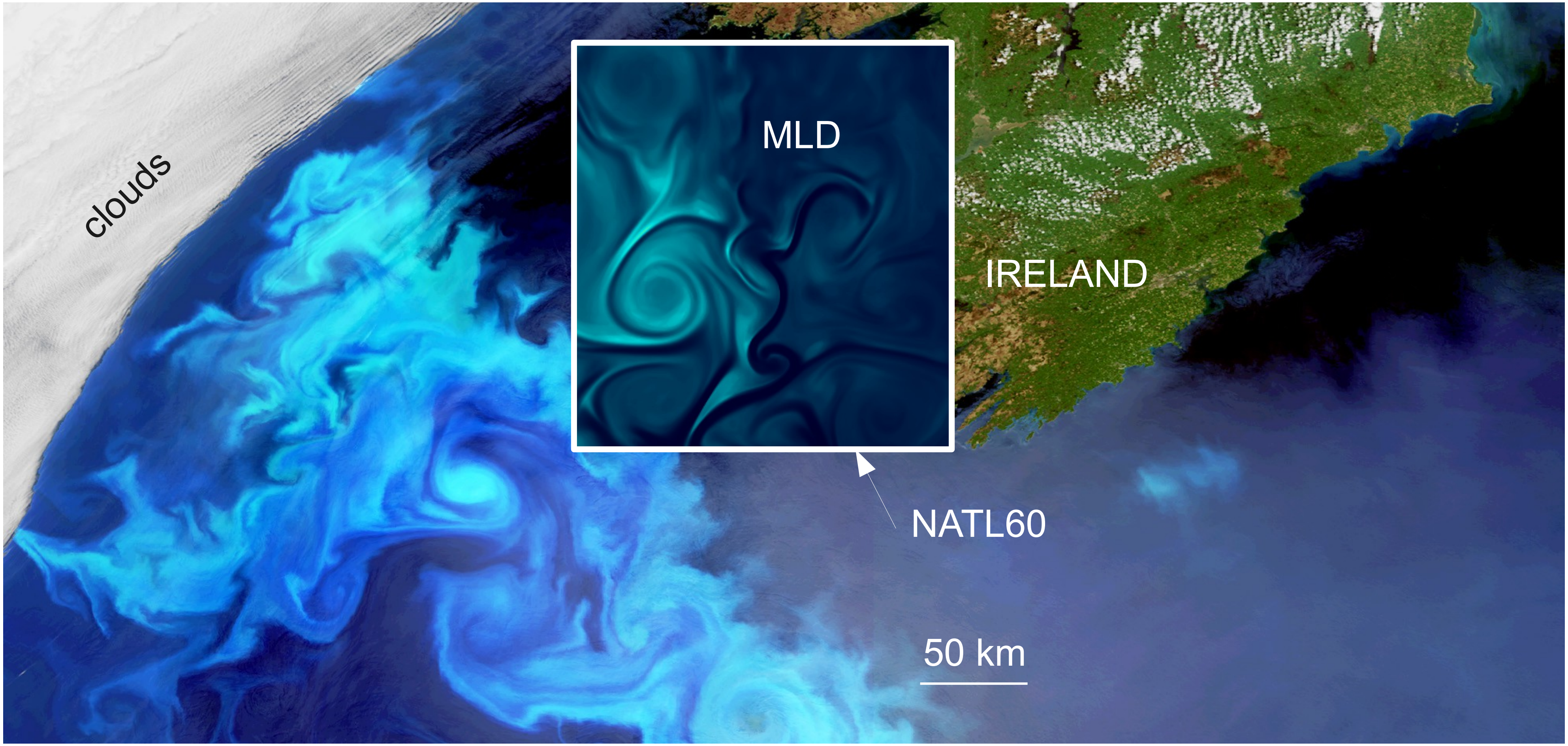
Influence de XIOS/placement



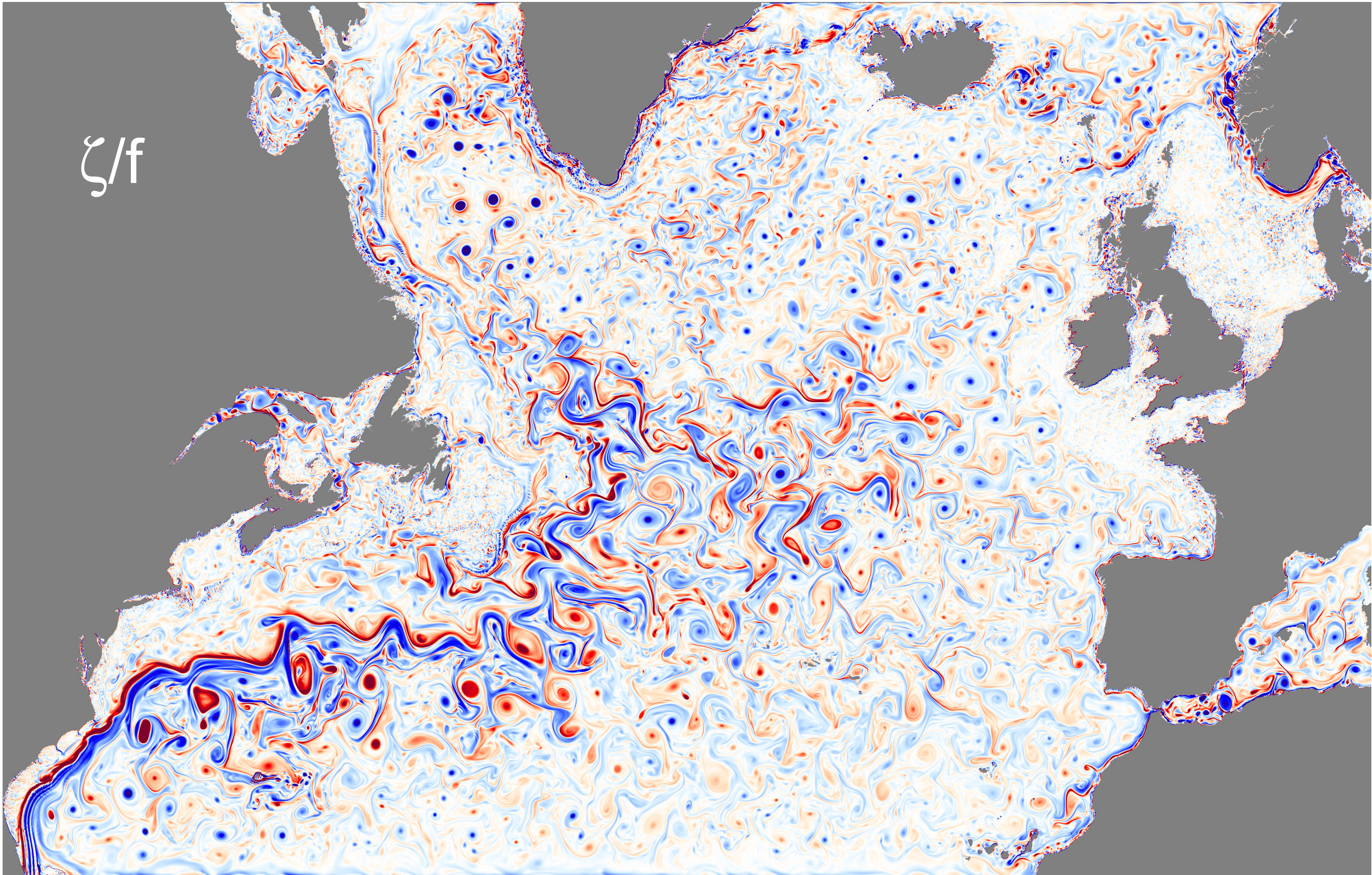
Sub-mesoscale representation



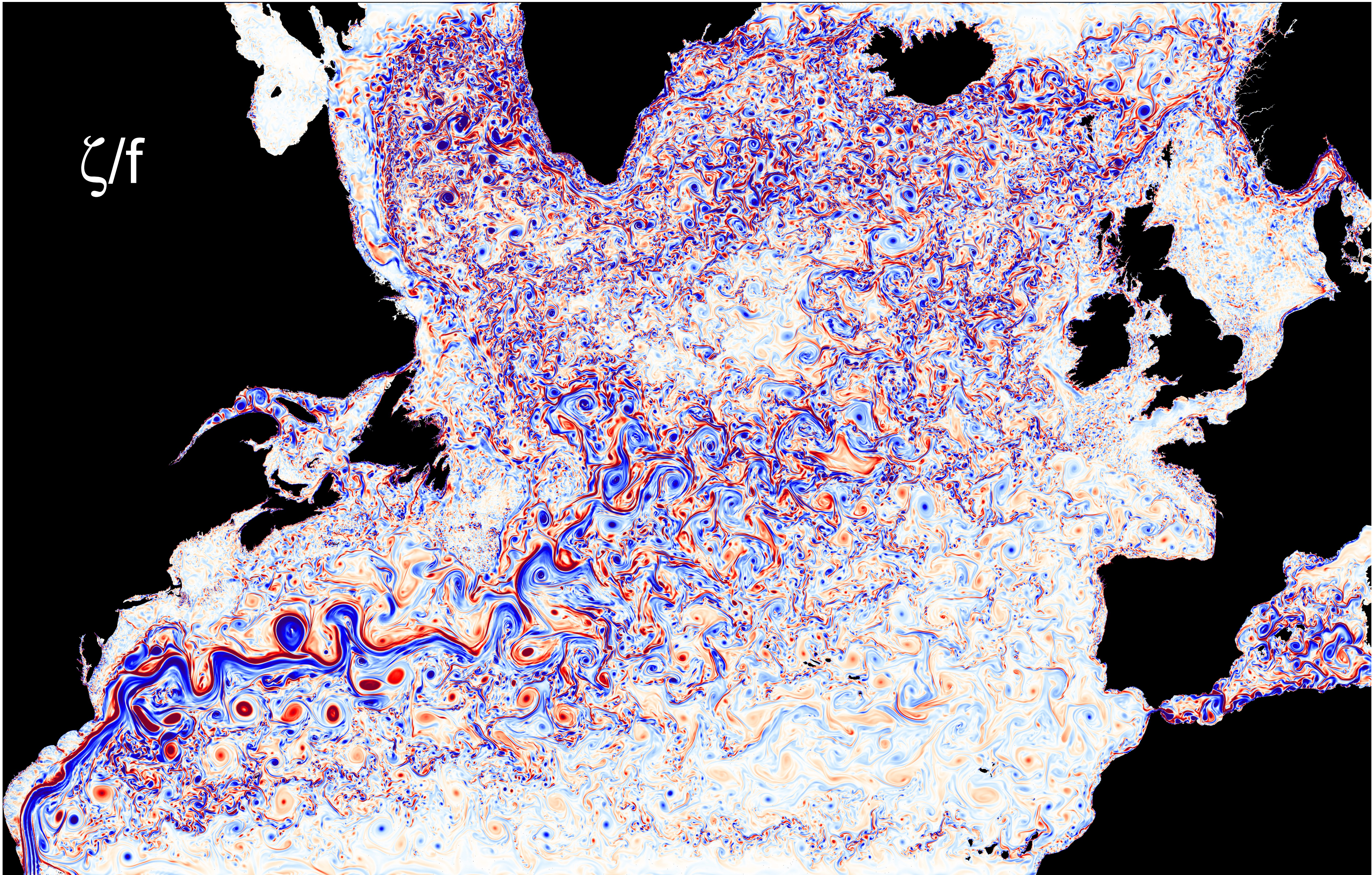
Chlorophyl spring bloom seen by Envisat satellite (ESA)

MLD = mixed layer depth ==> Model represent *similar* features than observed

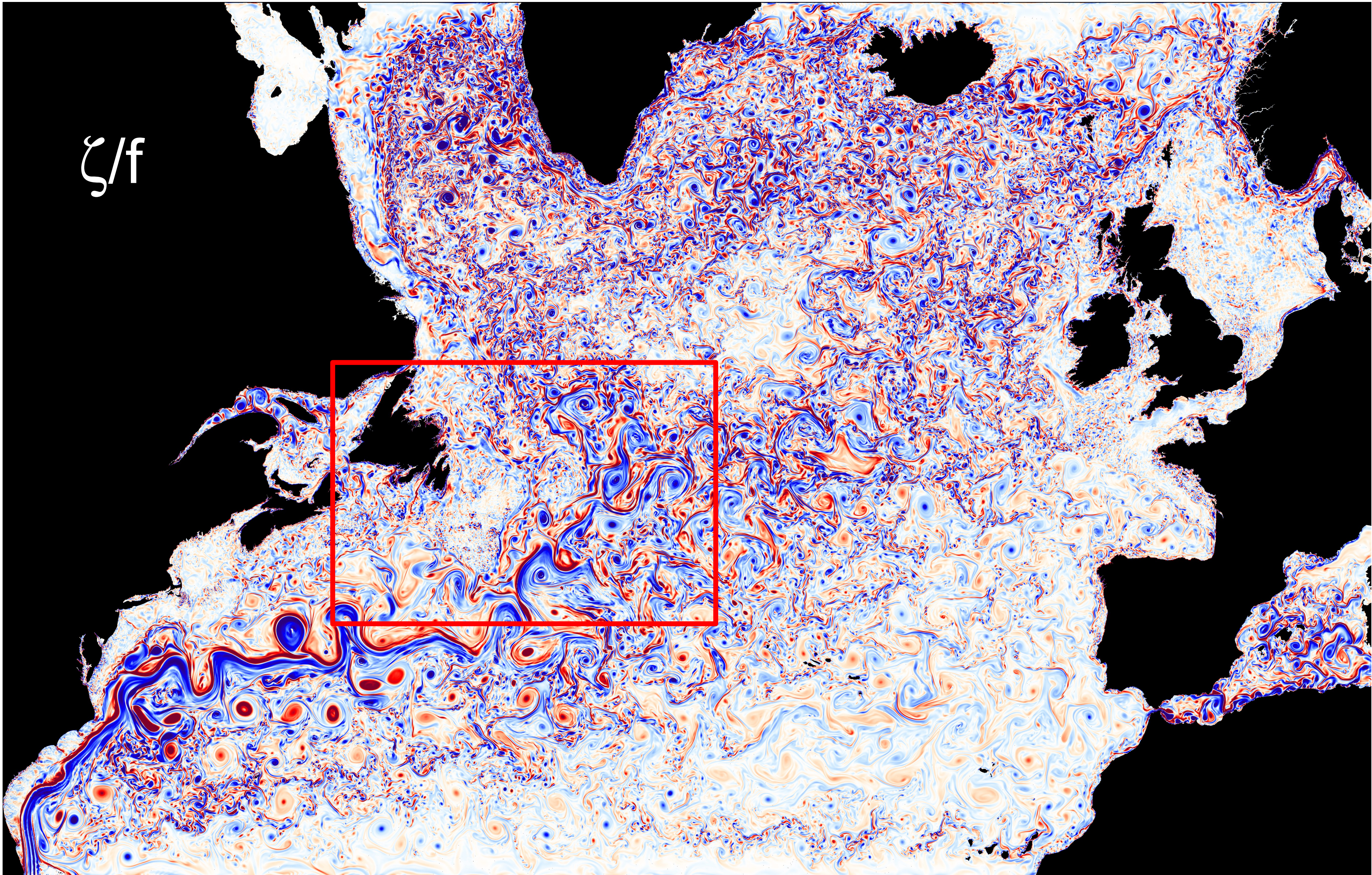
Seasonal Cycle : 01/09/08

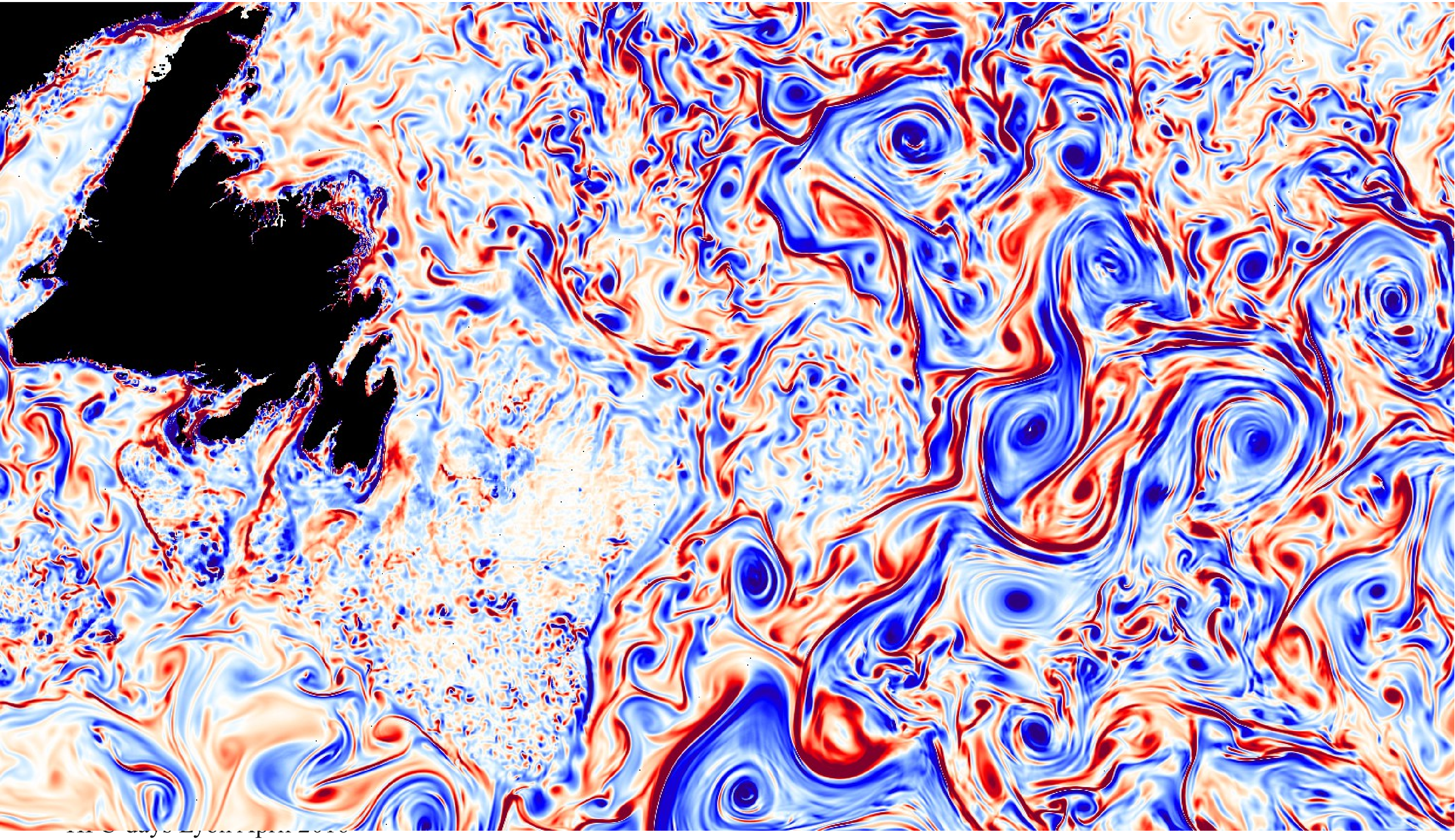


Seasonal Cycle : 15/03/08



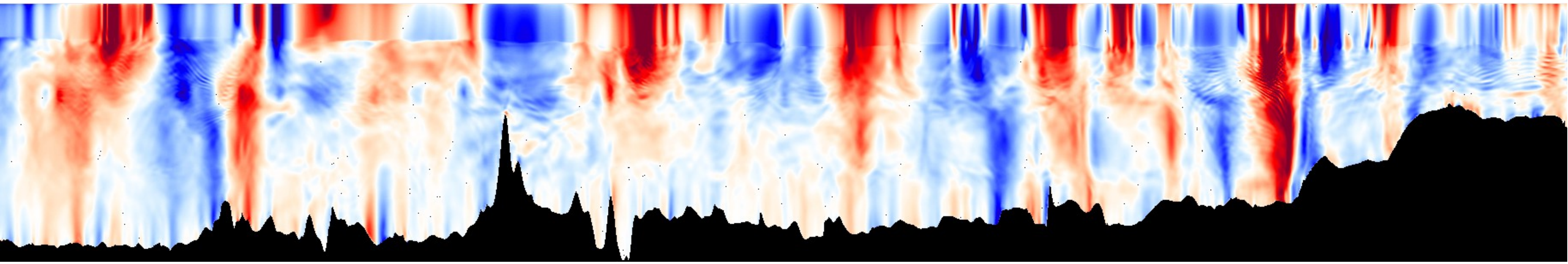
Seasonal Cycle : 15/03/08





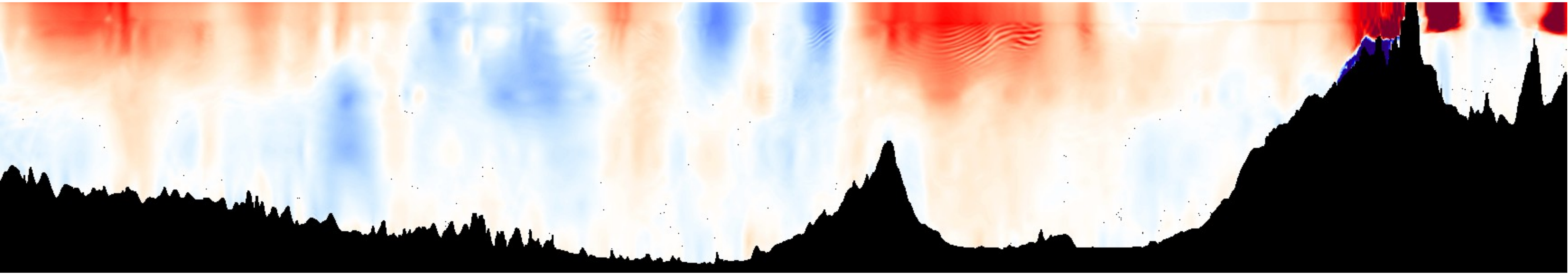
Internal Waves

S N



Section 19W south of Iceland
Zonal velocity
→ **a new view of the ocean**

W E



Section 36N (Gibraltar).
Zonal velocity
→ Med Sea outflow

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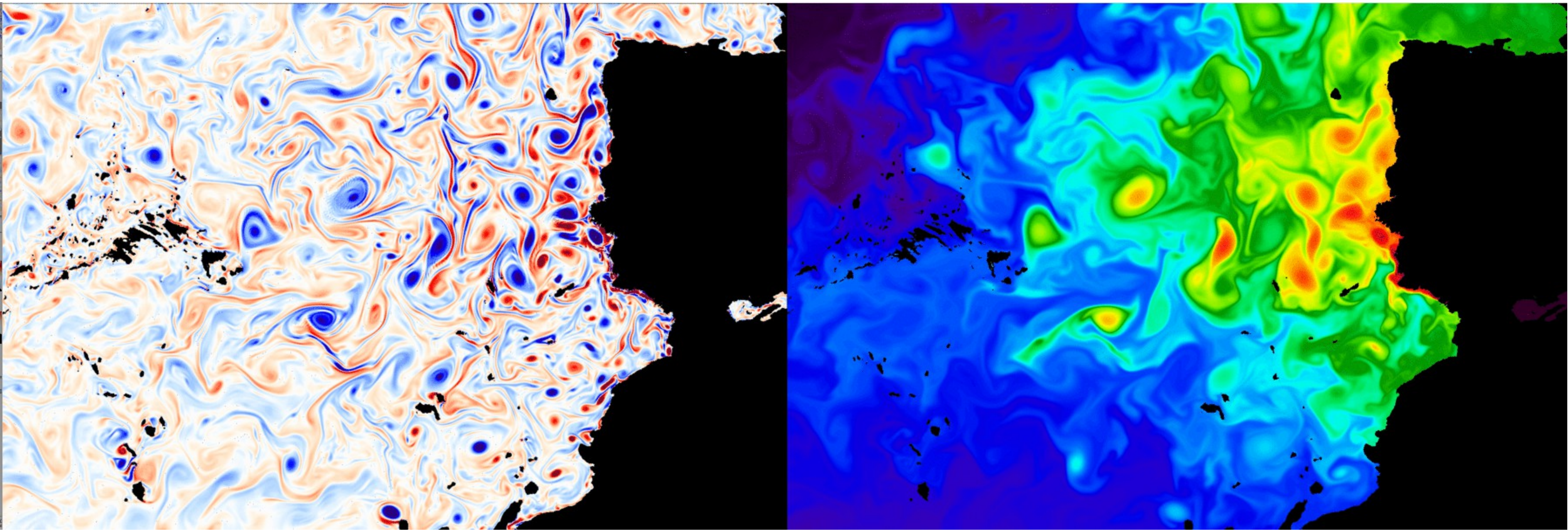
Meddies : MEDiteranean EDDIES (1100 m depth)



Relative vorticity   Salinity

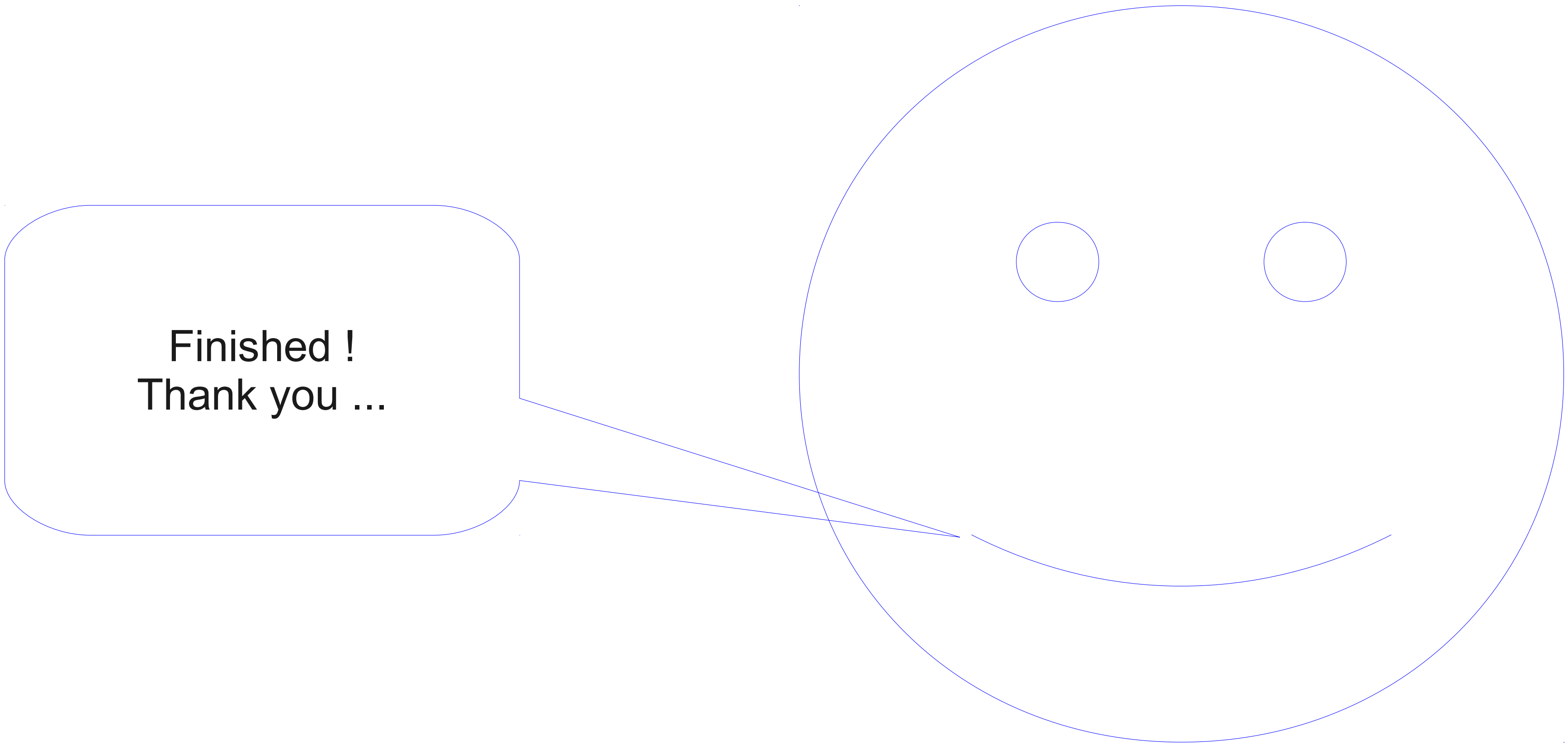
Med Sea water is spread out in the North Atlantic by the meddies ...

Summary/ discussion

- We showed 2 ways of using increasing HPC facilities
  - Toward very high resolution
    - Understanding small physical processes
    - Preparing next generation of observing system
    - Preparing next generation of model configuration
  - Toward ensemble runs at lower resolution
    - Assesement of uncertainties due to instrinsic variability
    - Statistical description of ocean state
    - New promising direction (in oceanography)
- NOT the only ways !
  - Coupling with atmospheric model is of fundamental importance

Summary/ discussion

- Limitations
  - Data storage, post processing, distribution of data is a major concern. Need to join *existing* working groups on this topic
  - Scalabilty on machine with O(1M cores)?
    - ==> will require major model evolution
  - Numerics adapted to very high resolution ?
    - New parameterization to be developped ?


Finished !
Thank you ...