# Activities between CNRS and ESC under MOU

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This project realized in the frame a MOU between ESC and CNRS, is composed of two main themes sharing the same dynamical core of the ocean: OPA. They aim to explore (1) the impact of very shallow ocean mixed layers on the tropical climate intraseasonal variability and (2) the impact of sub-mesoscale physics on the North Atlantic balance (heat transport, nutrient cycling, CO2 pump), both using OPA, coupled to ECHAM5 AGCM and biogeochemical model LOBSTER respectively.

This report summarizes the technical and scientific achievements of both themes. Improvement of the model parallelization allowed us to use 54 nodes for our biggest configuration. The first theme focused its work on validating the physics of the 301 levels configuration. After solving a numerical instability problem, the model is now showing very realistic equatorial circulation and is ready to be coupled to the atmosphere. Achievements of theme 2 concern the 100-year spin-up runs of eight configurations (physics only) corresponding to increasing resolution. Preliminary results show spectacular intense fine scale structures in vertical current and mixed layer depth, and large differences in the mean state of the basin between when resolution is increased.

**Keywords**: high resolution OGCM, mixed layer, tropical climate variability, mesoscale physics, ocean coupling with atmosphere and biogeochemistry

This report first summarizes the developments and optimizations for the Earth Simulator that have been done on OPA (the shared dynamical core). Then it details the results obtained for each theme.

## 1. Numerical aspects

OPA is a highly vectorized code with massive used of unrolling. We therefore concentrated our efforts on the parallelization of the code. First, we merged 3D communications that were initially designed for macrotasking (autotasking NEC) in a unique and larger communication. Second, we worked on the 2D communications associated to the computation of the sea surface computation. Two strategies have been tested:

- The implicit time-scheme that needs an elliptic solver. We changed the solver from a preconditioned conjugate gradient (PCG) to a successive over relaxation (SOR). The SOR (using Red-Black technique for vectorization) is an older solver supposed to be less efficient, but, it requires less communications. In addition, taking advantage of the cheap computation coast of SOR, we add extra halos on the 2D solver part to further reduce its communication.
- The time-splitting scheme. In our first tests, it appears to be more time consuming than optimized SOR solver (over cost of 10%).

All these improvements lead to a very significant decrease of the elapse time. That was the key issue to be able to run our biggest target configuration (1622 × 1082 × 101) on 54 nodes.

## 2. First theme: "The impact very shallow ocean mixed layers on the tropical climate intraseasonal variability"

### 2.1 Objective

The aim of this project is to get a better understanding and quantification of the resolved upper oceanic structures with small vertical scale that can influence the development of large scale coupled phenomena. Specific objectives of the proposed research will concern the upper ocean equatorial dynamics with a focus on the impact of diurnal cycle [2] and the barrier layer on the tropical climate variability.

2.2 Model

To carry on this project, the use of an ocean-atmosphere coupled model is needed to explore the ocean-atmosphere interactions. The ocean component has a global 3 polar quasi-isotropic grid with a horizontal resolution of about half-degree (ORCA05) and a vertical resolution of 1 meter in the upper layers (301 levels). The Atmospheric grid is a T106 with 31 levels.

2.3 Achievements from April 2005 to March 2006

After validating the physics of the half-degree global domain (ORCA05) with 31 levels [1], we tested the equatorial physic of the version with 301 levels. Figure 1 shows comparison of the zonal current between the model and TAO moorings. By using 301 levels, we further improved the lower part of the Equatorial Under Current (EUC) that fits now almost exactly the observation in the eastern equatorial Pacific (see 140°W and 110°W in Fig. 1).

However, introducing the very high vertical resolution strongly deteriorates the western part of the EUC in both Pacific (see 156°E in Fig. 1) and Atlantic. To solve this issue, we had to trace it back until the first days of the experiment. After only 2 weeks of the spin-up, a strong numerical instability was already visible on the equatorial section of the temperature in Atlantic (see upper panel Fig. 2). Amazingly, the model did not explode. The EUC advected the instability that flattens and destroys the thermocline along its path with catastrophic consequences for the ocean dynamics in western equatorial basins (see 156°E in Fig. 1). This issue has been solved by introducing a time splitting for

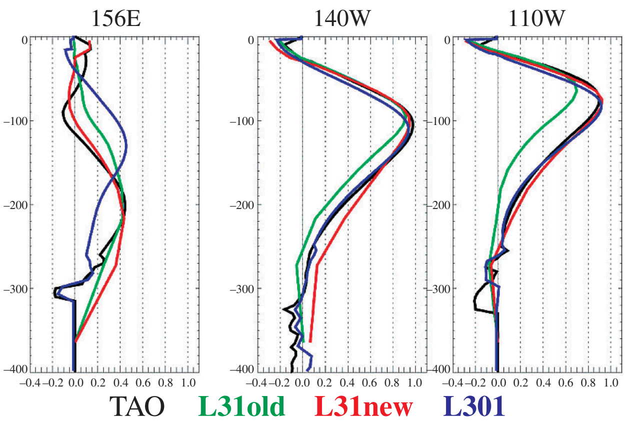


Fig. 1 vertical profiles of the mean zonal current (1992–2000) along the equatorial Pacific for TAO mooring (black), old model physics with 31 levels (green) and new model physics with 31/301 levels (red/blue). Units m/s

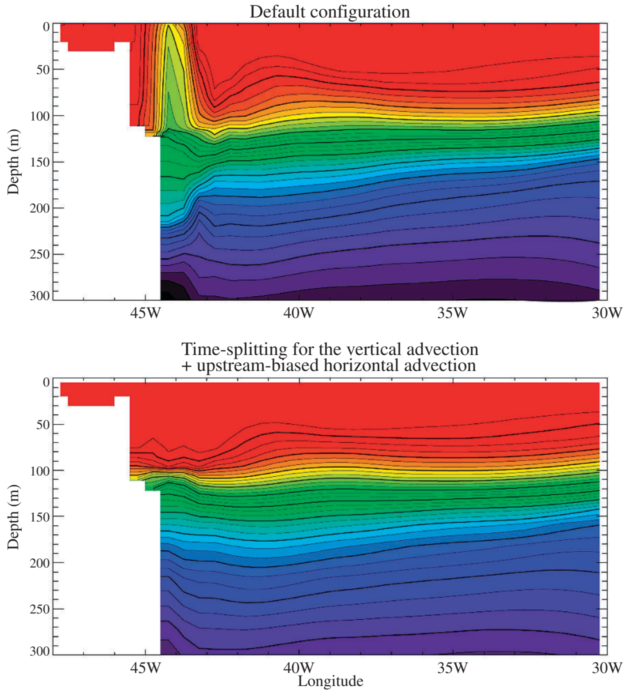


Fig. 2 equatorial section of the western Atlantic temperature after 2 weeks of spin-up.

the vertical advection (Fig. 2 bottom panel). We also switch to a 3rd order upstream-biased scheme for the horizontal advection that is more slightly diffusive than the TVD scheme originally used.

2.4 Perspectives:

We built an oceanic component with a very high vertical resolution that is now showing realistic features and ocean circulation. Our next step is thus to look further at the impact of the diurnal cycle in a 301 levels ocean. In addition we will move to the coupled model that has been technically assembled during this year.

## 3. Second theme: "The impact of sub-mesoscale physics on the North Atlantic balance (heat transport, nutrient cycling, CO2 pump)"

3.1 Objectives:

The scientific objective of this project is to get a better understanding and quantification of the contribution of sub-mesoscale physics (eddies and filaments) on tracer distributions and on large scale budgets (nutrient cycling, heat transport, salt transport) [3, 4]. Specific questions are:

(1) Is there depletion or enrichment of nutrients in the euphotic layer on the seasonal time scale due to sub-mesoscale physics?

(2) What is the contribution of the sub-mesoscale physics to the subduction of organic matter and thus nutrient cycling on longer time scales?

### 3.2 Method

To answer these question, we have set up an idealized double-gyre (3000 * 2000 Km) configuration (called GYRE) that mimics the North West Atlantic known as a crucial region of $CO_2$ sink (Fig. 3). This configuration reproduces the western boundary current, the subtropical and subpolar gyres and the subtropical mode waters. The model has a uniform horizontal resolution on the beta-plane. The basic resolution is 1° with 30 vertical layers. Forcings are analytical. Therefore, the resolution can be increased as many times as needed by simply dividing the nominal grid cell into smaller ones.

We have set up eight simulations, differing either in the resolution (horizontal and vertical) or in the physics (Table 1). Our most complete simulation has a resolution of 1/54° and couples the ocean dynamics (using the model OPA9) with an online biogeochemical model (called LOBSTER). The impact of the small-scales will be assessed by:

- Comparing the mean state of the model (equilibrated heat, salt and nutrient distributions) for the various model resolutions
- Evaluating the transport trends at fine scales and at large scales, in the mixed-layer and in the thermocline for each experiment

### 3.3 Achievements from April 2005 to March 2006

The first achievement concerns the runs of the eight configurations (physics only). The runs were performed in five steps:

- R1 was integrated for 1000 years starting from analytical profiles.
- In order to avoid long-term basin-mode variability, R1 has been restarted for another 1000 years with sea surface salinity (SSS) restoring towards the annual mean SSS field at year 1000.
- Outputs after these 2000 years were extrapolated on the higher-resolution grids and each configuration was run until equilibration. We have found that a minimum of 100

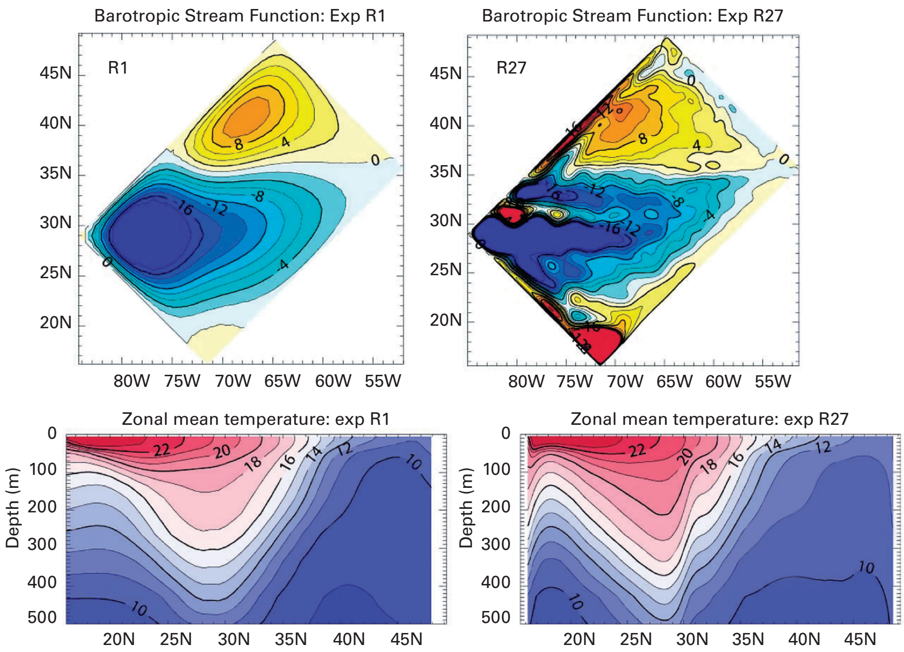


Fig. 3 Barotropic stream function and temperature (zonal and annual mean) in Experiments R1 and R27 showing the two gyres and the presence of 18-19°C mode waters in the subtropical gyre.

Table 1 Characteristics of the GYRE experiments (iso: isopycnal diffusion, bilap: biharmonic horizontal diffusion or dissipation, Aht0: diffusion coefficient, Ahm0: dissipation coefficient, Dt: time step)

| Experiments | Resolution | Vertical layers | Grid points | T | U | Aht0 | Ahm0 | Dt |
|---|---|---|---|---|---|---|---|---|
| R1 | 1° | 30 | 32 × 22 × 31 | iso | hor | 100<br>0 | 10000<br>0 | 2h |
| R3 | 1/3° | 30 | 92 × 62 × 31 | iso | bilap | 300 | $-10^{e}11$ | 1h |
| R9 | 1/9° | 30 | 272 × 182 × 31 | iso | bilap | 200 | $-5^{e}10$ | 24mn |
| R9bb | 1/9° | 30 | 272 × 182 × 31 | bilap | bilap | –<br>$5^{e}10$ | $-5^{e}10$ | 24mn |
| R27 | 1/27° | 30 | 812 × 542 × 31 | bilap | bilap | $-5^{e}9$ | $-5^{e}9$ | 5mn |
| R27v | 1/27° | 90 | 812 × 542 × 101 | bilap | bilap | $-5^{e}9$ | $-5^{e}9$ | 5mn |
| R54 | 1/54° | 30 | 1622 × 1082 × 31 | bilap | bilap | $-1^{e}9$ | $-1^{e}9$ | 2mn |

years is required to spin-up the basin starting from the R1 first guess (Fig. 3)

- Each experiment was restarted for 10 years with annual output
- Each experiment was restarted for 1 year with 2-days outputs

Preliminary results give spectacular intense fine scale structures in vertical velocity, SST and mixed layer depth (Fig. 4) and large differences in the mean state of the basin (Fig. 2). We have started the analysis to elucidate the link between the small scale transport and the mean state of the basin.

The second achievement concerns the coupling between the physics and the biology. This has been done in R1 and R3. A modification in the analytical formulation of the atmospheric forcing has been found necessary to reproduce the various biogeochemical provinces and seasonal cycles in the North Atlantic.

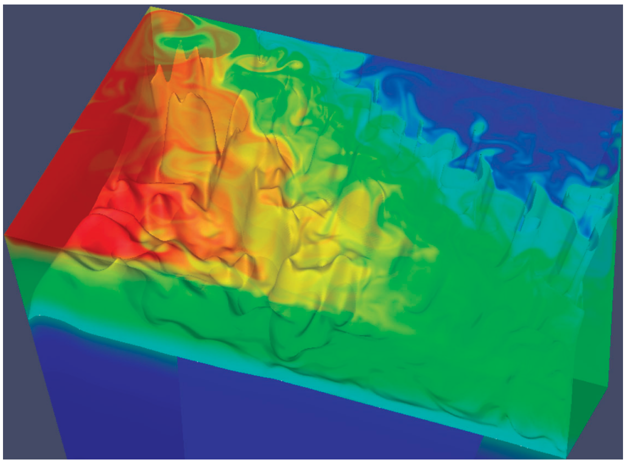

Fig. 4 SST and surface showing the mixed layer depth in R27.

3.4 Perspectives: The next steps will be:

- to run the coupled experiments at high resolution
- to continue the analysis of the model physical response when resolution is increased
- to start the analysis of the model biological response when resolution is increased.

## 4. References


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キーワード：high resolution OGCM, mixed layer, tropical climate variability, mesoscale physics, ocean coupling with atmosphere and biogeochemistry

本プロジェクトは、地球シミュレータセンターとCNRSとのMOUのもとに、2つの主なテーマ:

(1) 熱帯気候の季節変動における非常に浅い海洋混合層のインパクト

(2) 北大西洋におけるバランス（熱輸送、栄養循環、CO2パンピングなど）におけるサブメソスケールの海洋物理のインパクト

についての共同研究を推進している。上記2つのテーマにおいては、海洋大循環モデルOPAを、大気大循環モデルECHAM5と生物化学モデルLOBSTERにそれぞれ結合したモデルを使用している。

本報告では、上記の2つのテーマについて、技術的、科学的な成果をまとめて報告する。まず、モデルの並列性能を向上したことにより、最大54ノードの使用が可能になった。数値計算的な不安定を解消し、現時点においては、赤道域における非常にリアリスティックな循環が再現可能となった。これにより、大気との結合を進める準備が整ったといえる。テーマ(2)について、高解像度の設定に対応した8ケースの設定において、それぞれスピンアップとして100年の積分を実行した。初歩的な結果ではあるが、鉛直流や混合層の深さについて、非常に詳細なスケールの構造が再現できること、さらに、解像度が異なる場合には海盆スケールの平均場が非常に異なることが示された。

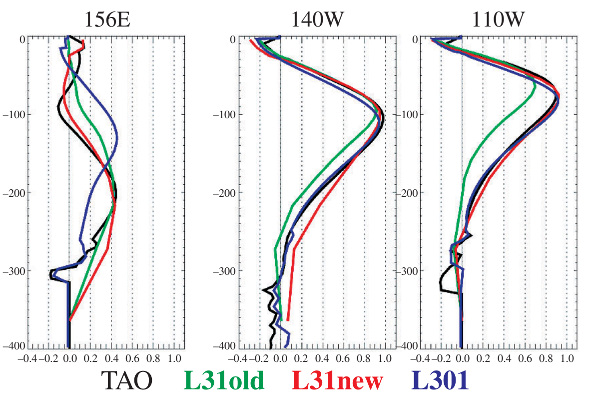


Fig. 1 1992年から2000年までの赤道に沿った緯度圏の平均流れ分布の鉛直断面。Tropical Atmosphere Ocean Project (TAO) での観測値（黒線）、鉛直31層の旧モデルの結果（緑線）、鉛直31層の新モデル（赤線）、鉛直301層新モデル（青線）の結果。

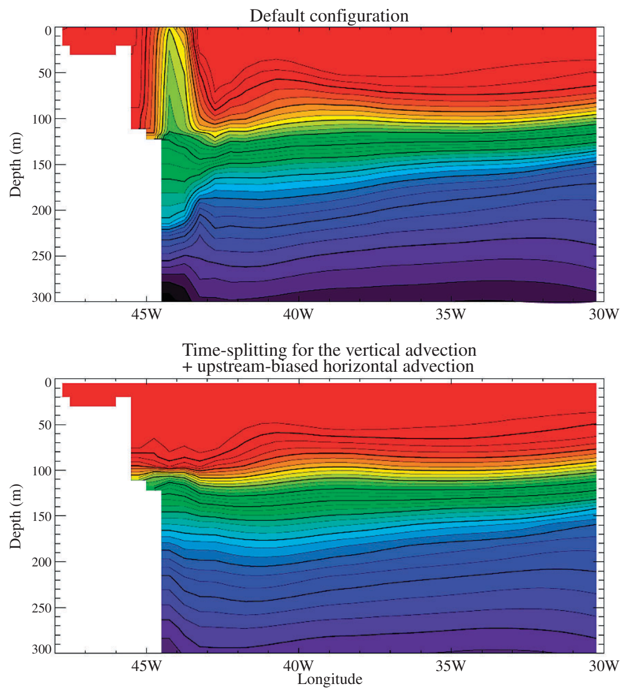


Fig. 2 2週間のスピンアップの後における西大西洋赤道域の鉛直温度分布。

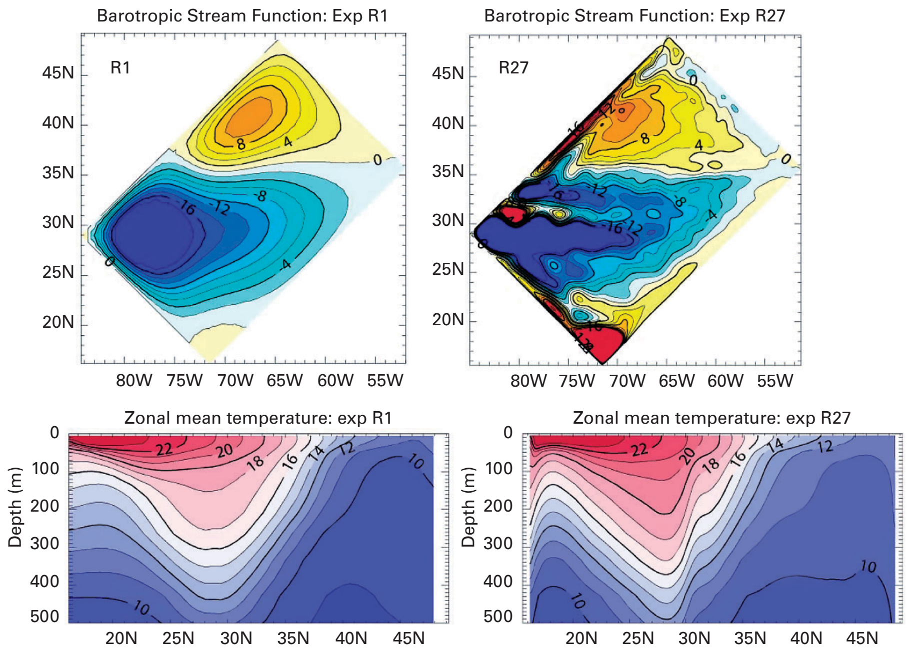


Fig. 3 水平1/27°、鉛直90層(R27)と水平1°、鉛直30層(R1)の実験によって得られたバロトロピック流線関数と温度分布を緯度圏平均値と年平均値で示す。亜熱帯還流の中に2つの還流と18–19°Cモード水が存在する。

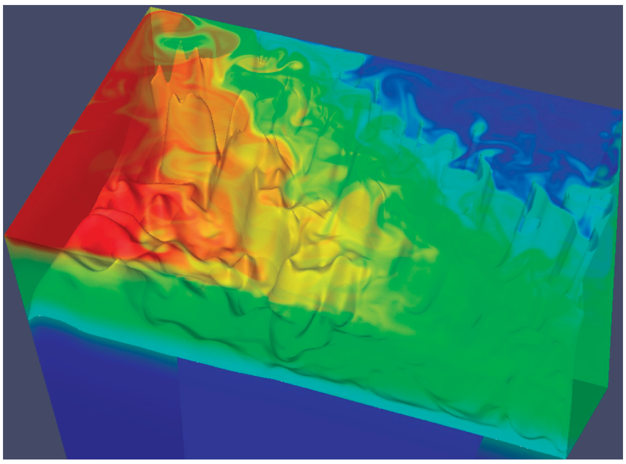

Fig. 4 水平1/27°、鉛直90層の実験(R27)から得られた海表面温度分布と混合層の厚さ分布。

Table 1 8ケースの実験設定の特徴。iso: isopycnalな拡散、両膝:両和声の水平の拡散あるいは消費、Aht0:拡散係数、Ahm0:消費係数、Dt:時間ステップを示す。

| Experiments | Resolution | Vertical layers | Grid points | T | U | Aht0 | Ahm0 | Dt |
|---|---|---|---|---|---|---|---|---|
| R1 | 1° | 30 | 32 × 22 × 31 | iso | hor | 1000 | 100000 | 2h |
| R3 | 1/3° | 30 | 92 × 62 × 31 | iso | bilap | 300 | –10$^{e}$11 | 1h |
| R9 | 1/9° | 30 | 272 × 182 × 31 | iso | bilap | 200 | –5$^{e}$10 | 24mn |
| R9bb | 1/9° | 30 | 272 × 182 × 31 | bilap | bilap | –5$^{e}$10 | –5$^{e}$10 | 24mn |
| R27 | 1/27° | 30 | 812 × 542 × 31 | bilap | bilap | –5$^{e}$9 | –5$^{e}$9 | 5mn |
| R27v | 1/27° | 90 | 812 × 542 × 101 | bilap | bilap | –5$^{e}$9 | –5$^{e}$9 | 5mn |
| R54 | 1/54° | 30 | 1622 × 1082 × 31 | bilap | bilap | –1$^{e}$9 | –1$^{e}$9 | 2mn |