# Impact of Small-Scale Structures on Two Energetic Dynamical Oceanic Regimes

Project Leaders
Patrice Klein Laboratoire de physique des Oceans, IFREMER, France
Hideharu Sasaki The Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology

Authors
Patrice Klein [*1], Bach Lien Hua [*1], Sylvie Le Gentil [*1] and Hideharu Sasaki [*2]
*1 Laboratoire de physique des Oceans, IFREMER, France
*2 The Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology

The big challenge of the next decade for the oceanic sciences is to adopt a multi-scale approach because of the strong non-linearity of the oceanic fluid. This can be undertaken only through numerical simulations with ultra-high resolution. Within this context, the purpose of our projects is to fully explore two energetic dynamical oceanic regimes that have a major impact on the general oceanic circulation: the mesoscale eddy regime at mid-latitudes and the equatorial regime. Expected results will help for the configuration of realistic numerical simulations to be performed in 2006 by the OFES group on the Earth Simulator and they should benefit to future climate models. These studies make use of the Primitive Equations model ROMS (Regional Ocean Modelling System).

**Keywords**: mesoscale oceanic eddies, equatorial dynamics

## 1. Impact of the vertical pump due to oceanic mesoscale eddies at mid-latitudes

### 1.1 Research objectives

As mentioned in the preceding annual report, the purpose is to get new insights on the effectiveness of the vertical velocity field triggered by the mesoscale (30–100 km) eddies and small-scale (2–10 km) structures at mid-latitude (i.e. the vertical pump). This can be done only through numerical experiments using ultra-high resolution that is consistent in the three dimensions since horizontally thin oceanic structures are also vertically thin. Questions that are addressed are: what is the quantitative impact of the effective vertical pump on the restratification of the upper oceanic layers at a basin scale? How do the submesoscale structures trapped near the surface affect the ocean interior? How does the vertical pump affect the 3-D dispersion of all tracer fields?

### 1.2 Results achieved in 2005

During 2005 high resolution simulations of mesoscale eddy turbulence have been successfully performed on the Earth Simulator (Fig. 1). The parameter setting corresponds to energetic regions such as the Antarctic Circumpolar

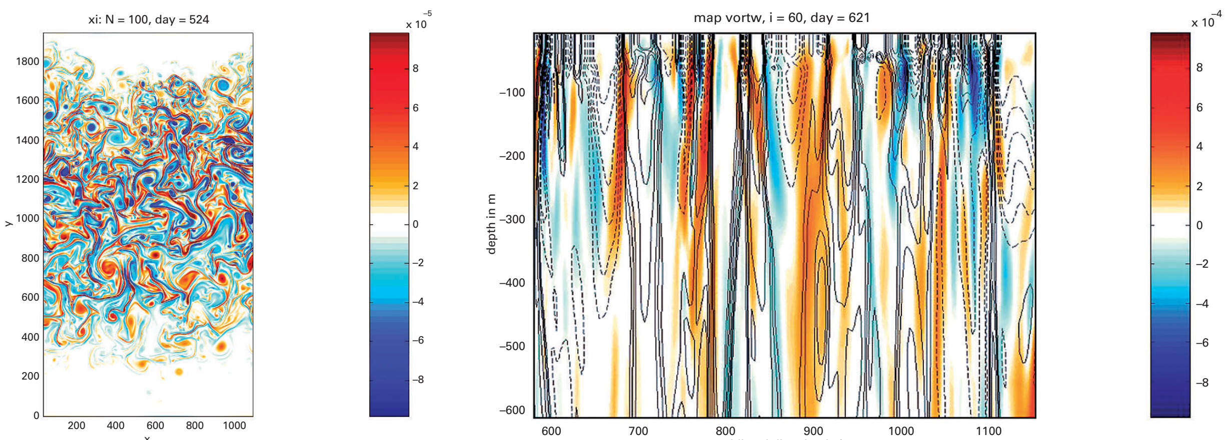


Fig. 1 (left) Relative vorticity field near the surface and (right) vertical section of relative vorticity (contours) superposed to the vertical velocity (color).

Current region. We have activated a tracer equation in order to characterize the effects of the dynamics on the vertical and horizontal exchanges (at a basin scale) of any properties. The highest resolution is 1/100th degree in the horizontal and 200 levels on the vertical.

Results clearly emphasize that the magnitude of this vertical pump is much larger than anticipated. Thus the vertical velocity variance increases by a factor 30 when the resolution increases from 5 km to 1 km. Consequence of this increase is a warming of the oceanic surface layers of nearly one degree Celsius which strongly reinforces previous results ([1]). Furthermore, impacts of the small 3-D scales on the tracer fluxes also explain that the correlation between tracer and relative vorticity is quite much stronger than previously found. Two publications on these results, coauthored by scientists from IFREMER and the OFES group of the ESC, should be submitted in 2006 in peer-reviewed journals.

1.3 Perspectives for 2006–2007

The work proposed is first to confirm the robustness of these results for other mesoscale eddy regimes. The purpose is to quantify the impact of the energetic submesoscale physics on the mesoscale eddy turbulence and in particular on the energy and enstrophy cascades. Furthermore, we intend to force the mesoscale eddy field with a realistic high-frequency wind time series. The objective is to understand how the high-frequency (several hours) winds can accelerate the vertical pump triggered by the mesoscale eddies.

## 2. Dynamics of deep equatorial transport and mixing

2.1 Research objectives

The overall aim is to quantify the contribution of deep equatorial circulation to the meridional cell of the oceanic general circulation, popularized as the "great ocean conveyor" which plays an essential role in the Earth climate system. Despite a good knowledge of surface horizontal transports and of deep convection locations at high latitudes, the deep branch of this meridional cell as well as the locations of deep water upwelling remain to be elucidated. Since in the vicinity of the equator the presence of quite specific dynamics generates a deep circulation, much more intense than at high and mid latitudes, such energetic dynamics are susceptible to cause important vertical mixing ([2]). The deep equatorial circulation can thus be a good candidate to favor upwelling of deep water masses through intense zonal jets, with alternate directions in the vertical. Tracer fields measurements, such as the recent CFCs surveys, suggesting an important dynamical role of the equatorial deep jets in closing the oceanic deep general circulation budget. The overall role played by such deep jets is analogous to that of radiator fins for diffusing heat, but also for transporting tracer fields from one side to the other of oceanic basins inside the equatorial track. The very fine spatial scales of the jets (smaller than 0.75° in latitude and a few hundred meters in the vertical throughout most of the water column) explains why most general circulation models still cannot reproduce them correctly.

Specific questions that are addressed are: Which mechanisms can create alternate zonal jets and what is their role in the oceanic general circulation? Which mechanisms are responsible for mixing of water masses at the equator and for the meridional transport of tracer fields across the equator? Which proportion of the world ocean upwelling can be insured by equatorial deep circulation? The proposed approach is the use of direct numerical simulation at ultra-high resolution in order to resolve the nonlinear interactions between the involved spatial and temporal scales which are quite disparate. This approach is complemented by an analytical rationale of observed instabilities and turbulence cascades as well as a confrontation with observations. Our simulations are in a bihemispheric basin of idealized geometry, centered about the equator and of comparable size either to the Atlantic and Pacific basin's with a resolution of 1/24° in the horizontal and more than 300 levels in the vertical.

2.2 Results achieved by using the Earth Simulator

Numerical solutions have enabled us to identify the main parameters which govern the formation mechanisms of alternate equatorial jets and we have been able to reproduce the very different characteristics of the jets which are observed in the equatorial Atlantic and Pacific oceans.

The very high three-dimensional resolution has been crucial for obtaining our results, in particular for representing the Pacific flow regime (Fig. 2).

Two papers ([3] and [4], based on the results of these simulations, reveal that the temporal variability inside the western boundary layer plays an essential role for determining the spatial characteristics of alternate jets that are created inside the equatorial track. Explicitly, low vertical modes Mixed Rossby gravity waves [5] are excited in the western boundary layer and their subsequent destabilization leads to the formation of vertically alternate-signed zonal jets of high vertical mode.

2.3 Perspectives for 2006–2007

The initial phase concerning the identification of alternate jets formation mechanisms being completed, our next goals concern:

(i) **the quantification of their associated mixing**: numerical simulations in a basin size which is comparable to the Atlantic Ocean will be pursued with a zoom on the deep equatorial circulation inside an equatorial track at 1/24° and 300 levels for multi-decadal duration for the study of tracer

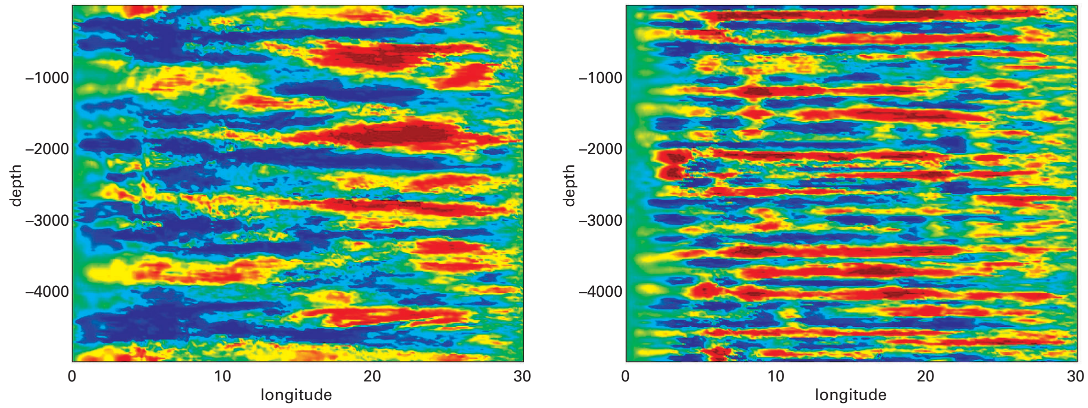


Fig. 2 Longitude-depth section along the equator of the zonal flow velocity for a 40 days (left) and a 74 days (right) variability in the Western boundary layer.

fields distributions.

(ii) **the influence of a realistic stratification** such as the Atlantic equatorial stratification on the depths of the equatorial bifurcation of tracer fields from the western boundary layer.

(iii) **the influence of the longitudinal extent of the basin** (Atlantic vs. Pacific) on the characteristics of the spatial and temporal characteristics of the deep jets that are observed in reality.

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# Impact of Small-Scall Structures on Two Energetic Dynamical Oceanic Regimes

プロジェクトリーダー
Patrice Klein　フランス国立海洋開発研究所（IFREMER）
佐々木英治　海洋研究開発機構　地球シミュレータセンター

著者
Patrice Klein *1，Bach Lien Hua *1，Sylvie Le Gentil *1，佐々木英治 *2
＊1　フランス国立海洋開発研究所（IFREMER）
＊2　海洋研究開発機構　地球シミュレータセンター

海洋は流体として強い非線形があるために、小さいスケールから大きいスケールまで同時に取り扱うマルチスケールアプローチが必要であり、その研究は超高解像度シミュレーションによって可能になる。本研究プロジェクトでは、海洋モデルROMS（Regional Ocean Modelling System）を用い、中緯度の中規模渦や赤道域のDeep Jetsを対象に、超高解像度シミュレーション研究を行っている。その研究成果は将来の気候モデルへの貢献となると考えられる。

中緯度の中規模渦を対象としたシミュレーションでは中規模渦やさらに小さなスケールの構造と関係のある鉛直流が表層の温度に影響を及ぼす事、さらに下層からのトレーサフラックスを大きくする事を捉え、それらの現象は渦度場と関係がある事を示した。今後、小さなスケールの構造が中規模渦に与えるインパクトを定量的に示すとともに、より現実的な高周期の風応力を海面に与えて鉛直流の変化を研究する予定である。

赤道域では東西方向の流れが鉛直方向に交互に重なるように分布するDeep Jetsが存在するが、海水の湧昇域に存在するその生成メカニズムや混合などへの影響について不明な点が多い。本研究プロジェクトでは、超高解像度シミュレーションによってのDeep Jetsを再現することに成功し、西岸での変動の時間スケールがDeep Jetsの鉛直方向の空間スケールを決定する主なパラメータであること、西岸の小さな鉛直モードの混合ロスビー波が東に伝播し不安定になり相対的に大きな鉛直モードのDeep Jetsとなることを示した。今後は大西洋におけるDeep Jetsによるトレーサの分布に対する影響や海盆の東西スケールの違いによる影響について研究する予定である。

キーワード：mesoscale oceanic eddies, equatorial dynamics