Impact of Small-scale Structures on Two Energetic Dynamical Oceanic Regimes

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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 project 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. Results will help for the configuration of realistic numerical simulations to be performed in 2007–2008 by the OFES group on the Earth Simulator and also 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. Dynamics of mid-latitude eddy turbulence and mixing

1.1 Research Objectives

The mid-latitude oceanic eddy regime is characterized by strongly interacting mesoscale eddies (30–100 km) and resulting smaller scale structures (<10 km). The key dynamical impacts of this regime are to drive the meridional heat fluxes in oceanic basins (between the equator and high latitudes), to catalyse the air-sea interactions at mid-latitudes and to trigger a powerful vertical pump that links the oceanic surface layers to the deep interior. Assessing these dynamical impacts at a basin scale can be done only using ultra-high resolution that is consistent in the three dimensions.

1.2 Results achieved in 2006

High resolution simulations (1/100th degree in the horizontal and 200 vertical levels) of mesoscale eddy turbulence have been successfully achieved on the Earth Simulator. Some simulations include realistic high-frequency atmospheric forcings and the activation of a tracer equation.

Three classes of results have been obtained. First the existence of a specific surface dynamical mode (with a $k^{-5/3}$ velocity spectrum), highlighting the strong efficiency of

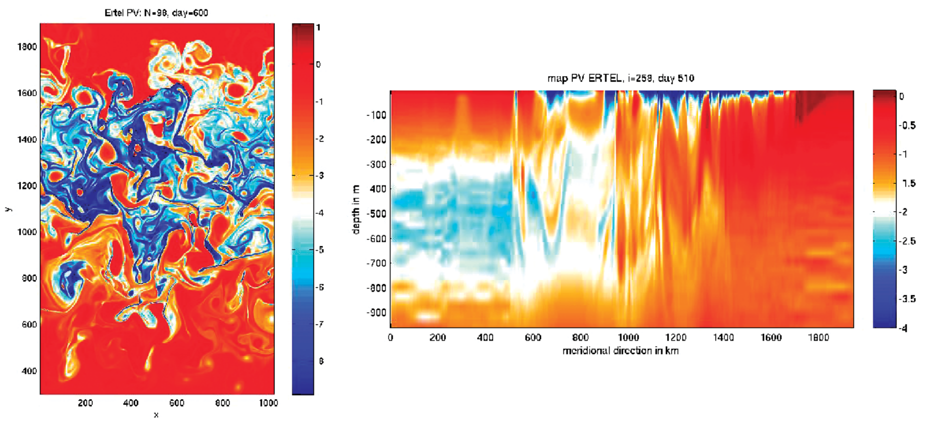

Fig. 1 Ertel Potential Vorticity surface map (left) and vertical section (right) highlight the strong dynamical connection between the surface and the interior (down to 1000m).

small (10–30 km) scales, has been confirmed. Its characteristics have led to develop new methods for the interpretation of satellite data. Second, the high-frequency wind energy has been found to propagate much deeper into the oceanic interior (reaching depth as large as 3000–4000m) where its characteristics make it potentially available for mixing through the parametric subharmonic instability. Third, the small horizontal scales trigger a vertical pump much larger than anticipated whose consequence is a warming of the oceanic surface layers of nearly one degree Celsius. This powerful vertical pump is also a key factor for the link between the oceanic surface layers to the interior and therefore for the ventilation of the main thermocline (as illustrated on Fig. 1).

These results have been reported in a first publication ([1]) and in an invited lecture at the 2006 AGU fall meeting ([2]). Two other publications will be submitted in 2007 in peer-reviewed journals.

1.3 Perspectives for 2007-2008

The work proposed for the fiscal year 2007–2008 is:

(1) to confirm the robustness of these results for other mesoscale eddy regimes;

(2) to quantify the impact of the energetic sub-mesoscale physics on the eddy turbulence equilibrium and meridional heat fluxes;

(3) to fully examine the impact of high-frequency wind forcings on the small-scale mixing in the deep interior.

2. Dynamics of deep equatorial transport and mixing

2.1 Research Objectives

The closure of the mass budget in the global ocean circulation is a fundamental and still open problem in Earth climate system. In particular, the dynamics of the resupply to the abyssal oceans with potential energy lost through polar deep water formation is poorly understood. Equatorial deep zonal jets are a significant reservoir of kinetic energy, and their transport reaches about 2/3 of the thermohaline circulation. For these reasons, the equatorial regions are thought to be preferential places for abyssal mixing: for instance tracer fields measurements such as the recent CFCs surveys, suggest an important dynamical role of the equatorial deep jets in closing the oceanic deep general circulation budget. Overall the deep equatorial jets play an analogous role to radiator fins for diffusing heat, but also for transporting tracer fields from one side to the other of oceanic basins inside the equatorial guide.

Specific questions that are addressed are: Which mechanisms can create alternating-signs deep equatorial zonal jets and what is their role in the oceanic general circulation? Which mechanisms are responsible for mixing of water masses at the equator?

2.2 Results achieved on the Earth Simulator

The approach uses direct numerical simulations at very high resolution in order to resolve the nonlinear interactions between a large range of spatial and temporal scales. 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. 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.

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 guide. Explicitly, low vertical modes Mixed Rossby gravity waves are excited in the Western boundary layer and their subsequent destabilization leads to the forma-

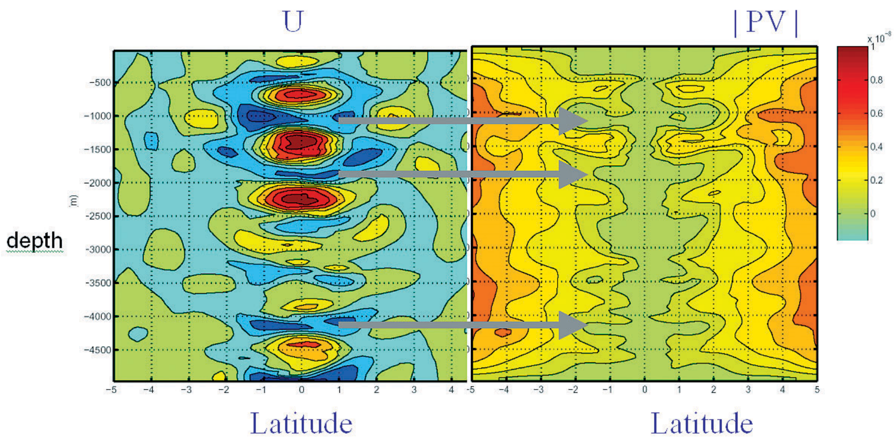

Fig. 2 Depth-latitude sections of zonal velocity (left) and Ertel Potential Vorticity (right) in the immediate vicinity of the equator.

tion of vertically alternate-signed zonal jets of high vertical mode. These results were presented in an invited Lorenz lecture at the December 2006 AGU in San Francisco [5].

2.3 Perspectives for fiscal year 2007–2008

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 decadal duration for the study of tracer fields distributions. Figure 2 shows instantaneous depth-latitude sections of the deep equatorial jets and the corresponding Ertel Potential vorticity distribution (active tracer field), revealing a strong impact of the deep equatorial jets on the vertical and meridional mixing of Ertel PV.

(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.

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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、理想的な条件を用いた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や、OFESを用いた現実的シミュレーションの設定に役立つと期待される。

中緯度の中規模渦を対象とした超高解像度シミュレーションでは、以下の3つの成果が得られた。1) 10–30kmの小さなスケールで海表面に特徴的な力学モードがみられる。2) 高周波成分の風のエネルギーは海洋内部の深層まで(3000–4000m) 伝播する。3) 小さなスケールの現象が予想以上に鉛直方向混合 "Vertical Pump" を促進し、海洋の表層をほぼ1°C暖め、"Vertical Pump" が海洋の表層と内部の結合の鍵になる1つの要因であることが示された。今後は、渦乱流の平衡状態と子午面熱フラックスに対する小さなスケール現象のインパクトの定量化、高周波成分の風が海洋内部の混合に及ぼすインパクトの研究を予定している。

赤道域のDeep Jetsを対象とした超高解像度シミュレーションでは、生成メカニズムを支配するパラメータを明らかにし、大西洋と太平洋の異なる性質のDeep Jetsを再現した。その生成メカニズムは、西岸で励起された混合ロスビー波が不安定化し、鉛直高周波の東西方向に折り重なるDeep Jetsを引き起すというものである。また、Deep Jetsの鉛直空間分布を決定するパラメータは、西岸における時間的変動であることを把握した。今後はDeep Jetsによる混合の定量化、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について研究を進める予定である。

キーワード：mesoscale oceanic eddies, equatorial dynamics