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

Project Leaders

Patrice Klein Laboratoire de Physique des Océans, 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, Guillaume Roullet *1, Mark Fruman *1, Claire Menesguen *1 and Hideharu Sasaki *2

*1 Laboratoire de Physique des Océans, IFREMER

*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 impact of the small scales on the ocean circulation through the nonlinearities of the oceanic fluid. This can be undertaken only by performing numerical simulations with ultra-high resolution. Within this context, the purpose of our project is to fully explore two energetic nonlinear 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 the future by the ESC 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 circulation is characterized by the presence of energetic mesoscale eddies (30–100 km) that are known to drive a large part of the meridional heat fluxes (between the equator and high latitudes). Little is known however on the vertical velocity field they induce (mostly because of the lack of resolution), as well as its impact on the vertical transfers of any properties (such as nutrients) and on the strength of the thermohaline circulation. Purpose of this project is to better estimate - as well as to quantify the impacts of - the vertical velocity field associated to a turbulent eddy field in a large domain by using a spatial resolution never attained so far.

1.2 Results achieved in 2007

High resolution simulations (1/100th degree in the horizontal and 200 vertical levels) of mesoscale eddy turbulence, performed on the Earth Simulator, have revealed a strong impact of the small scales (<10 km) that was never suspected and thus never reported so far. The principal new mechanism is the efficient frontogenesis associated to the small-scale structures. Three classes of results have been confirmed and strengthened in 2007 and have incited further studies.

First these small scales, generated and organized near the surface by mesoscale eddies, have a strong impact on the eddies themselves and drive a very large part of the vertical transfers in the first 300–400 m below the surface. The detailed knowledge of this new surface dynamics has furthermore led to develop with success new methods to retrieve the 3-D circulation in the first 300–400 m using high-resolution satellite data (such as SST and the SAR data).

Second, the vertical propagation of the high-frequency wind energy is strongly catalyzed by these small scales leading to a significant mixing at a 3000–4000 m depth (highly needed for the thermohaline circulation) [1]. The potential of these results has been further explored with success in a coupled ocean-atmosphere model by the ESC [2].

Third, results of last year about the impact of the small scales on the warming of the oceanic surface layers of nearly one degree Celsius have been subsequently deepened. The mechanism involved - related to the energetic vertical pump triggered by the small scales - is also the one that links the surface dynamics to the interior dynamics. Some work has still to be done to rationalize this link, which is a key factor for the ventilation of the main oceanic thermocline.

Seven publications [3–9] related to this project have been accepted in 2007 in referee journals. Some of them are coauthored by scientists from the ESC. Four conferences have been given in scientific international meetings.

1.3 Perspectives for the fiscal year 2008-2009

In the coming year our work will be:

(1) to further rationalize the link between the upper oceanic layers and the deep interior through the vertical velocity field. Activation of a tracer field in the simulations will help to decipher and quantify this link;

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

(3) to extend the results on the vertical propagation in the deep ocean interior by using results from a coupled atmosphere-ocean model. This will be done in cooperation with the ESC.

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, 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 have been co-authored by scientists from IFREMER and from the ESC (d'Orgeville et al. 2007 [10] and Hua et al. 2008 [11]). These papers that are based on the results of these simulations, reveal that the temporal variabil-

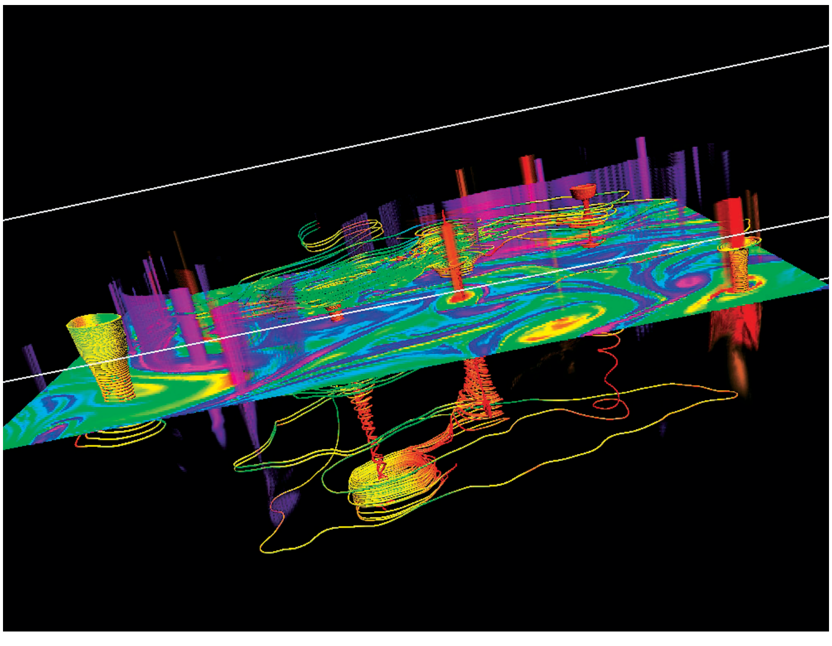

Fig. 1 Relative vorticity 2-D map (cyclonic (anticyclonic) structures in red (magenta)) and 3-D lagrangian trajectories of particles initially seeded in eddies (where they remain trapped) and small-scale filaments (from where they can cover long horizontal distance).

ity inside the Western boundary layer plays an essential role in determining the spatial characteristics of alternate jets that are created inside the equatorial track. Explicitly, low vertical modes Mixed Rossby gravity waves 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.

The initial identification of alternate jets formation mechanisms being completed, we next studied

(1) The quantification of their associated mixing: numerical simulations in a basin size which is comparable to the Atlantic Ocean have been performed with a zoom on the deep equatorial circulation for the study of tracer fields vertical dispersion. Enhanced vertical mixing of the tracer field inside the equatorial track have been consistently observed, with the formation of pancake structures in the density field, characteristic of "**layering** "with characteristic vertical scales of about 50 m (Menesguen et al. 2008 [12]) corresponding to the black contours in Fig. 2, overlayed on the zonal velocity field with eastward and westward jets.

(2) 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 and the influence of the horizontal component of the Earth rotation on the jet dynamics. Both effects have a non-negligible effect on the depth of eastward jets positions such as the CFC jet which is observed to be semi-permanent in the Atlantic (Fruman et al., 2008 [13]; Bunge et al., 2008 [14]).

2.3 Perspectives for fiscal year 2008–2009

In the coming year, our work will concern

The quantification of equatorial lateral and vertical mixing: further numerical simulations with tracers will be pursued in order to better capture the characteristics of vertical mixing. Specific attention will be given on vertical resolution: primitive equations simulations will be performed with a number of vertical grid points varying between 500 to 1000 levels in the vertical to quantify and attribute mixing efficiency to the various vertical scales present in the flow (i.e. the equatorial deep jets scale (300–500 m) and the 50m-scale layering). Furthermore, collaborative work with H.Sasaki of ESC and K.Richards of IPRC will be initiated on the influence of layering on lateral mixing properties in the upper layers of equatorial flow.

Intercomparison with nonhydrostatic dynamics: the above primitive equations results will be intercompared with non-hydrostatic simulations (of shorter duration span) in collaboration with H. Aiki of FRCGC to assess the different time characteristics of layering dynamics.

References

[1] Klein P., E. Danioux, G. Roullet, S. Le Gentil and H. Sasaki, "Wind ringing of the deep mid-latitude ocean at 2f frequency", to be submitted to J. Phys. Oceanogr., 2008.

[2] Komori, N., W. Ohfuchi, B. Taguchi, H. Sasaki, and P. Klein, "Deep ocean inertia-gravity waves simulated in a high-resolution global coupled atmosphere-ocean GCM" Geophys. Res. Lett., 35(4), L04610, doi:10.1029/2007GL032807, 2008.

[3] Capet X., Klein, P., Hua B.L., G. Lapeyre, and, J. McWilliams, "Surface kinetic and potential energy transfer in SQG dynamics", J. Fluid Mech., In press, 2008.

[4] Klein, P., Hua B.L., G. Lapeyre, X. Capet, S. LeGentil and H. Sasaki, "Upper ocean dynamics from high 3-D

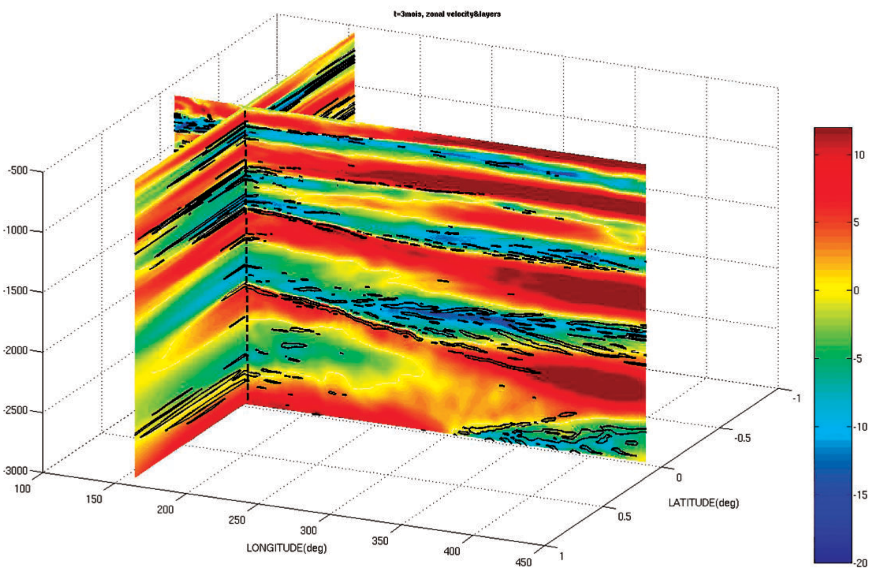

Fig. 2 Layering in density (black contours) superposed on zonal velocity field (color field).

resolution simulations", J. Phys. Oceanog., in press, 2008.

[5] Klein P., "High-frequency winds and eddy resolving models", AGU monograph: "Eddy-Resolving Ocean Modelling", in press, 2008.

[6] Danioux E., P. Klein and P. Riviere, "Propagation of wind energy into the deep ocean through mesoscale eddies. J. Phys. Oceanogr., in press, 2008.

[7] Danioux E. and P. Klein, "A resonance mechanism leading to wind-forced supra-inertial motions with a 2f frequency", J. Phys. Oceanogr., in press, 2008.

[8] Isern-Fontanet J., G. Lapeyre, P. Klein, B. Chapron and M. Hecht, "Ocean dynamics reconstruction from surface information", J. Geophys. Res., in press, 2008.

[9] Le Traon P.Y., P. Klein, B.L. Hua and G. Dibarboure, "Do altimeter data agree with interior or surface quasi-geostrophic theory", J. Phys. Ocenogr., in press, 2008.

[10] d'Orgeville M, B.L. Hua and H. Sasaki, "Equatorial Deep Jets triggered by a large vertical scale variability", J. Mar. Res.,65, 1–25, 2007.

[11] Hua B.L., M. d'Orgeville, C. Menesguen, M. Fruman, P. Klein, R. Schopp and H. Sasaki, "Destabilization of Mixed Rossby Gravity waves and equatorial zonal jets formation", revised for J. Fluid Mech., 2008.

[12] Menesguen, C., Hua, B.L., and Schopp, R. "Intermittent mixing in equatorial deep jets as a consequence of inertial instability", in preparation, 2008.

[13] Fruman, M.D, Hua, B.L. and Schopp, R., "Eastward equatorial jet formation in the aftermath of MRG destabilization", in preparation, 2008.

[14] Bunge, L. C. Provost, B.L. Hua and A. Kartavtseff, "Variability at intermediate depths at the equator in the Atlantic ocean in 2000-2005: equatorial deep jets and low-frequency meridional flows", J. Phys. Oceanog in press, 2008.

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

プロジェクトリーダー
Patrice Klein　Laboratoire de Physique des Océans, IFREMER, France
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], Guillaume Roullet[*1], Mark Fruman[*1],
Claire Menesguen[*1], 佐々木英治[*2]
＊1　Laboratoire de Physique des Océans, IFREMER, France
＊2　海洋研究開発機構　地球シミュレータセンター

海洋において微細構造現象が大規模循環場へ及ぼすインパクトとそのメカニズムを明らかにするために実施した、1）中緯度の中規模渦現象、2）赤道域のDeep Jetsを対象とした超高解像度海洋シミュレーションの結果を紹介する。2007年度は、中緯度域における高周波の風による深層へのエネルギー伝播、赤道域の深層における鉛直混合に関連する層状構造のシミュレーションに成功し、そのメカニズム研究を行った。

キーワード：mesoscale oceanic eddies, equatorial dynamics