MODIFICATION OF GYRE CIRCULATION BY SUB-MESOSCALE PHYSICS

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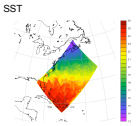
INTRODUCTION

The aim of this study is to provide a better understanding of the impact of sub-mesoscale physics on the large scale circulation and on the large scale thermo-haline equilibrium.

This is addressed by comparing mean characteristics of basin-scale, seasonally-varying, subtropical and subpolar gyres in a suite of numerical experiments varying in horizontal resolution (up to 2 km) and, accordingly, in subgrid scale mixing.

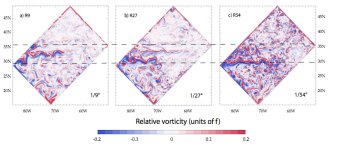
1- MODEL & CONFIGURATION



Idealized model configuration, representing some aspects of the western North Atlantic (or North Pacific).

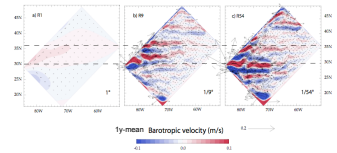
- ***NEMO***: z-coordinate free-surface primitive equation model.
- Rotated double-gyre configuration, (3000 × 2000 × 4) km domain with uniform horizontal resolution on the β-plane and 30 vertical layers.
- Analytical, zonal forcings (wind stress, heat and salt flux) which vary sinusoidally between winter and summer extrema.
- 4 simulations with increasing horizontal resolution:
  R1 = 1° R9 = 1/9° R27= 1/27° R54 = 1/54°
- Simulations carried out for 100 years in order to reach equilibrium of intermediate waters. Model means are defined as time averages over the last 10 years.

2- EMERGENCE OF SUBMESOSCALE WITH RESOLUTION



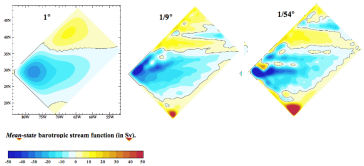
Snapshots of relative vorticity at the surface show the explosion of the number of eddies and the emergence of energetic sub-mesoscale turbulence with increasing resolution.

3- EMERGENCE OF ZONAL JETS



A significant impact of the sub-mesoscale concerns the intensification of zonal jets with directions alternating with latitudes and mean speeds of several cm/s. The jets are absent in R1 but occupy the whole domain in R9 and are particularly intense close to the western boundary. They are further enhanced in R54, particularly in the subtropical gyre.

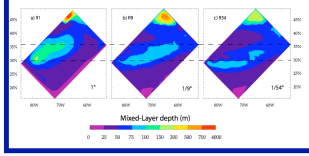
4- MODIFICATION OF BAROTROPIC CIRCULATION



At coarse resolution, the 10y-mean barotropic circulation consists of a distinct double-gyre structure in agreement with the Sverdrup linear theory. The western boundary current (WBC) deflects at the zero wind stress curl (~36°N).

At higher resolutions, the barotropic circulation is intensified and strongly deviates from the typical two-gyre structure. The WBC deflects further south (~30°N in R54). A second eastward jet emerges in the mean circulation (located where the wind stress reverses). Cyclonic recirculation gyres appear in the the subtropical region. A weak anticyclonic gyre appears in the eastern subpolar region. These modifications arise from the presence of the alternative zonal jets.

5- MODIFICATION OF MIXED-LAYER DEPTH

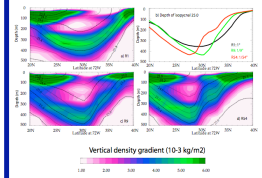


Two important discrepancies in the MLD appear when mesoscales and submesoscales are explicitely taken into account:

-Decrease of the intensity of deep-convection in the north

-Shallowing of the MLD at mid-latitudes (by 20-30m on average between R9 and R54)

6 - MODIFICATION OF VERTICAL DENSITY STRUCTURE & STRATIFICATION

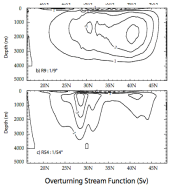


The vertical density structure is characterized by a bowl shape of isopycnals in the subtropical gyre and outcropping in the north. Resolution modifies both the isopycnal depth and the isopycnal slope. The strenghtening of the WBC from R1 to R54 is associated with the steepening of the isopycnal slopes. In addition, deeper isopycnals in the subtropical gyre and shallower isopycnals in the subpolar gyre correspond to a southward shift of the bowl shape.

In the internal thermocline, stratification increases by more than a factor of two between R9 and R54. The opposite result is found between R1 and R9.

In the mode waters, stratification increases progressively from R1 to R9 to R54.

7 - MODIFICATION OF THE MERIDIONAL OVERTURNING CIRCULATION



In all simulations, the major feature of the MOC is a primary cell which comprises a northward flow above 1000m, a sinking flow at around 45°N and a southward return flow at depth.

In R54, the transport associated to the MOC in the north (centered at 41°N) is strongly reduced compared with R9 and is associated with a smaller vertical extent. This is the response to the decrease of deep-wintertime convection. On the other hand, the strong reinforcement of the WBC and the associated alternating zonal jets makes the secondary circulation at mid-latitudes to be much stronger.

SUMMARY

We have computed long integrations of an idealized double-gyre circulation at sub-mesoscale resolving resolution (2 km) that allows us to demonstrate the effect of sub-mesoscale dynamics on an equilibrated, fully prognostic density field.
When horizontal resolution is increased from eddy-resolving to sub-mesoscale resolving, a strongly turbulent eddy field emerges with the consequence of significant modifications of the model mean fields. One original aspect of our simulations consists in the emergence of a regime of zonal jets. Another original aspect is the restratification of the upper layers when submesoscales are taken into account. This much reduces the deep convection in the Northern part of the domain. Furthermore, we find that the wind-driven subtropical gyre is deeper at high resolution, due to the rectifying effect of eddy fluxes. Stratification does not vary monotonically as the model grid is refined: a stratification decrease within the internal thermocline is observed from coarse to mesoscale resolutions, but taking into account the submesoscales leads to a significant stratification increase. Impact of submesoscales appear to reduce the Meridional Overturning Circulation in the North - because of the restratification of the upper layers - and to locally intensify it at the latitudes of the western boundary current - because of the emergence of the zonal jets.

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