IMPACTS OF MESOSCALE VERTICAL MOTION ON NITRATE DISTRIBUTION

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1 Introduction: importance of vertical motion

Vertical motion associated with **mesoscale** and **sub-mesoscale** oceanic features is of fundamental importance to the exchanges of heat, fresh water and biogeochemical tracers between the surface and the ocean interior. Unfortunately, direct measurements of the vertical velocity are difficult to obtain for typical values (order 10's m/day). Various indirect methodologies have thus been proposed to estimate vertical velocity from observed density and geostrophic velocity fields. The most used technique is based on the solution of the quasi-geostrophic (QG) Omega equation (Tintoré *et al.* 1991; Buongiorno Nardelli *et al.* 2001; Pascual *et al.* 2004; Ruiz *et al.* 2009, Benítez-Barrios *et al.* 2011).

2 Objectives & Context

The objective of this study is to estimate and analyze vertical exchanges associated with mesoscale dynamics from an observational data set.

(1) Apply QG diagnostics to existing databases (model and observation based).

(2) Investigate the influences of QG vertical exchanges on several oceanic tracers using a Lagrangian particle-tracking code (Mason *et al.* 2012)

3 Data & Methods

ARMOR3D reanalysis

3D fields of **temperature**, **salinity** and **dynamic height** derived from an observational-based product that combines **satellite** (SST and altimetry) and **in-situ data** (Argo profiling floats, XBT, CTD and moorings) (Mulet *et al.* 2012)

Preprocessing

Vertical interpolation: 10:10:1000 m

Horizontal interpolation: regular grid (1/3º)

Conversion of data files to be ingested into the fortran code for the estimation of vertical velocity

QG vertical velocities: Omega equation. Vector Q formulation

$$f^2\frac{\partial^2\omega}{\partial z^2}+\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\left(N^2\omega\right)=\nabla_h Q \qquad R_L=\frac{U}{fL}\ll 1$$

$$Q=2\left[\frac{\partial V}{\partial x}\frac{\partial U}{\partial z}+\frac{\partial V}{\partial y}\frac{\partial V}{\partial z}\right]=2\left(\frac{\partial U}{\partial x}\frac{\partial U}{\partial z}+\frac{\partial U}{\partial y}\frac{\partial V}{\partial z}\right)$$

Hoskins *et al.* (1978)

Where (U,V) are the geostrophic velocity components, *N* Brunt-Väisälä frequency and *f* the Coriolis parameter.
By assuming a BC for ω and from a 3D snapshot of the density field, the vertical velocity can be inferred.
First tests:
W=0 at the upper, lower and lateral boundaries
N is considered to vary only in the vertical: N = N(z)

3D velocity re-analysis

Period: 2002-2010
Temporal resolution: Weekly
Horizontal resolution: 1/3º
Vertical levels: 10:10:1000
Domain: Southeastern Pacific

Particle tracking simulation

Period: 2009
Number of floats: 40000
Outputs (particle position): stored every day
Domain: Eastern South Pacific

Auxiliary Data

Nitrate from World Ocean Atlas biogeochemical climatology (WOAPISCES):
See *www.romsagrif.org* for details.
Temporal resolution: monthly
Spatial resolution: 1°

Lagrangian Simulation:

A Lagrangian drifter-tracking code is used to simulate water parcel trajectories using a 3D velocity field. The tracking code is ROMS Offline (Roff, Mason *et al.* 2012). A total of 40000 floats are released randomly between 150-250 m depth within our region of study (see Fig. 1). A group of simulations has been carried out for every week of 2009, during 30 days (Chelton *et al.* 2011a).

Post-Simulation objective analysis:

With the nitrate distribution of the particles, we interpolate the data into a regular grid using optimal interpolation (Gomis *et al.* 2000). The horizontal resolution is 1/3º and the correlation scale used is 100 km.

4 Sensitivity analysis

Nitrate distribution with w = 0 (RNUV) — **Nitrate distribution with w = wqg (RNUVW)**

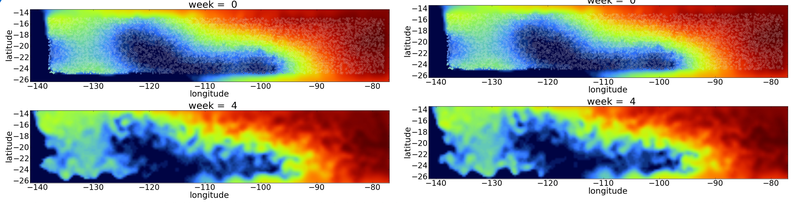


Figure 1: Impact of horizontal (left) and total (horizontal + vertical, right) velocity on nitrate distribution at 200m. Week 0 corresponds to the initial date of the first simulation (31/12/2008) where 40000 particles have been randomly released. The position and the initial value of the particles are plotted in the upper panel. The fields are obtained with the objective analysis described in the previous section.

Vertical section of nitrate distribution

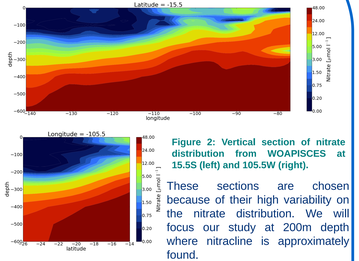


Figure 2: Vertical section of nitrate distribution from WOAPISCES at 15.5S (left) and 105.5W (right).

These sections are chosen because of their high variability on the nitrate distribution. We will focus our study at 200m depth where nitracline is approximately found.

The initially smooth nitrate field is modified by the horizontal and vertical velocities (Fig. 1), small structures are formed during the 4 weeks. We can see small differences due to the vertical contribution.

To better see the differences and better quantify the influence of horizontal and vertical motions we compute the anomalies: RNUV with respect to the initial field gives an indication of the **contribution of horizontal velocities** (**AHC**); RNUVW with respect to the initial field gives an indication of the contribution of total velocities; and by subtracting the horizontal anomalies to the total anomalies, we obtain the **contribution of the vertical velocities** (**AVC**).

In previous studies we showed that the vertical velocity contribution is 30% of the total contribution.

To make a statistical support to our study, we computed the **root mean square for the AHC** (**rmsH**) and **for the AVC** (**rmsV**). This analysis has been performed for 3 different domains, each one smaller than the previous one in order to avoid boundary problems; for three different correlation scales (100, 110, 120 km), and for 10 simulations, for the purpose of demonstrating the robustness of our method.
In table 1 the mean of the rmsH and rmsV for every domain and correlation scale are shown.

$AHC = RNUV_{Wi4} - RNUV_{Wi0}$
$ATC = RNUVW_{Wi4} - RNUVW_{Wi0}$
$AVC = ATC - AHC$

$rmsH = rms\ (AHC)$
$rmsV = rms(AVC)$

rmsH	L = 100km	L = 110km	L = 120km
Domain 1	0,950	0,927	0,912
Domain 2	0,929	0,912	0,897
Domain 3	0,977	0,961	0,945

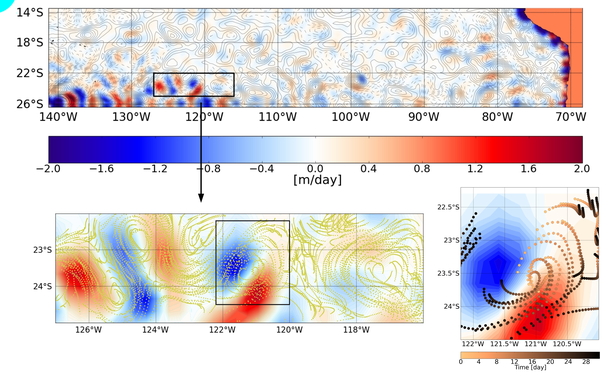
rmsV	L = 100km	L = 110km	L = 120km
Domain 1	0,292	0,259	0,229
Domain 2	0,334	0,306	0,277
Domain 3	0,300	0,264	0,233

Domain 1: 15S – 25S, 78W – 138W
Domain 2: 16S – 24S, 79W – 137W
Domain 3: 16S – 23S, 79W – 136W

Table 1: rmsH (left) and rmsV (right) for different domains and correlation scales

5 Studies / Illustrations

Southeast Pacific



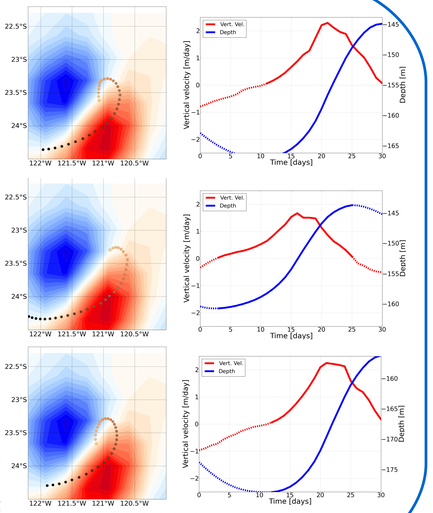


Figure 3: Region of study (Chelton *et al.* 2011a). Vertical velocity with dynamic height contours at 200m depth averaged for the 5 weeks of simulation (31/12/2008 – 28/01/2009). Bottom left zoom shows the floats trajectories during the 30 days of simulation in a region with high vertical velocity. Bottom right zoom shows one specific eddy with the trajectories of the upwelling floats.

In order to demonstrate the importance of the vertical velocity on the nitrate distribution, a detailed study has been performed for the first simulation. If we consider a specific region of high vertical velocity, we can see how the floats are distributed in the horizontal and in the vertical. In figure 4 is shown the relation between the vertical velocity and the upwelling of the floats. When the vertical velocity is positive (continuous line), an upwelling of the floats is produced. This displacement can be from a few meters to 20m. It demonstrates the importance of the vertical velocity in the emigration of water parcels and their properties, including nitrate concentration.

Figure 4: Three examples of trajectories floats. Spatial and temporal interpolation have been done for the weekly QG vertical velocity computed with Omega Equation in the time and position of each float.

6 Summary

An study of the influence of vertical velocity on nitrate distribution has been carried out in the Southeast Tropical Pacific for 4 weeks and at 200m depth. A Lagrangian Simulation has been used to analyze the distribution of 40000 particles within the region of study, with initial nitrate concentrations taken from WOAPISCES. With this distribution, an objective analysis has been carried out to analyze the influence of horizontal and vertical velocities on the nitrate distribution. In previous studies we concluded that vertical velocities account for approximately 30% of the change in distribution for the simulation at 200m depth. In this study we can conclude that the objective analysis is robust enough because the rms for the AVC and for the AHC don't have significant changes in different domains and in different correlation scales.
To better see the influence of the vertical velocity on the water parcels distribution, and in their passive properties, we have studied the case of one eddy and the trajectory of 3 floats that cross it. It is obvious the relation between positive vertical velocity and upwelling of floats.

7 Future work

- To investigate the potential impact of QG velocities on primary production (nitrate, chlorophyll, etc.) at different depths and zones (Gulf Stream and Agulhas current) to make the study statistically more robust.
- The eddy identification and tracking tool proposed by Chelton *et al.* (2011b) will be used to detect the position of eddies from the surface ARMOR3D fields of sea surface height.

8 Acknowledgments

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