A multi-platform experiment for understanding coastal mesoscale and sub-mesoscale processes

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Objectives

GENERAL

Characterization of coastal fronts and mesoscale dynamics combining multi-sensor data

SPECIFIC

- To develop methods for the combination of different sensors
- To estimate vertical velocities and derived variables to study coastal dynamics
- To investigate the limitations and potential improvements of both altimetry and glider in the coastal area
Outline

- Area of Study
- Glider vs altimetry general characteristics
- SINOCOP
- Vertical velocity: Alboran Sea Missions
- Horizontal velocity: Balearic Sea Missions
- Summary & Future Work
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**Area of study**

**11 glider missions** from July 2007 to December 2009 in the WMed along altimeter tracks

**Glider Missions Background**

**ENVISAT:**
- Balearic Sea: T-773. 6 missions (every 70 days)

**JASON-1/2:**
- Balearic Sea: T-70 (August 2008).
- Alboran Sea: T-172 (July 2008).

**JASON-1 (new orbit):**

5500 full CTD casts + oxygen, chlorophyll, turbidity
The Mediterranean Sea can be considered as a reduced scale ocean laboratory, where processes are characterized with smaller scales than in other oceanic regions.

Glider missions perpendicular to the main features of the basin

From Bouffard et al. (2010, in revision)
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**ENVISAT (773) /Jason 1-2 (70,172)**

- **Variable:**
  - *(M)SLA and along track SLA (1Hz / 20Hz)*
  - MDT: Rio et al. 2007 (ADT = SLA + MDT)

- **Horizontal resolution**
  - Gridded: 1/8°, 1Hz ~ 7km, 20Hz ~ 350m

- **Vertical resolution**
  - NO (surface information)

**Glider**

- **Variables:**
  - P, T, S, oxig., chl., turb.
  - Depth averaged absolute current (GPS)

- **Horizontal resolution:**
  - GPS: 6km, others: 300 m / 1.1 km

- **Vertical extension:**
  - 10-180 m /600 m (SINOCOP)

**Prob in coastal zone**

**Complementary tools**

**Ref. Level issue**
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**Specific objective**

To study **mesoscale and sub-mesoscale** processes of a coastal front using a **multi-sensor** observational approach.

**Observations**

Gliders, drifters, standard CTDs together with remote sensing (**altimetry**, SST and ocean color).

*From Pascual al. (2010)*
**SINOCOP**

**In situ data processing**

**Surface temperature and drifter trajectory**

**Drifter S2 velocities**

- 22 km
- 41 km

**DH and Geostrophic Velocity at 26 m (ref. level 150 m)**

**Anticyclonic Eddy**

**Velocity from Drifter**

- Filtering HF signals (cut off at 36h)
- Reinterpolation every 6 hours + Velocity computation by finite differences
- Reinterpolation for daily values

**Relative velocity (CTD and glider)**

- Computation of DH (ref. level 150/570 m depth) from individual T & S Profiles: Removal of spikes, Vertical smoothing ...
- Objective analysis: several correlation scales...
- 3D map of Geostrophic velocities by finite differences
SINOCOP

Analysis of sensitivity

Geostrophic Velocity at 26 m ref 570 m Corr. 15 km

Geostrophic Velocity at 26 m ref 570 m Corr. 40 km

<table>
<thead>
<tr>
<th>Corr. Scale 15 km</th>
<th>Ref. Level 150 m</th>
<th>Max 14.11 Mean 5.67 Std 3.10</th>
<th>Ref. Level 570 m</th>
<th>Max 27.04 Mean 11.05 Std 5.50</th>
</tr>
</thead>
</table>

Large sensitivity to reference level and correlation scale that can reduce/increase geostrophic velocities (> factor of two)
Auto-correlation scale from pairs of glider show **signals at \(~10\text{km}\)** (Internal Rossby Radius of Deformation of 10-14 km, Robinson *et al.* , 2001)

Corre. scales used in OI (100km) for standard (M)SLA and windows to filter standard SLA (30km) **are too large to capture such features**
We are now able to characterize in 3D the structure and geostrophic velocities associated to small scale eddies ...

... The next step should consist in exploiting quantitatively these informations in order to evaluate the vertical velocity in the heart of such a (sub)mesoscale structure
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Vertical motion associated with mesoscale oceanic features is of **fundamental importance** for the **exchanges of heat, fresh water** and **biogeochemical tracers** between the surface and the ocean interior...

... **but** it is difficult to make direct measurements of the vertical velocity...

... Instead, it can be inferred from a 3D snapshot of the density field by assuming a **few simplifications in the QG formulation**.
Vertically velocity

How?

**Step 1: build a 3D density field**

*Approach 1:* From OI of in situ profil (see SINOCOP)

*Approach 2:* EOF decomposition to merge vertical profiles with standard gridded altimetry, inferring the 3D density and dynamic height fields

In the case of a single dominant mode, the modelled profile can be expressed as (Pascual and Gomis, 2003):

$$\Phi_{x,y}(p) = A_1(x,y)\text{EOF}_{1}(p)$$

Thus, obtaining the single amplitude $A_1(x,y)$ corresponding to each profile would be straightforward given the surface altimetry data $[\Phi_{x,y}(p_0)]$ and the surface component of the leading EOF $[\text{EOF}_{1}(p_0)]$ from vertical profiles (standard CTDs, ARGO floats, gliders).

**Step 2: Use QG Omega Equation to examine vertical velocity**

$$f^2 \frac{\partial^2 \omega}{\partial z^2} + \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) (N^2 \omega) = \nabla_h Q \quad Q = \left[ 2f \left( \frac{\partial V}{\partial x} \frac{\partial U}{\partial z} + \frac{\partial V}{\partial y} \frac{\partial U}{\partial z} \right), -2f \left( \frac{\partial U}{\partial x} \frac{\partial U}{\partial z} + \frac{\partial U}{\partial y} \frac{\partial V}{\partial z} \right) \right]$$

where $(U,V)$ are the geostrophic velocity components

By assuming a BC for $\omega$ and from a 3D snapshot of the density field, the vertical velocity can be inferred. We set $w = 0$ at the upper and lower boundaries and Neumann conditions at the lateral boundaries (Pinot et al., 1996)
Deployment of a glider in a very energetic area.

To improve our knowledge on the driving mechanism in the area: Mesoscale structures (filaments, eddies, etc).

Altimetry Cal/val Jason1/2 just two weeks after Jason 2 launch.
This study represents a first attempt on the combination of glider technology data with altimetry to **diagnose vertical velocities**.

The **vertical motion** diagnosed is **consistent** (magnitude is smaller) with previous studies (Tintoré et al., 1991; Allen et al., 2001b)

The magnitude is very sensitive to the scales included in the analysis. **(100 km correlation scale in gridded altimetry is too large)**
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PROBLEMATICS ADDRESSED

For altimetry:
- How to improve altimetry in coastal area?

For Glider:
- How to solve the Reference Level issue?

Develop and evaluate processing methods to compute homogeneous absolute altimetric and glider velocities

Explore the use and limitations of altimetry data in the coastal area

Four glider missions have been specifically performed between July 2007 and June 2008
Horizontal velocity

Altimetric processing

EDITING

SLA
LF spatial filtering (13 km<cut off<40 km)

MDT

Slope calculation
Powell and Leben filtering (13 km<cut off<40 km)

Absolute geostrophic velocity

Datasets

- 3 sets of corrected SLA: Aviso 1Hz data - CLS 20 Hz data - Aviso gridded data + MDT

Editing spatial filtering and slope calculation

- New editing strategy on SLA (see Bouffard et al., 2008, 2010)
- SLA along track filtering
- Slope: optimal filtering (Powell and Leben, 2004) across track absolute current
Dynamic height computed from T, S profiles with a ref. level 180 m.

Computation of surface geostrophic velocities (Vg surf / 180m) from DH

\[ V_{g\ abs} = V_{g\ surf_{180}} + V_{g\ 180\ bottom} \]

Reference Level Correction

Computation of absolute geostrophic currents by combining Vg /180 m and depth averaged GPS currents:

\[ V_{abs} = V_{g\ 180} + V_{g\ 180\ bottom} + V_{bar\ wind} + V_{ag} + \varepsilon \]

denotes vertical average over the upper 180 m (glider vertical extension)
The glider and altimetric pass cross several dynamical patterns both observed at **surface** (GPS and remote sensing) and **in depth** glider CTD.

**Color:** SST (Source: ICM) / **Vectors:** Absolute geostrophic currents (Source: AVISO)
Impact of Reference Level Correction (RLC)

- **RLC allows to improve** the comparisons both in terms of RMS explained (> 40% in velocity !!!!) and mean difference
- **However bias** (~5cm/s) maybe due to glider positioning error (compass ...), synopticity issues and physical content

Impact of High Frequency geophysical correction (HFGC)

Positive sub-centimetric impact over the four missions *(magnitude < altimetry and glider error)*

(More details in Bouffard et al., JGR 2010; in revision)
Impact of MDT

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<tr>
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<tbody>
<tr>
<td>Mean</td>
<td>13.6</td>
<td>23.2</td>
<td>4.8</td>
<td>9.5</td>
</tr>
<tr>
<td>STD</td>
<td>2.9</td>
<td>8.6</td>
<td>7.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

MTD allows to improve the comparisons (especially in terms of mean difference)...

...But problem of spatial resolution (too much smooting in OI)

Impact of sampling and editing

Important disagreement in coastal zone (especially in July ...) between 1Hz and glider SAGC

20Hz + New editing strategy allow to better constraint velocity in coastal zone

(More details in Bouffard et al., JGR 2010; in revision)
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Multi-sensor approaches are useful for studying dynamics at regional scales both in terms of horizontal and vertical characterizations of coastal currents and mesoscale features.

New methodology in the velocity computation improves the altimetry-glider consistency by partially solving Reference Level issue for glider and using 20HZ for altimetry.

M(SLA) have not sufficient resolution for the detection (sub)mesoscale features present both in glider and along-track altimetry (sensitivity to spatial resolution and correlation scales...).

These highlight therefore the need of high resolution ocean surface topography measurements (SWOT).

On Going work: Testing new retracking for 20Hz altimetry (within the framework of PISTACH) and implementing data fusion techniques to characterize in 3D (sub)mesoscale...
Thank you for your attention