Uncovering finescale ocean vertical velocities from the synergy of in-situ and satellite observations

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Vertical motions associated with mesoscale (10-100 km) and submesoscale (1-10 km) ocean processes play a critical role in the exchange of heat, fresh water and biogeochemical tracers between the surface and the ocean interior. The measurement of ocean vertical velocities is one of the key challenges for earth observation.
To estimate vertical velocities from a combination of in-situ (CTD, glider, Argo, XBT, ADCP, ...), satellite observations (altimetry, SST, ...) and supporting numerical simulations.
Horizontal currents first!

Multi-platform experiment (ship, glider) during commissioning phase of Sentinel-3A. SAR mode improves SLRM.

Decrease in percentage error between SARM and P-LRM product. Heslop et al. GRL (2017)

See also comparisons with HF radar data (e.g. Pascual et al. 2015a), vs glider data (e.g. Cotroneo et al. 2019)
Vertical velocity at 100 m from NEMO model PSY2V3R1 (Lellouche et al., 2012), compared to solutions of omega equation in the North Atlantic.

Buongiorno Nardelli et al. 2012
QG-w explains 80% of the model-w variance.

Buongiorno Nardelli et al. 2012
Vertical velocity (m day$^{-1}$) at 100 m, obtained by integrating the QG omega equation from the 3D field of ARMOR3D (Mulet et al. 2012; Guinehut et al. 2012) corresponding to September 2005. Horizontal geostrophic currents are overimposed.

Pascual et al. GRL 2015 \[ U = 1 \text{ m s}^{-1}, f = 10^{-4} \text{ s}^{-1}, \text{ and } L (\text{half diameter}) = 100 \text{ km} \rightarrow Ro \sim 0.1 \]
QG-w eddy composites (Brazil-Malvinas)

QG-w eddy composites show dipole patterns of alternating upwelling/downwelling.

Mason et al. JGR 2017
Comparing a Multivariate Global Ocean State Estimate With High-Resolution *in Situ* Data: An Anticyclonic Intrathermocline Eddy Near the Canary Islands

Barbara Barceló-Llull*, Ananda Pascual¹, Evan Mason¹ and Sandrine Mulet²

Underestimation of the local Rossby number by a factor of 3 of ARMOR3D compared to in situ observations (CTD-ADCP)
Objective: sampling an intense front, impacts on biogeochemistry

Eastern Alboran Sea
25-30 May 2014

Pascual et al. 2017
Olita et al. 2017
Troupin et al. 2019
Glider observations
QG-w patterns partially explain the vertical excursions of CHL.

QG-w \sim \pm 10 \text{ m/day}

Ruiz et al. in rev.

500 m resolution
Initialized with observations

$W \sim 20$ m/day
One common objective..
Evaluate the interest of the west Med SWOT crossover

Gain experience in multi-platform (two ships, two gliders, drifters,...), multi-lateral campaign coordination (LOCEAN, MIO, SHOM, IMEDEA, SOCIB).

Explore the dynamics present in this region.
PRE-SWOT cruise design

- Mimic SWOT swath width and resolved scales
- Radiator grid covered 100% in 4.5 days
Dynamic Height – Geostrophic Velocity

Impact of correlation scale

OI - L = 20 km (SWOT)

OI - L = 100 km (DUACS)

+ drifter trajectories
Nutrient & particle trajectories (PARCELS)
Initialized with CTD observations PRE-SWOT experiment

Preliminary results: E. Cutolo (IMEDEA)
Coherent Lagrangian Pathways from the Surface Ocean to Interior

NRV Alliance during the Calypso Pilot Cruise 2018 (Photo credit: Parrot drone piloted by Mathieu Dever)
CALYPSO objectives

Unravel the three-dimensional coherent pathways by which water carrying tracers and drifting objects is transported from the surface ocean to depths below the mixed layer.

- How are water and properties from the surface boundary layer exported to depth?
- What coherent pathways act as conduits for exchange?
- What dynamics shapes these pathways? What are the Lagrangian trajectories, what are the time and space scales of subduction and where does the water end up?
Technical approach

- Focus on Western Mediterranean
  - Strong meandering current and front
  - Deep subduction previously determined
- Joint pilot experiment in July 2017, May/June 2018
- Experiments planned for 2019 (March) and 2020
- Modeling - multi-scale approach
- Lagrangian perspective /coherent structure detection
Drifter divergence and vorticity

Drifters divergence

Drifters vorticity

Model vorticity
Lessons learned & recommendations

• Need of integrated multi-platform and interdisciplinary approach for understanding fine-scale processes.

• Vertical velocity plays a key role in carbon export, supply of nutrients to upper ocean, phytoplankton production,…

• Estimates of vertical velocities with SWOT could be improved by a factor of 10.

• Surface horizontal current measurements (SKIM) will be crucial.

• Additional data (e.g. Sentinel-2 and innovative observations) provide valuable information.
Future prospects

- New developments to measure and predict vertical velocities. Autonomous and ship-based observing.
- Outlook for present and future satellite missions applications: big data, artificial intelligence, data-driven and deep learning.

R. Fablet (2018)
Thank you! – also to co-authors, collaborators and sponsors