Estimating oceanic physics-driven vertical velocities in a wind-influenced coastal environment

Reply to community comment: B. Blanke

Maxime Arnaud, Anne Petrenko, Jean-Luc Fuda, Caroline Comby, Anthony Bosse, Yann Ourmières, and Stéphanie Barrillon

We would first like to thank you for your commitment and detailed comments about this paper. Your help has been sincerely appreciated. Before answering, please note that we decided to add the latest JULIO time series (from July 12, 2023 to May 22, 2024) to our revised manuscript as we obtained the data during the review process. We think that it brings valuable information on our work as it adds ~ 20% of data compared to the previous dataset in the original version of the paper. Following your suggestions, we have modified our manuscript and answered your comments. We detailed our manuscript modifications below.

1) The abstract should better highlight the key findings and their broader implications listed below:

(i) Methodological work: The authors combine three different measurement techniques (JULIO ADCP, FF-ADCP, and VVP) and introduce an innovative approach using echo intensity to separate biological noise from physical signals. This demonstrates that bottom-mounted ADCPs can provide reliable vertical velocity measurements, but only when biological activity in the water column is properly accounted for.

(ii) Scientific results: Measuring vertical velocities in the ocean is notoriously difficult, yet these motions are crucial for understanding ocean dynamics. The authors document vertical velocities for upwelling and downwelling events that transport water several hundred meters per day on average. This has real consequences for how nutrients and other biogeochemical tracers get transported throughout the ocean.

(iii) Thorough validation: Over a decade of data is cross-validated against satellite observations and model outputs. The study demonstrates that multiple types of measurements (acoustic, satellite, and meteorological) are necessary to understand the processes that occur in this coastal system.

We have changed the abstract accordingly.

“Despite the challenge of measuring them due to their small intensities, oceanic vertical velocities constitute an essential key in understanding ocean dynamics, ocean-atmosphere and biogeochemistry interactions. Coastal events and fine-scale processes (1-100 km / days to weeks) can lead to high-intensity vertical velocities.

Such processes can be observed in the Northwestern Mediterranean Sea. In particular, the Gulf of Lion is a region prone to intense north-westerly and easterly wind episodes that strongly impact the oceanic circulation. The JULIO mooring (JUdicious Location for Intrusion Observation) is located on the boundary of the Eastern side of the Gulf of Lion's shelf at the 100m isobath. JULIO provides Eulerian measurements of three-dimensional current velocities over two main time-periods: 2012-2015, and since 2020. Vertical velocities measurements from JULIO show a good agreement with two independent methods, a Free-Fall Acoustic Doppler Current Profiler and an innovative Vertical Velocity Profiler.

To measure physics-driven vertical velocities, we developed a method to identify and filter out biology-induced vertical velocities. Combining satellite and in situ observations with wind model outputs, we identify wind-induced downwelling and upwelling events at JULIO associated with physics-driven vertical velocities with maximum amplitudes of -465/127 m/day. Hence, this analysis underlines the need for long term multimethod observations in such coastal areas forced by intense wind episodes. This work presents mooring ADCPs as reliable tools for physics-driven W measurements, with an adaptive algorithm which is applicable anywhere offshore in the ocean to detect W in fine-scale processes."

Issues:

Interpretation of the biological signal: The study attributes recurring nighttime negative vertical velocities to biological processes but immediately dismisses diel vertical migration (DVM) because only descending motion is observed. Alternative biological explanations could be explored, such as asymmetric DVM behavior, sinking dead biomass, or ADCP backscatter bias due to the geometry of biological material. Could the authors present additional biological data (collected during patch events) to validate the assumption of a biological origin?

We were not clear in the original text. DVM consist generally in ascending velocities at dusk, and descending velocities at dawn. Here, at JULIO, we do not observe these classical DVM; but at certain periods of the year (generally spring & summer), during the night, we observe biological groupings or patches, which origin we ignore. The peculiarity of these groupings is that they appear rather stationary in space (subsurface layers), despite exhibiting overall negative velocities.

This kind of negative W patches have been observed and is not usually considered as DVM. We cleared the text in this way (new lines 114 to 120):

"Between the ascending (descending) phases at dusk (dawn) of DVMs, the zooplankton stays at the surface or subsurface during the night. These stationary patches are sometimes associated with recorded ADCP negative vertical velocities (Tarling et al 2001, BioSWOT-Med and FUMSECK cruises (unpublished work)). Some hypotheses attempt to explain these counterintuitive negative vertical velocities of stationary patches. Among them, a sinking phenomenon due to satiation of living scatterers that occurs during the night as mentioned in Tarling and Thorpe (2017) or the angle of displacement of living scatterers, varying depending on whether they ascend or descend in the water column thus impacting the ADCP returning signal (pers. comm. M. Ohman)."

We have also exchanged with biologists about observations which could be useful for upcoming work, including biological sampling at nights in the JULIO area.

Methodological choices: The 15 m depth × 4 h time window is based on an open-ocean study in the Scotia Sea. Should this choice be more carefully validated for coastal studies such as those in the Gulf of Lion? How might the bin size affect the detection of vertical velocity structures, particularly near the seabed or near the surface? Similarly, how do wind curl and coastal geometry influence Ekman transport at this specific site compared to open-ocean conditions?

The virtual window dimensions (12 m depth and 4 hours long) are inspired from Tarling 2009 but a sensitivity analysis has been made with our data: we varied depth from 8 to 20 m, time from 2 to 8 hours, and percentage from 50 to 90%. We kept the optimized parameters that are able to target our observed patches (which take into account the different bin sizes over the time series).

The algorithm is optimized for our specific study case and its characteristics would need to be changed for studies in open ocean or in other geographical zones. The method itself (sliding window to identify patches) is easily exportable (new lines: 281-285 & 312-317).

Ekman transport is indeed influenced by wind characteristics and localization. In our specific case, orography, with the Alps close to the sea, coast orientation, together with wind characteristics, added to the fact that JULIO is on the edge of the continental shelf thus influencing Ekman transport and the occurrences of upwellings and downwellings. Open-ocean conditions are very different, an ADCP mooring there would measure W from other physical processes.

Measurement uncertainty: The claimed minimum resolvable vertical velocity approaches many measured values, which requires rigorous quantification of standard deviations and biases for each method, particularly the JULIO ADCP. The study partially addresses this issue but lacks discussion of biologically active layers and systematic error propagation assessment. For instance, wind measurements contain uncertainties (instrument precision, space and time sampling limitations)… that can project onto vertical velocity estimates.

The error measurement of vertical velocities combines the instrumental and the methodological errors. In our case, the errors are the following:

- Intrinsic ADCP error due to hardware which includes (for our ADCP 300 kHz) 0.5% of the measured value and a quadratic addition of a conservative value of +/- 5 mm/s, both given by the manufacturer.
- Methodological ADCP, depending on the deployment characteristics: number of bins (cell size), number of pings. This conservative error (private communication with RDI) is +/- 5 mm/s, added quadratically

The combined error gives us the absolute instrument error of +/- 7mm/s.

The errors coming from the biological identification can also influence the average W calculated in each specific event. For instance, we computed W averaged over U_{2022} for both smaller and bigger boxes, giving a difference of 2.8 mm/s between these two extremes (new lines: 314-316).

The wind model, on the other hand, is only used to identify upwelling and downwelling events.

Statistical rigor: The 15 m/s wind intensity threshold requires statistical or bibliographic justification. How sensitive are the results to this threshold? Can its validity be statistically tested? More generally, several conclusions rely on visual interpretation (wind-vertical velocity alignment, SST drops, SLA peaks) rather than on quantitative correlation or thorough analysis. Could the authors strengthen some of their interpretations for added robustness in their results?

Indeed our threshold was not clearly established. We use the strong wind intensity value from Berta et al 2018 (10 m/s) to select our events. 12 events are selected with all the parameters (new lines 298 to 305 in the text). Nonetheless we also observe that our chosen events correspond to stronger gales (15 m/s) before or during the upwelling/downwelling event. A Pearson correlation has been performed between wind and intense W but we found a weak correlation, which is not surprising giving the fact that intense W exist without being related to strong wind events and upwelling or downwelling events. Regarding SST and SLA, direct correlations with vertical velocities are tricky as satellite observations are daily and JULIO data features a sampling frequency of 48 times a day. This highlights the need, in our case, to systematically use multiple observations to identify such coastal events.

Event selection and generalizability: Were other upwelling/downwelling events identified by other methods and excluded from this analysis? If so, what criteria disqualified them? How generalizable are the documented characteristics (duration, depth extent, SST signatures) to other Mediterranean coastal systems? The conclusion could acknowledge that localized JULIO observations may not represent basin-scale processes and discuss the applicability of their method across the Gulf of Lion.

Thank you for your comment. We have now described precisely our method of detection of up- and downwellings (new lines 298 to 305). This way, we detected 9 upwellings and 3 downwellings.

We chose the four events detailed in the paper as illustrative examples for their good agreement with satellite observations. These events indeed do not represent basin-scale processes, but the conclusion is that this method (moored ADCP and biological filtering) could be used to measure physics-driven vertical velocities in open seas and assess other physical processes than upwellings and downwellings (for example internal waves, eddies, fronts or filaments).

We added information both in abstract and conclusion about the generalization of our observations to different basins.
New lines 13-15 "This work presents mooring ADCPs as reliable tools for W measurements when combined with other types of observations, with an adaptive algorithm which is applicable anywhere offshore in the ocean to detect W fine-scale processes."
New lines 455-458 "The filtering algorithm of biological-induced vertical velocities can be adjusted to DVMs, or to any region of the world ocean, coastal as offshore. Then the study of the remaining physics-driven vertical velocities will enhance our understanding of fine-scale oceanic processes, which have real consequences on how nutrients and other biogeochemical tracers get transported throughout the ocean."

The manuscript is readable and informative, but some syntax, grammar, and phrasing issues reduce its clarity. A careful proofreading of the manuscript should eliminate the most glaring errors, including the following:

All these corrections and suggestions have been taken into account.

Line 1: challenge of measuring

Changed.

Lines 7 and 139: three-dimensional

Changed line 7 and new line 144.

Line 15: most ocean dynamic processes

New line: 17.

Line 16: one of the most complex aspects

New lines: 17-18.

Line 16: usually of several orders

New line: 18.

Line 41: including in situ observations

New line 43.

Line 75: These forcings and their impact on the oceanic circulation have been studied

New lines: 76-77.

Line 135: offshore of Marseille on the border of the Gulf of Lion shelf

New line: 141.

Line 146: with the initial purpose of measuring

New line: 153. Rephrased to “The initial purpose was to measure the Northern Current intrusions on the continental shelf of the Gulf of Lion (Barrier et al., 2016).”

Line 152: thickness of the blanking

New line: 157.

Line 156: than that calculated

New line: 161.

Line 160: between 6 a.m. and 6 p.m.

New line: 170.

Line 173: to a 30 s temporal resolution

New line:183.

Line 175: from 78.9 to 3 m.

New line 184.

Line 262: filtered out from the W dataset,

New line 285.

Line 391: this work shows

New line: 438.

Line 397: “SUCH measurements” (unclear reference)

Indeed, thanks for pointing it. We rephrased it to: “W measured with JULIO exhibited strong intensity values for both upwellings and downwellings.” new line 444.

Thank you again, your help has been highly appreciated.