Review of the paper entitled Global Thermocline Vertical Velocities: a Novel Observation Based Estimate

1 Major Points

This study proposes the global OLIV3 product of geostrophic vertical velocity in the thermocline, which is derived from ARMOR3D observation-based meridional geostrophic currents and ERA5 surface wind-stress used to derive Ekman pumping. The methodology adopted in OLIV3 relies on the linearization of the vorticity equation, where the vertical stretching term balances the meridional advection of planetary vorticity. The validations of OLIV3 against the perfect OGCM model and the GLORYS12v1 and ECCOv4r4 reanalyses are convincing. OLIV3 captures the interannual variability of tropical and subtropical regions, but fails at fronts and boundary current systems, precisely where subduction and modal water formtion occur. Regions between mesoscale structures are also populated by submesoscale strutures such as filaments, eddies, whose contribution in terms of integrated vertical transport represents about 50% of the total vertical transport (Klein et al., XX ? I don't remember the date). In short, OLIV3 is efficient in large-scale structures, but has significant shortcomings in crucial regions.

Many products, such as reanalyses, and OGCM, OAGCM models outputs, produce vertical velocities in the thermocline, even at high frequencies. It is therefore important to demonstrate the added value of the OLIV3 database in comparison with these models and reanalyses, simply because models and reanalyses provide the full vertical velocity, which is an important variable for biogeochemistry, for example. Deriving the vertical velocity from the complete vorticity equation or the omega equation shed light into processes driving vertical motion, as well as the balances between these processes. Here the added values of these approaches. Your article should demonstrate the usefulness and applications of the OLIV3 database, and not just show that the main large-scale balance lies between meridional advection of the planetary vorticity and vertical w-stretching.

The meridional geostrophic velocity (v_g) is taken into account in the linear balance equation. I don't understand why the geostrophic vorticity was not conserved in the balance equation $(f + \zeta_g)\frac{\partial w}{\partial z} = \beta v_g$?

I do not understand how the Ekman pumping is taken into account. In fact, I suspect it is $w_{tot} = w_g + w_{ek}$. From my understanding it is about:

$$f \int_h^0 \frac{\partial w}{\partial z} dz \simeq f \int_h^{z_{geo}} \frac{\partial w}{\partial z} dz + f \int_{z_{geo}}^{z_{ek}} \frac{\partial w}{\partial z} dz = \beta \int_h^0 v_g dz \tag{1}$$

where h, z_{geo} and z_{ek} are the level of no motion, the depth of thermocline where w_g is computed and the depth of the Ekman layer, respectively.

$$\begin{cases} f(w_g + w_{ek}) = f w_{tot} = \beta \overline{v}_g h \\ \\ \overline{v}_g = \frac{1}{h} \int_h^0 v_g dz \end{cases} \tag{2}$$

This point is essential and must be clarified.

It is mentioned in the conclusion that total meridional velocities $(v_g + v_{ag})$ and additional terms from the vorticity equation, such as the horizontal advection of relative vorticity should be incorporated. In some way, you have already incorporated an ageostrophic component of the current with Ekman pumping. By introducing v_{ag} in equation $f\frac{\partial w}{\partial z} = \beta(v_g + v_{ag})$, what do you expect on OLIV3 performances ?

How do you intend to compute v_{ag} ?

To have consistency between v_g and v_{ag}, isn't it better to use v and also the vorticity ζ from a reanalysis ?

Figures 4, 5, and 6 show OLIV3, GLORYS12, ECCOV4 and OMEGA3D. However, it is the differences between OLIV3 and these other products that are discussed. These differences are very difficult to see. Please provide Figures illustrating these differences.

It is better to use the vertical velocity in m/day rather than in m/s.

2 Detailed Points

- Line 76 : typos: change "gesotrophic" to "geostrophic"
- Line 98: "local mass balance between meridional divergent flow and an opposing vertical convergence". Ok but what equation 1 shows is a balance between vertical convergence and meridional advection of planetary vorticity.
- Line 101: This sentence is confusing because the horizontal geostrophic flow is non-divergent. Please reformulate.
- Line 106-107: The Ekman pumping w_{ek} occurs at the Ekman pumping depth ($D_{ek} = 0.2 * \sqrt{\tau}/f$, Li et al., 2021; GRL). So a vertical profile of w_{ek} is often prescribed from the surface, where $w = 0$, to $z = z_{ek}$, where $w = w_{ek}$, to $z = 2D_{ek}$, where $w = 0$. So $w = w_{ek}$ at $z = 0$ is not a good surface boundary condition. Please correct.
- Line 133: Ekman pumping is not clearly shown in Equation 2. See remark in the "Major Points" Section.
- Line 135: Here again it is not w_g because it includes w_{ek}. This is confusing because, as said lines 131-132, the product w of OLIV3 has two components, which are w_g and w_{ek}. Please clarify this point.
- Line 150: Isn' it better to calculate v_g from the thermal wind equation ? Based on pressure, the result is often noisy, unless the pressure is first smoothed. In this case, the filtering procedure should be mentioned.

- Line 153: The reference Jean-Michel et al., 2021 is not adequate. You cannot use the first name of the authors in references. Please correct.
- Line 165: Omega-equations need not only surface momentum and heat air-sea fluxes, but also fluxes in the ocean. Where do these fluxes come from ?
- Line 178: The equator band (5S/N) is large. Geostrophism can be applied from 2S/N degrees, and even 1S/N degree. For example see Dourado and Caniaux, JGR, 2001 (their Figure 4).
- Line 182-184: Why was the isopycnal level $\sigma 26$ chosen ? How does it compare to the the mixed-layer depth ? Why not choose the mixed-layer depth ?
- Line 188-189: Explain why Figure 1 emphasises the role of atmospheric forcing as the primary driver of vertical flow within the upper ocean. Are you implying that the Sverdrup balance can be used to obtain a good estimator of v_g ?
- Line 194-195: This aspect is an issue because we do not see the point of using LVB. Please identify and discuss the missing processes in the LVB to correctly represent the frontal dynamics.
- Line 196-197: Please show a Figure of Ekman pumping.
- Line 230: Equation 4. Using $\sigma 27 - \sigma_{MLD}$ makes difficult to understand the following discussion, because we do not know the sign of this difference. Then the speech is difficult to follow. I suggest the metric $\left(\frac{\partial w_g}{\partial z}\right)_{z=MLD} - \left(\frac{\partial w_{tot}}{\partial z}\right)_{z=MLD}$ instead, normalized or not.
- Line 245-250: This shows the limits of the method in frontal regions. Even in coastal regions, Ekman pumping fails to capture vertical transport of physical and biogeochemical tracers.
- Line 272-273: I don't understand why a downward decrease of w_g. I would instead expect a positive vertical gradient. I am having trouble following the discussion about the vertical gradient of w, because the sign of $(\sigma 27 - \sigma_{MLD})$ is unclear.
- Line 330-331: Reanalyses are significantly affected by spin-up effects, primarily vertical velocity. This is why incremental analysis update techniques are used in data assimilation procedures. Consequently, how much confidence can we place in such reanalysed vertical velocities, given that they are partially affected by unphysical spurious effects ? In other words is it reasonable to use them as w-references ?
- Line 335: Reanalyses are significantly affected by spin-up effects.
- Line 348-349: I don't understand this sentence. I would say that the geostrophic vertical velocity in the ocean interior results from the convergence/divergence of the Ekman drift.

- Line 355: Figure 5. Sorry but I am lost with vertical gradient expressed in ms^{-1}/kgm^{-3}. Where does $\sigma 27$ fit in relation to σ_{MLD} ? I suggest expressing this gradient in $day^{-1} = mday^{-1}/m$.

- Line 375-376: Be careful $w(z=0) \neq w_{ek}$.

- Line 387: Change Fig.5b to Fig.6b.

- Line 391-393: Arbitrary conclusion at first glance (Fig 6). Make difference maps.

- Line 428: Not good due to spin-up.

- Line 446: OMEGA3D also integrates vertical stratification.

- Line 450: OMEGA3D is a physical investigating tool because it is based on the destruction of the thermal wind balance by current and turbulence.

- Line 527-530: If I am a biogeochemical scientist, or physicist who wants to estimate modal water production, what is the benefit of using OLIV3 rather than a reanalysis ? Sorry, I'm not convinced, but I would like to be.

- Line 532: Before incorporating non-linear processes, integrate before the total meridional velocity and vorticity.

In conclusion, I request substantial changes, particularly on the interest of using OLIV3, and clarifications on the incorporation of Ekman pumping in Equation 2, and the physical interpretation of this equation balance.