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Interactive comment on "On the role of domain aspect ratio in the westward intensification of wind-driven surface ocean circulation" *by* Kaushal Gianchandani et al.

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We thank the referee for helping us improve the quality of our paper. In the following we address the minor comments raised in the review.

While I agree that non-dimensional equations are useful, it is unclear what the new physical findings of this study are. Is there a change in how the vorticity balances in the western boundary layer? The authors need to clarify that the parameter dependence of the WBC solution is not just a result of the mathematical formulation that the authors have chosen.

Response: While the role of damping (α or ϵ in our formulation) in the westward intensification has been previously discussed extensively in the literature, the dependence of the WBC's transport on the domain aspect ratio has not been studied (save for its mention in Bye and Veronis, 1979). The novel finding of our study is the first quantification of the dependence of the WBC's transport on the domain aspect ratio. This finding enables, in turn, its application to the five known WBCs.

Clearly, the vorticity balance in the boundary layer is unaffected by our scaling but in the interior of the basin our formulation and scaling shows that the term of the Laplacian proportional to $\partial^2\psi/\partial y^2$ can be neglected only for $\delta \geq 1$ (see our detailed response to the next comment). Our concise formulation underscores features that exist in the dimensional formulation (as in our numerical simulations) but are hard to see when dealing with five model parameters.

(1) I would like the authors to discuss the sensitivity of the results to the choice of the boundary current width. In terms of mass balance, the WBC simply returns the Sverdrup interior so if the Sverdrup interior is kept constant, the transport of the WBC will not change. The meridional velocity at the western boundary also varies differently in the zonal direction for S48 and M50: for S48, it decays exponentially with epsilon while for M50, a maximum occurs near epsilon. The way the transports are estimated (Equations 4 and 8) does not seem to fully take these differences into account.

Response: It is indeed correct that the WBC's transport is equal in magnitude to the Sverdrup transport in the basin's interior. However, the Sverdrup transport itself is dependent on the basin's aspect ratio. The correction to the Sverdrup transport in bounded domains was developed in Bye and Veronis (1979).

In terms of our scaling this correction can be derived by noting that since $\alpha = \epsilon/\delta^2$, equation (1) of the manuscript implies:

$$\left(\epsilon\frac{\partial^2}{\partial x^2}+\frac{\epsilon}{\delta^2}\frac{\partial^2}{\partial y^2}\right)\psi+\frac{\partial\psi}{\partial x}=\sin(\pi y)$$

where $\epsilon=(r/\beta L_x)$ is a proxy of damping and the non-dimensional width of the WBC. Under the assumption of small damping i.e. $\epsilon \ll 1$, the term $\frac{\epsilon}{\delta^2}\frac{\partial^2\psi}{\partial y^2}$, cannot be neglected in the interior solution when $\delta^2 \sim O(\epsilon)$ i.e. the Sverdrup balance becomes a function of δ in this case. As was rightly pointed out by the referee, the WBC 'simply returns' this δ-dependent Sverdrup transport.

We employed the simple scaling to obtain our ad-hoc definition of the boundary layer width [i.e. $\epsilon=r/(\beta L_x)$ for Stommel's model and $\epsilon=[\mu/(\beta L_x^3)]^{(1/3)}$ for Munk's model] to make the paper more accessible to oceanographers that are inclined towards observations or numerical modeling. Equations (4) and (8) are of the form:

$$Tr=\frac{\delta}{\alpha\pi^2}[1-O(\epsilon)] \qquad (4')$$

and

$$Tr=\delta[1-O(\epsilon)] \qquad (8')$$

These expressions are valid for values of ϵ for which a WBC exists and they show that our results are not sensitive to the precise definition of the WBC's width. For instance, the width of the WBC can also be defined as the value of x for which the stream function reaches an extrema. By this definition, $\epsilon_S \sim 5\epsilon$ for Stommel's and $\epsilon_M \sim 2\epsilon$ for Munk's model, where ϵ is the current definition of the WBC's width in the two models. The respective transports in the two cases are given by:

$$Tr_S=\frac{\delta}{\alpha\pi^2}(1-pe^{5A\epsilon}-qe^{5B\epsilon})$$

and

$$Tr_M=\delta\left(1-e^{-1}\left[\cos(\sqrt{3})+\frac{1-2\epsilon}{\sqrt{3}}\sin(\sqrt{3})\right]\right)$$

Here, we see that the two transports calculated by the new definition of WBC's width are also of the form (4') and (8'), which indicates that the results presented in this paper are independent of the precise definition of WBC's width.

We thank the referee for this comment and we will further highlight the independence of our results to the choice of WBC's width in the revised manuscript.

(2) The scaling of the stream function depends on delta [$\gamma\beta L_y^3=\tau\pi/(\rho H_0\beta\delta)$]. Is the sensitivity of the WBC transport to δ a consequence of using such a scaling? As L_y changes, so do the magnitude of the wind stress curl and the scaling of the stream function. What is the benefit of using such scaling? To focus on the WBC, isn't it better to keep the wind stress curl constant and keep the Sverdrup interior the same?

Response: No, the sensitivity of the WBC's transport to δ is not a consequence of using our particular scaling. To appreciate this subtle dependence one should compare a square basin, where $\delta=1$, with a "narrow and long channel-like" basin where $\delta \ll 1$. In a square basin, the classical approach of equating $\partial\psi/\partial x$ to $\sin(\pi y)$ works well since the North-South gradient of the zonal velocity (represented by $\partial^2\psi/\partial y^2$) is small and can be neglected from the interior solution. However, in a "channel-like" ocean this quantity is large and cannot be neglected from the balance of terms in the interior solution. Surely, an examination of the 3 vorticity terms in the interior ($\partial\psi/\partial x$, wind-stress and $\partial^2\psi/\partial y^2$) clarifies that the WBC in the "channel-like" ocean should be weaker compared to a square ocean.

As in all non-dimensional problems, the choice of scaling is not unique. We choose this scaling to stay consistent with the one proposed in Bye and Verionis, 1979. The results are independent of magnitude of wind-stress curl because the differential operators in the vorticity equations of Stommel and Munk are all linear.

We thank the reviewer for this comment and we include the aforementioned example in the revised manuscript to further elaborate the conceptual aspect of our paper. We will also re-write the paper with ϵ as the damping parameter (instead of α) in both Stommel and Munk models.

(3) Figure 4 shows that the transport of the East Australian Current (EAC) is weaker than the other WBCs because of the small delta. But how was Ly determined for EAC? The meridional scale of this western boundary current appears to be different from the spatial scale of the winds. Zero wind stress curl does not exist around 22S (e.g. https://booksite.elsevier.com/DPO/chapterS10.html)

Response: The conflict between the geometry of the ocean basin and the overlying wind stress in the WBCs is independent of the model used for explaining the properties of the WBCs and hence does not affect our formulation and scaling. In appendix C of our paper we discuss in detail how the irregular shaped basin in the world ocean were approximated to obtain values of L_x and L_y. The error-bars along the ordinate provide a range between which δ can vary for different choices of L_y and L_x.

References: Bye, J. A. T., and George Veronis. “A correction to the Sverdrup transport." Journal of Physical Oceanography 9.3 (1979): 649-651.

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