

Authors Response to the Editor's comments

Editor comments and suggestions

I would like to thank the author for this submission, and it's almost there. One of the referees raise a scientific point about the dynamical interpretation with the Ekman effect; please see the referee report for details (it looks reasonable) and adjust accordingly. Additionally I did a read through of this and have a few minor comments in relation to writing (my linenumbers here refer to those in the "tracked manuscript" file), and please also see the comments raised during the file validation by the Copernicus colleagues:

We thank the Editor for the positive evaluation of our manuscript and for the constructive comments and suggestions. We address the different points raised by the Editor thereafter. The Editor's comments are shown in black and our responses in blue. When a line number is provided, it refers to the manuscript with track changes accepted. References can be found at the end of the document.

* line 41 and elsewhere: For tidiness please swap the ordering of "Park et al, 2014b,a" so it ends up reading "Park et al, 2014a,b"

We have swapped the ordering wherever applicable.

* line 43: "..., THE results remain..." reads better to me

Modified as suggested.

* line 43 and maybe elsewhere: no brackets for citation inside brackets (e.g. use ?r similar)

Modified as suggested.

* line 43 and 45: Not too attached to this one, but to me "find" instead of "found" reads a bit better, because around that region the text is in present tense.

Modified as suggested.

* line 74: Also not attached to this one, but "Dataset" on line 76 is used as a singular (which is fine) and would suggest using "...IS used as a reference..." purely for balance reasons (but make sure then "data" is used a singular throughout the text) We have modified the beginning of the sentence to: "These data are..."

L72

* sentence of line 80: This to me should go in the "code and data availability" section.

We have moved these sentences in the code and data availability section.

* caption Fig. 1: The "e" of "e-folding" should probably have dollar signs to make it a math "e", otherwise change all other uses in the text to text "e" for consistency.

Modified as suggested.

* line 123 to 129: Still reads unnecessarily convoluted and unclear, particularly when the only sentence the authors are really wanting is the last one right? In the grand scheme of things, the first part is then a repeated statement of that last sentence, so could just junk the first two sentences, maybe recycling a bit, e.g.:

"Hernandez et al. (2017)...we have used depth-independent profiles of Chl-a in all model simulations of this study, noting this is a limitation as the maximum Chl-a is usually found close to the nutricline."

We have modified this paragraph as follows: "Hernandez et al. (2017) found only small differences in SST between forced ocean simulations using depth-independent and depth-dependent profiles of Chl-a. Therefore, for simplicity and consistency with previous studies, we have used depth-independent profiles of Chl-a in all model simulations in this study. However, we note that this represents a limitation because the maximum Chl-a concentration is usually found close to the nutricline in the tropical Atlantic Ocean (Herbland, 1983)." *L111-114*

* Fig. 2 caption and many places elsewhere: It should be minus signs ("−") instead of hyphens ("-") in front of the relevant numerical values, please change that everywhere else (I see them in Fig. 3, 4, A2, A3)

Modified as suggested.

* line 224: I think "opposite signS" is safer (to imply plus and minus signS)

Modified as suggested.

* Fig. 4 caption: Here the dashes between the geographical lon/lats are minus signs or short/medium dashes ("−"), when it is a hyphen/short dash elsewhere in the article ("-"), which is inconsistent. Don't particularly care which convention to take, just be internally consistent.

Modified as suggested.

* Please acknowledge the people who have posted comments if you feel they have actually made an improvement to the scientific or presentation aspect of the article.

We have now acknowledged the editor and the two reviewers that helped to improve the manuscript.

References

- Herbland, A.: Le maximum de chlorophylle dans l'Atlantique tropical oriental : description, écologie, interprétation, *Océanographie Tropicale*, 18, 295–318, 1983.
- Hernandez, O., Jouanno, J., Echevin, V., and Aumont, O.: Modification of sea surface temperature by chlorophyll concentration in the Atlantic upwelling systems, *Journal of Geophysical Research: Oceans*, 122, 5367–5389, <https://doi.org/https://doi.org/10.1002/2016JC012330>, 2017.

Authors Response to Reviewer's Comments

Reviewer 2

I appreciate the additional work carried out by the authors, The paper is well written and the results should be published. However I am still unhappy about the interpretation around lines 206 of the revised paper and believe the interpretation needs further work.

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Wind stress, equatorial currents and the tropical cell

As far as I know Stommel (1960) was the first to investigate the terms of Eqn. 4 and showed, using a one layer model, that for a steady zonal wind, the vertically integrated Ekman transport balanced the vertically integrated geostrophic term. In fact he showed that the balance works in both the meridional and zonal directions. In the meridional direction the vertical structure of Ekman transport results in the tropical cell. In the zonal direction the balance results in the sea surface slope, the equatorial current and the equatorial undercurrent. The terms are also discussed in my own note Webb (2018). This zonal net transport is also consistent with the Sverdrup relation, which requires a wind curl to generate a vertically integrated north-south transport and with Munk's theory of the wind generated circulation, which even at the Equator requires a non-zero wind curl to generate a vertically integrated transport. Of course single-layer models are a bit simplistic. A better analytic model is that of McCreary (1981). He is only talking about the equatorial current and undercurrent but as far as I can tell the theory also applies to the tropical cell. He takes into account the vertical density structure of the ocean and the changes in viscosity. The additional of the baroclinic terms is found to be important but besides that, as stated in the discussion section: "The response varies weakly with the shape of the pycnocline below the mixed layer and also with the magnitude of friction in the deep ocean". However he does find: "The depth of the mixed layer does affect the speed of the surface drift, but other properties of the flow to a much lesser degree".

Application to the present paper

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1. Figures 3c and 3d show that the maximum vertical velocity occurs at around 100m, near the depth of the maximum vertical temperature gradient. As discussed in the papers referred to above the maximum vertical velocity occurs at the interface of the upper and lower branches of the tropical cell. Above this level

the pole-ward Ekman velocity term is greater than the pressure term, giving a net pole-ward velocity. Below this level the pressure term dominates giving an equator-ward velocity.

2. Figures 3c and 3d also indicate that the Ekman term must be significant down to around 150m. I would expect that this to match the depth of the core of the undercurrent in the model.

3. The results mean that the Ekman transport is not constrained to the surface mixed layer and so the parts of the text which are based on this assumption need correction.

4. The results show that biology does have a non-trivial effect on the structure of the tropical cell. It reduces the depth of the interface between the upper and lower parts of the tropical cell. It increases velocities above the interface and reduces velocities below.

5. From the figures it is not obvious whether the changed velocities are only due to the same transport being squeezed into a shallower layer above the interface, and a thicker layer below, or if it is partly due to a change in the total transport. For this you would have to see if the maximum vertical velocity increased. The one thing I could not explain was the small change in velocity at the surface. Whenever I tried to modify a plot of the Ekman transport as a function of depth, changing the depth at which the transport balance the pressure term but keeping the vertical integral constant, the simplest forms always changed the velocity near the surface. It may not be for this paper but at some stage it would be interesting to know why the effect on the surface velocity was so small.

6. I may have missed the reference in the text but if it is not there it may be worth adding something about the depth of the upper part of the cell being very similar to the depth where the light level is at 1% of the surface value in a clear ocean. I understand that this is the limit for photosynthesis.

We thank the reviewer for the clear explanation and discussion of the effects of Chl-a on the structure of the tropical cells, as well as the useful references.

Considering all points raised by the reviewer, we have modified the text in Section 3.1 and added the following paragraph:

“Although outside the scope of this paper, we note that Chl-a seems to exert a non-trivial effect on the vertical structure of the tropical cell. Indeed, the maximum vertical velocity (around 100 m at 20°W; Fig. 3c) occurs at the interface of the upper and lower branches of the tropical cell (Stommel, 1960; McCreary, 1981; Webb, 2018). Above this level, the poleward Ekman velocity is greater than the zonal pressure gradient, giving rise to a net poleward velocity (as previously discussed). The depth of the upper branch of the tropical cell seems to be related to the depth at which irradiance drops to 1% of its surface value (around 100–150 m), often used to define the base of the euphotic zone. Below this interface, the zonal pressure term dominates, resulting in an equatorward velocity and closing the cell. The upward shift of the maximum vertical velocity (Fig. 3d) suggests that Chl-a reduces the depth of the interface between the upper and lower parts of the tropical cell, increasing poleward velocities above the interface and reducing equatorward velocities below. In fact, the depth of the maximum vertical velocity in the ATL3 region is 10 m shallower in ICTP-MOM5-CTRL (54 m) than in ICTP-MOM5-CHL0.01 (64 m). In addition, the magnitude of the maximum vertical velocity is reduced by 6.4% in ICTP-MOM5-CHL0.01 ($4.4 \times 10^{-6} \text{ m s}^{-1}$) relative to ICTP-MOM5-CTRL ($4.7 \times 10^{-6} \text{ m s}^{-1}$). We also observe that Chl-a strengthens and shoals the core of the equatorial undercurrent (Fig. R2). An in-depth analysis of whether velocities are modified by the altered vertical extent of each branch or partly due to a change in the total transport is left for a future study.” *L216-228*

Fig. R1 shows that, relative to ICTP-MOM5-CTRL, ICTP-MOM5-CHL0.01 has a reduced magnitude of the maximum vertical velocity along the equatorial Atlantic, while the depth of the maximum vertical velocity is greater. Furthermore, Fig. R2 indicates that the core of the EUC in ICTP-MOM5-CHL0.01 is weaker and

deeper than in ICTP-MOM5-CTRL. Together these figures suggest changes in the equatorial Atlantic zonal and meridional circulations induced by Chl-a. We have included Fig. R2 in the revised manuscript as Fig. A4. We also note that we do not assume that the Ekman transport is constrained to the mixed layer. Rather, we use the vertically integrated zonal momentum budget to help explain changes in surface transport and associated upwelling across the base of the mixed layer.

References

- McCreary, J. P.: A Linear Stratified Ocean Model of the Equatorial Undercurrent, Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 298, 603–635, 1981.
- Stommel, H.: Wind-drift near the Equator, Deep Sea Research, 6, 298–302, [https://doi.org/10.1016/0146-6313\(59\)90088-7](https://doi.org/10.1016/0146-6313(59)90088-7), 1960.
- Webb, D. J.: A Note on Stommel’s Theory of the Tropical Cell, Research and Consultancy Report, No. 63, National Oceanography Centre, Southampton, U.K., <http://nora.nerc.ac.uk/id/eprint/520018>, 2018.

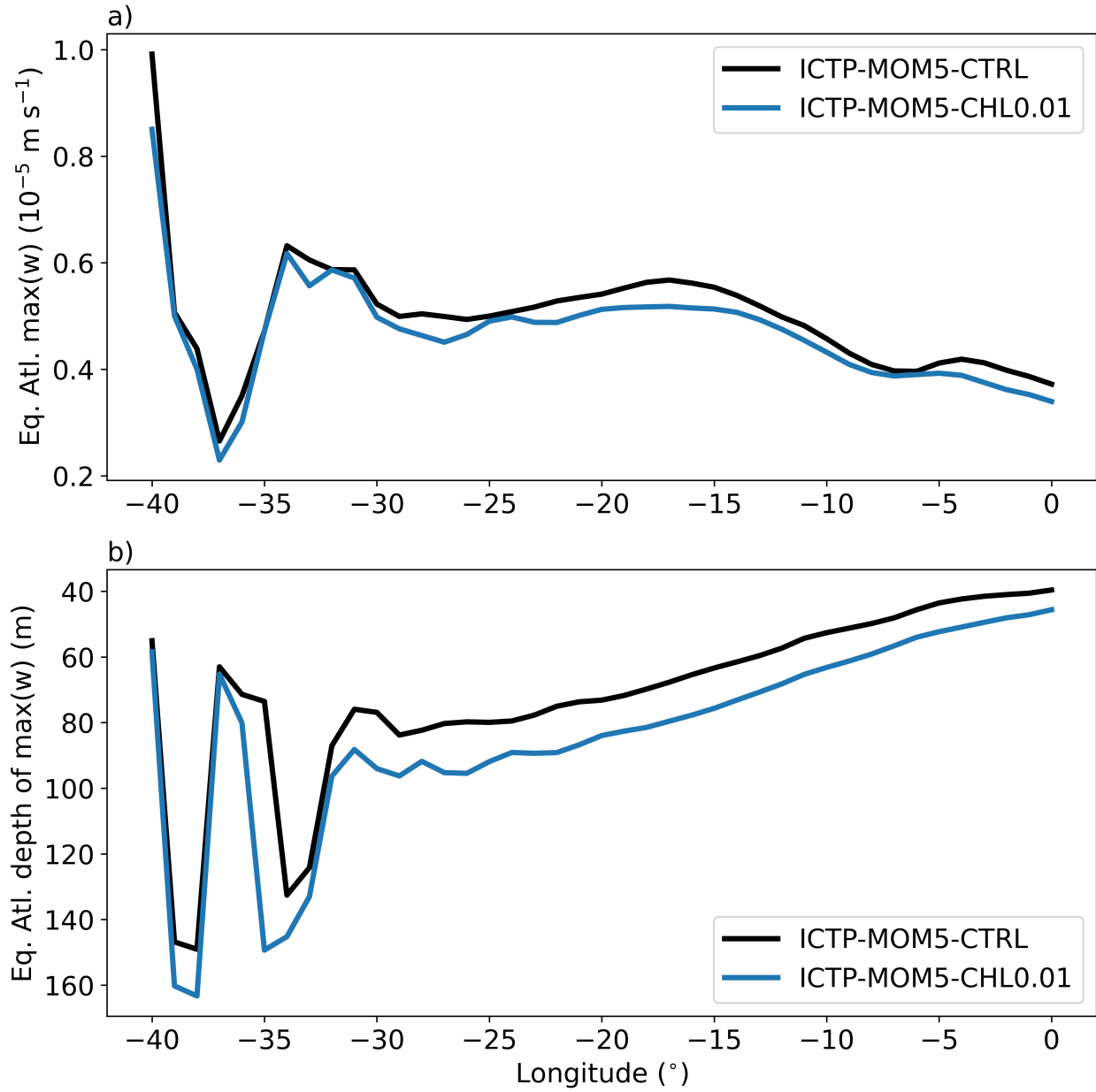


Figure R1: (a) Maximum vertical velocity in the equatorial Atlantic (40°W-0°E; 3°S-3°N) for ICTP-MOM5-CTRL (black) and ICTP-MOM5-CHL0.01(blue). (b) Same as (a), but for the depth of the maximum vertical velocity.

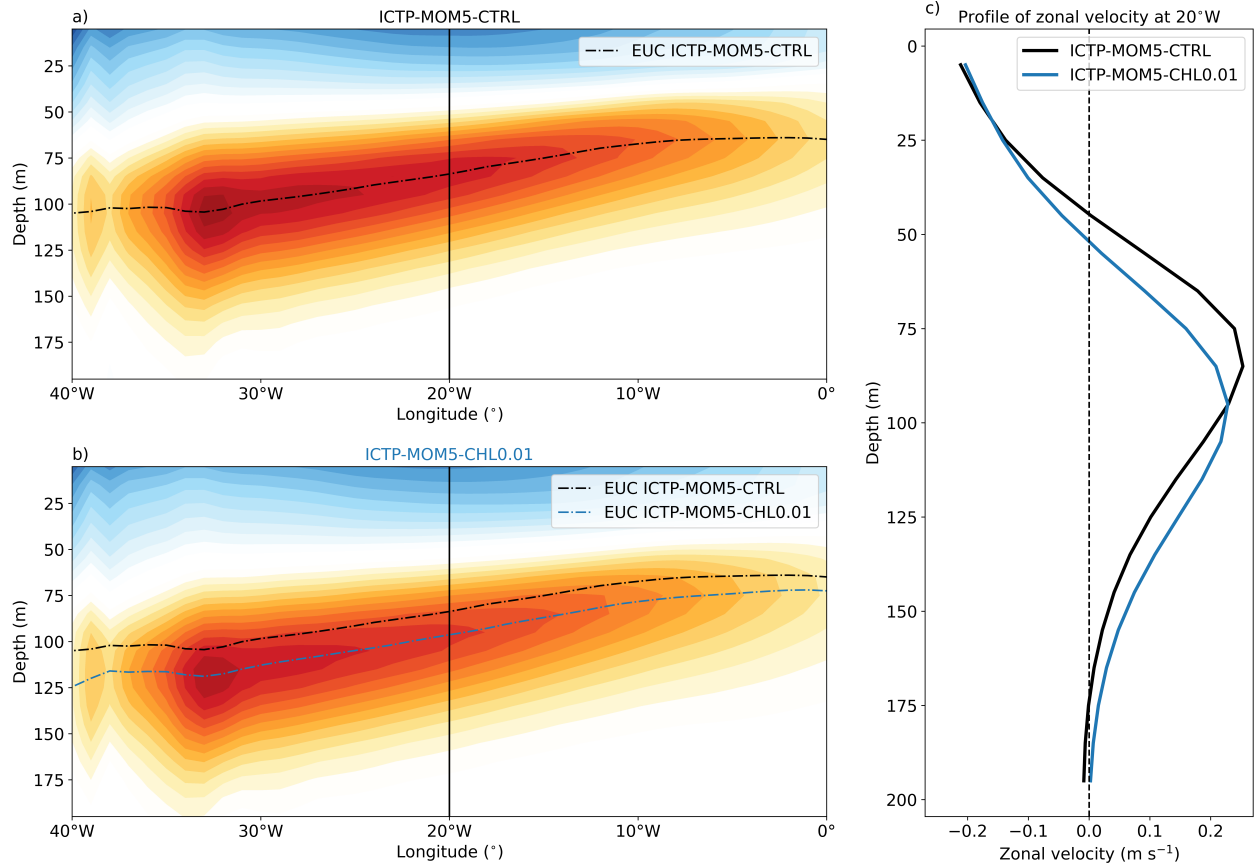


Figure R2: (a) Equatorial section (40°W-0°E; 3°S-3°N) of zonal velocity for (a) ICTP-MOM5-CTRL and (b) ICTP-MOM5-CH0.01 (blue). The dashed dotted lines indicate the depth of the core of the equatorial undercurrent. The EUC depth is defined as the depth of the maximum eastward zonal velocity. For each vertical profile, the maximum velocity is first identified, and a quadratic interpolation through the maximum and its two neighboring depth levels is then used to estimate the peak depth continuously. If the maximum occurs at the upper or lower boundary, the corresponding model depth is retained. (c) Vertical profile of the zonal velocity at 20°W and averaged between 3°S-°N.