Response to reviewer 1 of "Budget of the total nitrogen in the Yucatan Shelf: driving mechanisms through a physical-biogeochemical coupled model"

S. Estrada-Allis on behalf of all co-authors.

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Dear Reviewer, thank you so much for your time reading this paper and providing your suggestions to improving it. Following are responses (in blue) to your detailed comments.

1 General Comments

In agreement with the reviewer, we have extended the Yucatan shelf (YS) validation by comparing the transport and current velocity with observations found in the literature (Sheinbaum et al., 2002; Athié et al., 2015; Sheinbaum et al., 2016). The model transport, velocity and its standard deviation are in a good agreement with the observed mean values reported in the literature. A qualitatively comparison is made in terms of salinity with the observations reported in Enriquez et al. (2013). We have added a point-by-point comparison of the salinity from the GOMEX IV cruise and a comparison of the mean salinity and chlorophyll vertical profiles observed for different years in the YS with successful results. In order to prove that the model reproduce the seasonality of the upwelling, the bottom shelf temperature is also shown. Moreover, the model sea level anomaly over the YS is compared with altimetry data from satellite and the model current velocity with the OSCAR current product. We hope that all those new comparisons and model evaluation cal help to convince the readers that the background model physics and dynamics on the shelf is reliable.

Regarding the bias of the model, we have added an extra subsection named 'Impact of model uncertainties'. In general terms, the model tends to overestimate the NO3 and temperature, mainly at the surface. The phytoplankton growth is a function of the temperature through the maximun growth rate (Eppley, 1972). An overestimation of the temperature will produce an increase in the PON concentrations. A consequence of this is that DIN and PON concentrations would be higher than the reality leading to an increase of total nitrogen (TN) budget over shelf. However, the bias is reduced with depth, i.e., the model

uncertainties are important at surface having a little impact over the whole water column.

With respect to the budget units. The main budget for the YS was expressed in mmol N/s in our Figure 9. In the literature, only few papers are focus on the budget quantification enclosing the shelves of the Gulf of Mexico. A recent example is giving in Zhang et al. (2019), in their figure 14 and 16 they shown the sources and sinks of TN for part of the Gulf of Mexico in Gmol N yr^{-1}. Xue et al. (2013), their figure 13, denotes the TN budget for the shelves of the Gulf of Mexico (except for the YS) in mol N. Fennel et al. (2006), their Figure 8, show the sources and sinks of N in mmol N yr^{-1}, similar as in our Figure 9. None of these papers express the budget in units of area m^2. Moreover, notice that in our Table 1, the budget is expressed in molN yr^{-1}, such as in Table 1 of Fennel et al. (2006) and Table 2 of Xue et al. (2013), among others studies in the GoM (Fennel, 2010). These are examples of direct comparisons for the same area and with the same physical-biogeochemical coupled model, but different set-up.

2 Specifics Comments

1. Abstract, L11: Is there a reason for choosing the 250 m isobath as the shelf boundary?
The reason for choosing the 250 m is explained in P4 L16-20. 200-250 m is the mean depth for shelf break of the Yucatan peninsula (Ruiz-Castillo et al., 2016), please see also our Figure 1. We also pointed out that the YS can be separated into two compartments depending on its dynamics, showed by the mean kinetic energy (see Figure 1b and c).

Page 1
2. The first paragraph of the Introduction needs to be rewritten. References should be updated with recent relevant work on shelf carbon and nitrogen budgets. The last sentence in this paragraph incorrectly lists acidification and eutrophication as socio-economic activities. These processes may result from socio-economic activities but are not activities in themselves. Likewise, the processes listed as part of the climate system are not ones that would immediately come to mind. Please rewrite.
In agreement with the reviewer comment the Introduction will be rewritten and the most recent work about the nitrogen budget will be also added in the new manuscript.

Page 2,
3. L3: Probably should cite Walsh et al. 1989 here
The cited has been placed in P2 L3.
4. L12-13: It would be good to provide more detail about these controversies to help the reader understand the motivation for this study.
P2 L12-13 will be rewritten in order to provide more detail about the controversies regarding its dynamics which is related with the seasonality and generation

of the upwelling of Cape Catoche, the notch area, influence of the Yucatan Current and the effect of the coastal trapped waves.
5. L26: Show the Yucatan Current in Figure 1.
A better description of the Yucatan Current is included in the new manuscript. A yellow line has been added in Figure 1a to show a zonal transect of the Yucatan Current.

Page 3,
6. L23: Change "was ran" to "was run"
Thanks, this has been corrected in the new manuscript.
Page 4,
7. L12: Suggest deleting the first sentence and starting the paragraph with something like "The XIXIMI cruises provided profiles of nutrients and ...
Thanks, this has been corrected in the new manuscript.
8. L22: Does the SDet equate to dissolved organic nitrogen (DON) in the model? In the real world, the components of total nitrogen are DIN, DON, and PON (or PN since there's some adsorbed inorganic nitrogen on particles). Dissolved organic nitrogen is often equal to or greater than dissolved inorganic nitrogen in the coastal ocean and in coastal rivers. If the SDet does not equate to DON, then your TN definition is incorrect. If SDet does equate to DON, then the assumption of setting PON in rivers equal to 0.1 mmol N m-3 (see comment 11 below) is incorrect.
Here we want to clarify two important things, the first is that the YS does not have rivers. The freshwater sources come from a complex cave system called "cenotes". The second is that the Fennel model does not have DON as a state variable, hence cannot be equated with SDetN. The model variables are described in the manuscript in P4 subsesction 2.2. For a more detailed description of the model you must refer to Fasham et al. (1990); Fennel et al. (2006, 2011). For freshwater sources, the particulated Nitrogen fluxes are assumed to enter as the pool of SDet (Fennel et al., 2011) and, together with the freshwater DON, is set with a small and constant value of 0.1 N m^{-3}, see answer to comment 11 below for more details. The definition of TN is the combination of DIN and PON, with DIN the sum of NO3 and NH4, and PON the sum of Phy, Zoo and the two detritus pools. This definition is the one used in Xue et al. (2013), which until now, is the only study that quantify a long-term budget of TN for the whole GoM.
9. L26 and equation (2): This equation is only for the water-column. The total nitrogen budget also includes the loss to denitrification and to burial in the sediments. Please clarify.
In agreement with your comment this lines has been clarified in the new manuscript.

Page 5,
10. L16-20: More details are required about how the freshwater inputs were calculated. Since the freshwater inputs are unknown, it would be justified to include a time-series figure of these inputs, perhaps in the appendix.

In agreement with your comment, a time-series for the most important river systems and freshwater sources (Mississippi/Atchafalaya, Usumacinta-Grijalva, and two representative sources over the YS) will be included in a new Appendix B.

11. L23: Setting the PON to this small value is not justified. I suspect that PON must include DON, else the definition of TN used in this study is incorrect. DON concentrations are generally >> 0.1 mmol N m-3.

This question is related with previous comment 8. As we explained, DON is not included in the Fennel model as state variable. PON is taken as the sum of Phy, Zoo and the detritus pools, which together to DIN (NO3 and NH4), are the definition of TN as in Xue et al. (2013). PON were initialized with a small constant value of 0.1 mmol N^{-3}. This approach works well due that the physical-biogeochemical coupled model will evolve with time until reach a distribution representative of the model dynamics. In order to get this adjustment simulations began after a 30 year model spin-up. In fact, Fennel et al. (2006) argue that the adjustment timescales for biogeochemical variables are on the order of days to weeks. This of course does not guaranties that the biological model is validated with respect to a real ocean, but we can ensure that the initial conditions are far from the outputs values used in this study.

12. L26: Provide dates for the November cruise.

The dates for November cruise are now included in the new manuscript.

13. Section 3.1 seems like it should be in the appendix with the other basin wide modeling results. These results aren't really germane to the analysis except as boundary conditions to the shelf.

In agreement with your comment, section 3.1. is now included in the appendix A. Figures are now renamed as Figure A4, A5 and A6.

Page 6,

14. L20: Why is there no model comparison with salinity data? This should be included to provide confidence the model is accurately representing physical transports.

We have added a Figure and description of root mean square, mean and standard deviation in the appendix for salinity comparison with GOMEX IV observations. Moreover, zonal sections of salinity are qualitatively compared with observations shown in Enriquez et al. (2013). A mean vertical profile for salinity observed over the shelf during different years is also compared with the model salinity.

Page 7,

15. L3-9: Poorly worded paragraph. The explanation of why the model results cannot be compared with other results is incorrect. The results from this study should be compared to other studies to put the overall budget for the Yucatan shelf into some context in comparison to other more well-studied shelves in the Gulf such as the West Florida and Louisiana shelves. I recommend normalizing your budget fluxes to area so that they are comparable to other flux estimates.

Comparison with other shelves, even with those from GoM, must be take with care. For instance, the Yucatan shelf is influenced for a complex cave system,

the upwelling at Cape Catoche, the variability of the intense Yucatan Current and the rich mesoscale activity around the area, which is not present in the Florida shelf for example. Sources and sinks of nitrogen are not necessarily the same for the different shelf of the GoM. Please, refer to previous responses regarding the units and normalization of the budget.
16. L15: The trend is mentioned here but there's no explanation. Is it real? What is driving the trend? What source/sink terms have changed? The model is deterministic so there's no reason not to get to the bottom of this, especially since the trend suggests that the N budget is not at steady state.
The explanation of the trend is in P7 L 15-22. It is not an artifact of the model since chlorophyll from satellite products exhibit the same positive trend over nine years. We will further investigate the possible reason of this trend in the new manuscript.
17. L19: I'm not sure what you mean by "a very efficient biological cycle". Please be more specific.
This is related with the efficiency of the inner shelf in that sources and sinks of DIN are in balance with PON, i.e., almost all the NO3 is consumed by phytoplankton or remineralized being in balance with the particulate organic nitrogen.

18. L16-17: This logic doesn't make sense to me. Earlier in the ms it was stated that the chlorophyll time series were used in an inverse analysis to prescribe freshwater and N inputs (also see comment 10). Thus, the TN trend and the chlorophyll trend may not really be independent. Please address whether these are completely independent variables.
Please, see response to previous comment 17.

Page 8,
19. L22: Please report the rates of denitrification (mmol N m-2 d-1 or something similar) obtained from the model.
Thank you, the rates of denitrification are reported in the new manuscript.
20. L24: Fennel et al. (2006) was a study of the Mid-Atlantic and did not address GoM shelves.
This ha been corrected in the new manuscript.

Page 9,
21. L29-: This paragraph should be deleted. The last sentence makes it clear that the present analysis cannot address these phenomena. This has been corrected in the new manuscript.

Page 10,
22. L30: Insert "to" after "due" Thank you, this has been corrected in the new manuscript.
23. L31: Change "show" to "shows" Thank you, this has been corrected in the new manuscript.

Page 11,

24. L13: Is “2015” a typo? Thank you, yes, is a typo and has been corrected in the new manuscript.
25. L28: Delete “the” before “unique” Thank you, this has been corrected in the new manuscript.
26. Prior to Concluding Remarks there needs to be a discussion of the uncertainties in your budget analysis. How does model bias for N concentrations affect your budget? What is the error (standard deviation of the mean) of each term in the mean budget? Without including this, there is no way to make meaningful judgements about the magnitude of the budget terms.
Thank you, this has been rewritten and a new subsection about the impact of the model uncertainties has been added in the new manuscript.

Page 12,
27. L1-2: Figure 15 shows the physical system but not the biogeochemical system 28. Table 1: Normalizing the fluxes to a unit area would be more meaningful since the flux estimates presented are driven by the length of the boundaries and the area of the inner and outer shelf.
Figure 15 shows the physical processes that affect/modulate the biogeochemical system in the YS. Figure 9 shows the biogeochemical system. The units in Table 1 are according to other similar references, for example Fennel et al. (2006) or Xue et al. (2013), among others ...
29. Figure 1: These maps use degrees-minutes whereas other maps use decimal degrees. Be consistent. On Figure 1, the grey contours are difficult to see in panel (a). In panel (b), the vectors are too small to be seen in my copy.
According to the reviewer, the maps with decimal degrees have been modified to degrees-minutes. The grey contours of Figure 1 are now in black and we have increased the line width to improve the visualization. The vectors of panel b of Figure 1 has been also modified to be in black. It is not recommendable to use a higher vector size since the Yucatan Current is characterized to be more intense than the surrounding currents of the shelf. Higher vectors in panel b will distort the figure making it impossible to visualize.
30. Figure 2: It is hard to see the dashed boxes in my copy. Note the isobaths again in this figure caption so the reader knows what these lines are.
According to the reviewer we have increased the width of the dashed boxes and we note the three isobaths in Figure 2.
31. Figure 3: Should be in appendix with basin-wide results.
Figure 3 is now Figure A4 in the new manuscript.
32. Figure 4: Should be in appendix. In panel (a), the shadow and dashed line are difficult to differentiate. In panel (b), report the slope of the linear fit.
Figure 4, both panel (a) and (b), has been modified according your suggestion and it is now Figure A5 in the new manuscript.
33. Figures 5, 6, 7: Report model evaluation statistics such as bias and RMSE. The bias in temperature, NO3, and chlorophyll is generally positive with model results being greater than observations. How does this affect the TN budget calculated with the model?
In agreement with this comment, additional statistical metrics (bias, RMSE)

are now included in the new manuscript. We consider that due the focus of this study, a critical area that needs to be evaluated is the upwelling region. More attention is paid to its validation with observations in the new manuscript as we explained before in the general comments and comment 14.

34. Figure 8: For panels a, c, and e report the p-values for the trend lines. The legends are confusing. Perhaps rename them to Inner Shelf TN, Inner Shelf DIN, Inner Shelf PON, etc.

The p-values are now added and the legends have been changed accordingly.

35. Figure 9: There are differences in values and significant digits presented here and Table 1. Double check these values and make corrections. Also some numerical values for fluxes are difficult to read. A simple 2-D map may make a better figure. Plus, the upside down (S-N) orientation is odd for the 3-D figure.

Please, notice that the differences in Figure 9 and Table 1 are due the units. Table 1 is in mmolN yr^{-1} in order to be comparable with the budgets for the GoM shown in Fennel et al. (2006) and Xue et al. (2013). Numerical values of Table 1 are now bigger. Note that the orientation of the rotated 3-D diagram is marked by the cardinal rose at the left up corner. Now, Figure 9 has been rotated to a N-S diagram. Numbers are higher and isobaths are highlighted.

36. Figure 10: Font is too small for gray depths. Latitude is shown in decimal degrees here. "Isobtahs" is misspelled in the caption.

Thank you, Figure 10 has been modified accordingly in the new manuscript.

37. Figure 11: I can't see the red dot for the station at Lat = 18.3 and Long = -88.1.

The dots are now bigger in panel a, and the panel b is in degree instead of decimal latitude and longitude map.

38. Figure 12: Is this figure necessary? It seems to just show a correlation between currents and SLA that could likely be seen with a simple correlation analysis. What is the unit cpd-1 in the yaxis labels?

Figure 12 is a relevant Figure since shows the correlation between SLA and cross-shelf transport modulation. This can be only achieved by a more specific analysis rather than a simple Fourier spectral analysis. In fact, the analysis of wavelets were also useful to show correlations in the Cape Catoche and Notch area in the study of Jouanno et al. (2018).

39. Figure 13: Difficult to see isobaths in panel (a). In panels b, c, and d, change the blue lines to black to match the y-axis label or change the y-axis label to blue.

Isobaths in panel (a) are now thicker and in black. In panels b, c and d, each color lines match with the y-axis label.

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