

Thanks for this contribution to global marine N<sub>2</sub>O modeling. May I ask some questions regarding the model formulation and applied parameter sampling:

Line 148: Is there nitrification at 1  $\mu\text{mol O}_2/\text{l}$ ?

Almost none in our analysis. Nitrification declines in the same way with O<sub>2</sub> as remineralisation switches from O<sub>2</sub> to NO<sub>3</sub>. We added: "Since nitrification consumes O<sub>2</sub>, in the model it decreases as remineralisation switches from O<sub>2</sub> to NO<sub>3</sub> (supplementary material Eq. 70, 61, 67)."

Line 156: How is N<sub>2</sub>O consumption modeled? As a first order consumption term as applied in other studies? How large is gross consumption? What O<sub>2</sub> threshold do you use to separate nitrification, production from denitrification and consumption from denitrification? How large are aerobic and anaerobic remineralization fluxes in the model?

We added to Section 2.6:

"The ratios of the three processes are globally invariant (supplementary material Eq. 70, 61, 63, 71). The functional form of the O<sub>2</sub> dependence of N<sub>2</sub>O consumption (suppl. Eq. 71) was the same as that of denitrification (suppl. Eq. 67), and with an O<sub>2</sub> response function that is 1.5  $\mu\text{mol L}^{-1}$  lower than that of denitrification, which is similar to that used by Babbin et al. (2015). We independently optimised the ratios of N<sub>2</sub>O production and consumption from denitrification (Section 3.1), which controls the net N<sub>2</sub>O production as a function of O<sub>2</sub> concentration. There is not enough information at present to optimise the O<sub>2</sub> concentration parameters of denitrification and N<sub>2</sub>O consumption as well."

We have added the full set of equations for nitrous oxide to the model description as supplementary material, with references to the relevant equations throughout the Materials and Methods section. Optimised gross consumption is 0.21 Tg N/y, see the answer to reviewer 2 question on Line 201-202. The O<sub>2</sub> thresholds for N<sub>2</sub>O production (34  $\mu\text{mol O}_2 \text{ L}^{-1}$ ) and consumption (28  $\mu\text{mol O}_2 \text{ L}^{-1}$ ) are stated in Section 3.1, the O<sub>2</sub> threshold for nitrification is 0  $\mu\text{mol O}_2 \text{ L}^{-1}$  (see previous comment). Primary production is 64.5 Pg C/y, of which 99.5% is remineralised aerobically (using 7540 Tmol O<sub>2</sub>/y) and 0.008% is remineralised by denitrification (using 0.485 Tmol NO<sub>3</sub>/y). The rest is partitioned between removal of nutrients at the sediment to compensate for nutrients added by rivers (da Cunha et al. 2007, GBC) and changes in the inventory of total organic matter.

Line 166: Are modeled N<sub>2</sub>O concentrations not drifting substantially after such a spin

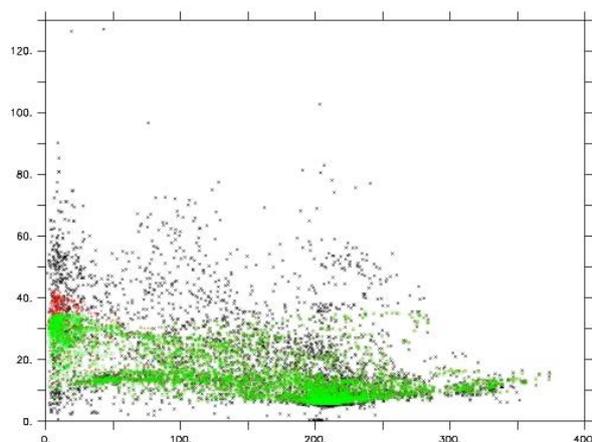
The length of the spin-up is a trade-off between keeping the runs short enough that the nutrient distributions are close to observed ones, so that the model behaves realistically when it is formulated and parameterised using physiological and ecological observations (Buitenhuis et al. 2006 Global Biogeochemical Cycles, 2010 Global Biogeochemical Cycles, 2013a, Le Quere et al. 2016), and long enough that the N<sub>2</sub>O concentration and  $\Delta p\text{N}_2\text{O}$  distributions can be used to optimised N<sub>2</sub>O process rates. Our optimized model is by definition as close as possible to observations, even if the deep ocean is not fully at equilibrium. With this method we were able to conduct a large number of model experiments, a sub-ensemble of which are presented here. We note in Section 3.1 that N<sub>2</sub>O production below 1600 m, where there is an increase in concentration, is only 5% of the total production. Given the slow ventilation of the deep sea, this accumulation will have a negligible effect on the optimised flux, and keeping the simulation short actually helps with this. We have added an analysis of the effect of variability to Section 3.1 and corresponding text as follows: "The results were the same in both diagnostic and prognostic submodels for the 2000-2004 and 2005-2009 averages, showing that the model was sufficiently spun up."

Line 199: How many parameter perturbation simulations did you run? Which sampling technique is applied to vary parameters? Over which range are parameters varied? What does the legend in Fig 8/10 stand for? Could you illustrate the sampled slopes and resulting optimal slope? Are fluxes tied stoichiometrically to remineralization fluxes? Why is N<sub>2</sub>O consumption slope given as N<sub>2</sub>O/NO<sub>3</sub><sup>-</sup>? Does this make sense stoichiometrically?

We did a large number of parameter perturbations, 6 of which were used to constrain the low O<sub>2</sub> N<sub>2</sub>O production in the diagnostic model (Fig. 9A), 23 to constrain the low O<sub>2</sub> N<sub>2</sub>O production in the prognostic model (Fig. 9B), 27 to constrain total N<sub>2</sub>O flux in the diagnostic model (Fig. 11A) and 26 to constrain total N<sub>2</sub>O flux in the prognostic model (Fig. 11B). Parameters were varied until they constrained the optimised rates and their confidence intervals. We've added to the Fig. 9 legend that "each point represents a simulation with a different low O<sub>2</sub> slope". We clarified the text following Eq. 2 : "To calculate the cost function (and also to calculate RSS in Eq. 3), the model was regridded to the same grid as the observations, and residuals were calculated at months and places where there are observations." We added to the Fig. 9 legend: "Range of parameter values is given in the supplementary material Section 8.7" Based on the question of reviewer 3 about Eq. 3 we have clarified the legend of Fig. 9 (was Fig. 8). Section 8.7 of the supplementary material also gives the optimal slopes, which are also given in Sections 3.1 and 3.2. N<sub>2</sub>O consumption occurs because N<sub>2</sub>O is consumed during denitrification. This was added in Section 3.1. NO<sub>3</sub> is the substrate of denitrification, and N<sub>2</sub>O is an intermediary, so it does make stoichiometric sense that N<sub>2</sub>O can act as an alternate substrate for denitrification.

Figure 6: Many global N<sub>2</sub>O modeling studies present N<sub>2</sub>O versus O<sub>2</sub> scatter plots for evaluation. What does this relationship look like in the model? The N<sub>2</sub>O flux estimate of 2.4+/-0.8 Tg N yr<sup>-1</sup> is much lower than what was reported in Suntharalingam et al. 2000/2012, on which the model builds ('4.6 Tg N yr<sup>-1</sup> (comprised of 3.0 Tg N yr<sup>-1</sup> from the 'nitrification' pathway, and 1.6 Tg N yr<sup>-1</sup> from the low-oxygen pathway', Suntharalingam et al. 2012). How come? Does your prior include these previous fluxes? Your N<sub>2</sub>O production at low O<sub>2</sub> is now ~10 times smaller compared to this previous model.

We present the modelled N<sub>2</sub>O and observed N<sub>2</sub>O next to each other in Fig. 7. Since this shows N<sub>2</sub>O as a function of depth for different basins, this has a higher information content than a scatter plot.



x-axis O<sub>2</sub>(μmol L<sup>-1</sup>), y-axis N<sub>2</sub>O(nmol L<sup>-1</sup>), black observations, green diagnostic model, red prognostic model.

The observational O<sub>2</sub> are used in the model, so this plot does not add any information relative to Fig. 7, and we have not included it in the manuscript.

We have added a discussion of the two main factors contributing to the different N<sub>2</sub>O flux in Nevison95:

“Because of differences in methodology it is not possible to provide reasons for why our estimate is lower than the more recent estimates. We can, however, compare our estimate to that of (Nevison95), because it is also based on a database of  $\Delta pN_2O$ . Compared to their high end estimate using the piston velocity of Wanninkhof of  $5.2 \pm 3.6 \text{ Tg N y}^{-1}$ , our estimate is lower because we use the more recent 13% lower estimate of piston velocity of (Sweeney07), and because our  $\Delta pN_2O$  of  $7.6 \pm 18.1 \text{ ppb}$  is 25 - 28% lower compared to 10.55 natm in Nevison (1995) (the range is calculate based on the water vapor correction for conversion between ppb and natm, which increases from 0.6 - 4.1% at temperatures from 0 - 30 °C, which brings the values slightly closer together)”

This is the only estimate where the methodologies are comparable enough (based on an observational database of  $\Delta pN_2O$ , and using a piston velocity that is a function of the square of the windspeed) that we can isolate quantitative reasons for the differences in the estimates.

This is not an inversion, so there's no prior.