We thank this reviewer for the helpful comments. Below we outline how we plan to improve the revised text in response to these comments.

General:

This generally well-written paper describes a coarse resolution ocean model coupled with an ecological model that resolves nitrogen isotope fractionation, nitrogen fixation as well as denitrification in the sediments and in the water column. The major results include the sensitivity of the model to the benthic denitrification fractionation and to the nitrate utilization in sub-oxic zones. In my analysis, the paper is relevant and new, and worthy of publication after relatively minor revisions.

The model is designed to represent the pre-industrial ocean state, hopefully the authors will consider the question of changing climate or a nitrogen system that is out of steady state in future efforts.

<u>Response</u>: We found it necessary to better understand the sensitivity to uncertain processes in the modern ocean, where sufficient data exist, before applying this model to climate change scenarios that we will be performed in the future.

I find the discussion of coastal denitrification a bit cursory. There have been regional studies of nitrogen cycling on coastal shelves that might inform the discussion. E.g. Fennel et al, 2006, GBC. This is particularly important to discuss because the resolution of the global model precludes representation of shelf processes. The tuning process described through which grid cells are subdivided is clever, and seems to match patterns of shelf width for example except perhaps in the Arctic. Also, denitrification is occurring in the middle of the watercolumn effectively but without shelf processes, the coupling between this and the open ocean is likely too strong. It seems likely that shelf denitrification and riverine inputs and primary production are all coupled to produce a net shelf isotope effect that may not be represented in a global model.

<u>Response</u>: Coastal dynamics in coarse-resolution models are, as to be expected, not well represented. The sub-grid scale shelf scheme accounts for where particulate organic matter sinks into unresolved coastal shelves, but it still does not influence the physical dynamics of these systems. Since the high-resolution features of the shelf are required to simulate the small-scale currents that are responsible for nutrient fluxes in these areas (Fennel et al., 2006), it can be expected that our coarse-resolution model will underestimate productivity, rain rate of carbon into the seafloor, and thus benthic denitrification there. This is one of the reasons why we provide sensitivity experiments that increase benthic denitrification rates by different factors in these areas, which shows

the sensitivity of this model deficiency on the model results. This discussion will be included in the benthic denitrification section (3.1.3) in the revised text.

Benthic denitrification occurring on the shallow shelves in this sub-grid scale bathymetry scheme will likely be too strongly coupled to deeper waters because vertical mixing can still occur and influence $\delta^{15}NO_3$ from below. This may bias model $\delta^{15}NO_3$ towards deeper waters that are typically lower than surface water due the surface NO_3 utilization that causes strong vertical gradients at the surface. This will be most significant in the upper 50 meters that is, on the global average, isotopically enriched relative to the next subsurface layer by 1.3 ‰. Since only ~10 % of global benthic denitrification in the model occurs in the upper 50 meters, the uncertainty from using this sub-grid scale bathymetry scheme (< ~1 ‰) is likely much less compared to the uncertainty in the net fractionation factor chosen for benthic denitrification (ε_{BD} = 0-4 ‰), which is analyzed with sensitivity experiments in this study. This will be noted in the revised text.

Riverine $\delta^{15}N$ input is not included in this model, which can also influence some coastal settings with the input of $\delta^{15}N$ between 1-5 ‰ (Brandes and Devol, 2002). Since riverine N input (~25 Tg N yr^{-1}) is relatively small compared to benthic denitrification (≥ 150 Tg N yr^{-1}) and introduces $\delta^{15}N$ near the oceanic average, it is unlikely to have a large global impact on the ratio of BD:WCD the pre-industrial ocean. However, it still may bias the model-data comparison at some locations. We will acknowledge this additional uncertainty in Section 3.2.2 (ii) "Isotope effect of benthic denitrification" in the revised text.

While all of the water column denitrification zones in the model are connected to a continental coastline, the majority of water column denitrification occurs in the open ocean. This is generally consistent with the Eastern Tropical North Pacific and Arabian Sea suboxic zones of the real ocean. However, a significant portion of the suboxic zone in the Eastern Tropical South Pacific and Atlantic occur directly over the continental shelf, where large rates of benthic denitrification also occur. Ryabenko et al., 2012 found this strong coupling of water column and benthic denitrification on the shelf reduced the net isotope effect of water column denitrification there. However, that study was unable to determine the ratio between benthic and water column denitrification occurring on the shelf making it difficult to quantify by exactly how strong this reduction is. Since the model does not have intense water column and benthic denitrification zones in such close proximity, it likely overestimates the net water column denitrification isotope effect to some degree and thereby the model would slightly overestimate global BD:WCD ratios. We will expand the discussion of how this model deficiency may effect the global ratios of BD:WCD on P 3144 L 3-14 and include another brief discussion in Section 3.2.2 (i) in the revised text.

Iron limitation is imposed as a mask based on iron deposition rather than as a mask of surface iron concentration. This is likely to lead to overestimation of iron limitation in upwelling regions including equatorial and perhaps open ocean gyre or dome regions (e.g. Cost-Rica Dome). Subramaniam et al, 2013

GRL show high rates of nitrogen fixation in equatorial Atlantic regions.

Response: It is likely that our simple Fe limitation mask for diazotrophs may lead to an overestimation of Fe limitation near some upwelling regions. We assume all upwelled Fe will be consumed along with other upwelled macronutrients by other phytoplankton in this parameterization. However, on the global scale, N_2 fixation occurs more abundantly across the oligotrophic ocean where little upwelling occurs. We chose our Fe limitation mask of diazotrophs to best reproduce large-scale meridional d15N and $N^*=NO_3-16\times PO_4$ patterns across the Pacific and Atlantic Oceans. We will expand our description and discussion of the Fe limitation mask for diazotrophs in the revised text.

Sections 2.2.2 and 3.1.2 describe the open ocean denitrification process – which is of course determined by oxygen concentration. The model obviously does a rather poor job of representing low oxygen regions – which should be expected given its resolution. Its clear from figure 2 that low oxygen occurs in the Bay of Bengal rather than the Arabian Sea. In the Pacific, the zones of low O2 are not separated (as expected), and there is low O2 in the Atlantic which is not observed, or at least not to that magnitude. What is the total volume of low O2 water relative to the global ocean? This will affect the budget and rates. How sensitive is the model to this net volume? Is the model representing the low O2 zones in the correct density space?

Response: The volume of suboxic water compared to uncorrected WOA09 is too large by a factor of 3. However, Bianchi et al., 2012 find after accounting for biases in historical low oxygen measurements and improving interpolation/mapping methods, that WOA observations are likely underestimating the volume of suboxia by approximately a factor of 3. This shows the uncertainty in validating global suboxic volume in models and suggests that the model suboxic volume is within the observational uncertainty.

Our coarse-resolution 3D model does not completely resolve the vigorous zonal equatorial currents that ventilate the eastern equatorial regions in the Atlantic and Pacific. This deficiency results in the displacement of suboxia over the productive eastern equatorial regions, where large amounts of remineralization would be expected to stimulate too much water column denitrification. We provide sensitivity experiments that "cut-off" water column denitrification at NO_3 thresholds to prevent too much water column denitrification from occurring in the core of the suboxic zone to account for this model deficiency.

The suboxic zones in the model also extend too deep in the water column (to ~1500 m), whereas WOA09 observations do not extend below ~1000 m. Since remineralization rates are much lower at these depths, only 15% of total water column denitrification occurs here. This suggests that our best model estimate may still be overestimating water column denitrification by ~15%. The revised text will include a more in-depth discussion of these suboxic zone dynamics and their affect on water column denitrification rates.

Line 2, P3137: The discussion of nitrogen fixation states that it occurs downstream of denitrification zones. What is "downstream" for the three denitrification zones in the model? This is an important point in light of the Deutsch et al theory on coupling between denitrification and nitrogen fixation zones. I see no evidence for a link between these zones in the model as presented. Indeed, lowest seafloor 15N values occur in the Atlantic which likely has the lowest open ocean denitrification.

Response: "Downstream" indeed refers to relatively low N:P water from denitrification zones that eventually reaches the surface where diazotrophs can grow, and thus providing an ecological niche for them. This applies not only to the three water column denitrification zones, but also to the benthic denitrification zones that occur with greater global rates, as well as across all ocean basins. Thus benthic denitrification stimulates more N_2 fixation on the global scale. In fact, it is the higher benthic denitrification rates in the Atlantic Ocean that stimulates the higher N_2 fixation rates there in experiment #5 (Figure 2, right panel) compared to experiment #3 (Figure 2, center panel). Since benthic denitrification occurs at higher latitudes and at greater depths than water column denitrification, much of this low N:P water does not immediately reach the warm tropics/subtropics where N_2 fixation occurs but, in an ocean with a balanced fixed nitrogen budget, will eventually be balanced by N_2 fixation. This discussion will be expanded in the revised text.

It might be possible to further constrain the model solution based on global distribution of nitrogen to phosphorus ratios – which the model generates. This might help to better constrain the spatial patterns observed in the model.

Response: This will be done in future model versions that evaluate the impacts of climate change on the nitrogen cycle. Here we chose to focus on the evaluation of how well this new nitrogen isotope database can constrain our global 3D nitrogen isotope model and improve our understanding of nitrogen isotope dynamics.

Specific Comments

Intro:

L10, P3124 is ETSP defined previously?

Response: This will be defined here in the revised text.

L14,P3124 Is the first time N is used (N-loss) for nitrogen?

Response: This will be defined here in the revised text.

L6, P3125 This discussion might benefit from mention of river and atmospheric canonical 15N numbers.

Response: The d15N values of river and atmospheric N deposition will be mentioned here in the revised text.

Line 17, P 3127 Perform better.

Response: This change will be included in the revised text.

Line 15, P3128 Variables are described e.g. D for detritus, but then the chemical formulas are used for oxygen, phosphorus and nitrate, but then elemental ratios are described as N:P which are not defined. This also holds for C. The abbreviations N,P,C should be defined. (Also Fe)

Response: The elemental ratios for N:P and C:N for each variable will be defined here in the revised text.

L11,P3132 This should be rewritten more clearly. L13,P3132 years, not yr

Response: This sentence will be clearly rewritten in the revised text.

L1, P3139: Dilution is stated as being simulated implicitly in the model. I think this should be explicitly simulated, because you are explicitly representing the spatial heterogeneity in nitrate distributions and thus the mixing effects between high nitrate and low nitrate waters are explicitly resolved, not implicitly parameterized...

Response: This change will be include in the revised text.

L18, P3140 misspelled denitrification

Response: This change will be include in the revised text.

L17, P3143 If they had. Model equations:

I find the model equations particularly difficult to decode. This is partly due to the overlapping use of P for phytoplankton and phosphorus, and D for detritus and diazotroph. Also, growth terms u and remineralization terms μ look very similar and are challenging to discriminate.

Response: Thank you for your comments on some inconsistencies with the model equations/variables. We will review and redefine some variable symbols for clarity in the revised text.

Specific issues: Eqn B6 – when is μP used? μPO seems to be used instead in eqns A6,7

Response: Equation B6 was meant to describe the fast-recycling term for both phytoplankton, which explicitly noted as μP_0 and μP_D in Equations A6,A7. Both equations will be include in Appendix B of the revised text.

In contrast, in Eqn B9, μD describes remineralization of detritus as a fn of temperature and depth, and it appears in eqn A9 rather than μDO

Response: Equation A9 describes the prognostic equation that is dependent on temperature so it correctly appears there as μ_D. The parameter μ_{D0} only defines this rate at 0°C. This will be explained better in the revised text.

Eqn A5 – Where is the diazotroph fast remineralization?

Response: Many thanks for identifying this error! This term is missing and will be including in the revised text.

μDO – is used twice in Table A1.

Response: The symbol for diazotroph fast-recycling will be changed in the revised text for clarity.

Eqn B4 describes a continuous decay of diazotroph growth consistent with text in the model description, but line 15, P3152 states that growth is set to 0 below 15C.

Response: This phrase in the main text is incorrect and will be removed in the revised text. Equation B4 in the appendix is correct.

I cannot be confident that I have caught all the errors – if these are errors - because the symbol naming and description is too minimal.

L10, P3153 cite OCMIP protocol and write out acronym.

Response: This will be include in the revised text.

Figure 1 symbols do not match the equations. $\mu P2$?

Response: This symbol inconsistency will be corrected in the revised text.