We thank the reviewer for the careful reading of the manuscript and all the fruitful comments and suggestions. Please find below our point-by-point replies:

I. General Comments

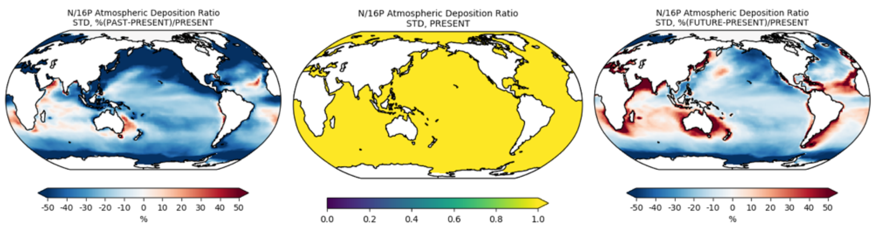
GC1. While the authors systematically validated their present day simulation against observations and described the effects of their new atmospheric nutrient deposition fields on surface ocean nutrient concentrations, as well as the rates of primary production and nitrogen fixation, I found that the quantity and organization of the material eclipsed crucial results, and that the depth of the analysis that was presented was somewhat limited. Since the title emphasizes global oceanic productivity, I was expecting significantly more discussion about the emergent rates of primary production and nitrogen fixation (currently ~1 page combined). That biological productivity/nitrogen fixation is relatively stable at the global scale while more significant changes occur regionally implies a compensatory mechanism, which is not really explored. I was looking for more information supported by encompassing and generalizing diagnostics than the numerous supplied maps could provide:

We appreciate the aforementioned valuable and constructive suggestions. Meanwhile, additional simulations were performed, and a deeper analysis of the results allowed more substantial insight into the questions raised by the reviewer. Altogether, this leads to a major revision of the manuscript taking up all the reviewers' suggestions and leading to substantial improvements.

- **How does the ratio of the atmospheric supply of nutrients change regionally/globally?**

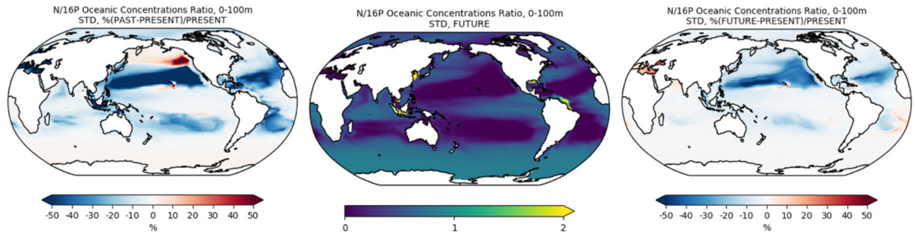
  The figure below (middle) shows the N/P ratio of atmospheric deposits relative to the Redfield ratio for the PRESENT and the changes in PAST and FUTURE periods. As can be seen for PRESENT atmospheric fluxes supply, nearly everywhere a surplus of nitrogen compared to phosphorus is demonstrated. By contrast, the same plot for surface water concentrations indicates a deficiency by nitrogen (in agreement with observational evidence). In both FUTURE and PAST periods, the atmospheric N/16P ratio is lowered which would favor N-fixation in warm water regions if not counteracted for by other processes.

  <u>**Atmospheric deposition ratios**</u>



Atmospheric nutrient deposition fluxes relative to the Redfield ratio for PRESENT (middle; values >1.0 denotes excess of nitrogen compared to phosphorus) and the relative changes for PAST (left) and FUTURE (right) for the STD simulation.

Oceanic Concentration Ratios



The implications for both productivity and N-fixation and are now discussed in the new Sect. 3.3.1 in the revised version of the manuscript, e.g., "*In regions with significant macronutrient limitations, the elemental ratio of deposited N:P can be, however, important. To estimate the relative impact of the changes in this ratio, we calculated the modeled nitrogen concentrations relative to the model's Redfield ratio (Fig. 5a). For PRESENT, the model exhibits almost everywhere a deficiency with respect to nitrogen (except for some coastal areas). This is in good agreement with data from WOA which likewise indicates a predominant nitrogen deficiency almost everywhere (Fig. 5b). Next, the N:P ratio relative to the Redfield as supplied by atmospheric deposition for PRESENT (middle) together with the changes in PAST and FUTURE (Fig. S8b) is calculated. Hence, a strong excess of N compared to P for modern times is indicated. As a consequence of the model's nitrogen deficiency (Fig. 5a), this atmospheric nitrogen excess maintains higher productivity than without the atmospheric supply. For preindustrial times, the atmospheric N:P ratio is almost everywhere reduced, thus increasing the N-deficiency. Hence, rather the lowered atmospheric nitrogen inputs than the lowered phosphorous inputs in PAST and FUTURE are responsible for the diminished productivity in these experiments. To further demonstrate this, we carried out an additional sensitivity simulation (namely PIP simulation) where, phosphorous atmospheric deposition fluxes kept constant at preindustrial levels, while the other studied atmospheric inputs (i.e., N and Fe) varied as for the STD simulation. As expected, the effect on phosphate concentrations (Fig. S9b) and productivity (Fig. S9d) in this sensitivity simulation remain extraordinarily low, i.e., the relative difference to STD is almost everywhere below 1%. This overall demonstrates that the changes in phosphorus do not play a significant role in marine productivity from preindustrial to future periods.*"

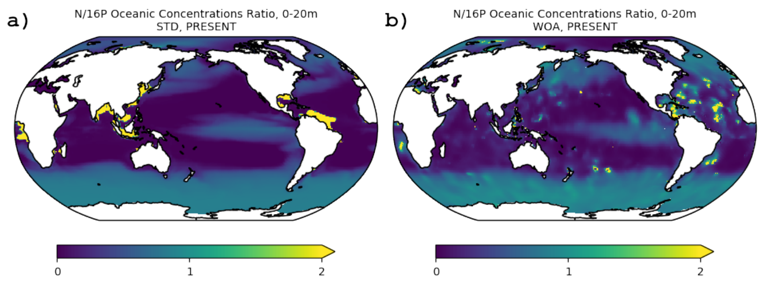


Figure 5: Molar oceanic ratios N:16P averaged in the upper 20m for PRESENT, as calculated by the model (left) and based on World Ocean Atlas (WOA; Garcia et al., 2010b) data (right). Values >1.0 denote overshoot of N vs P relative to the Redfield ratio (C:N:P =122:16:1); blue areas indicate a surplus of P or deficiency of N.

Please find a more detailed discussion in the revised manuscript.

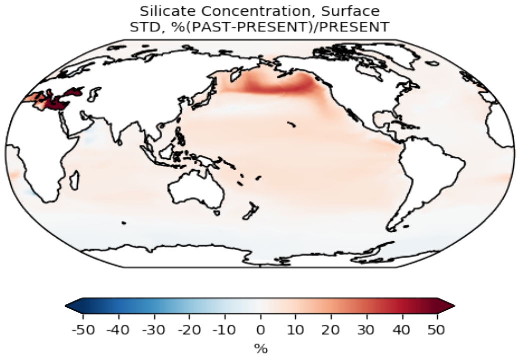
- **How does the combination of these resources promote or inhibit production vs diazotrophy?**

  The answer is complex since it varies regionally. In PAST most of the emitted nitrogen is deposited in cold water regions where the effect on N-fixation is low, while in some warm water regions iron deposition declines and further limits N-fixation by diazotrophs. In the North Pacific iron seems to be the key driver of found changes with cascading effects involving declining diatom production, nutrient accumulation in the subpolar gyre, and advective nutrient transport to remote regions.

  These interesting findings, however, are now detailly discussed in the revised manuscript, i.e., "*PISCES models two phytoplankton functional types: 1) the nanophytoplankton producing calcareous shells and 2) the diatoms producing siliceous shells (Aumont et al., 2015). In the high latitudes, a large part of productivity is related to siliceous diatoms (e.g., Malviya et al., 2016; Uitz et al., 2010) which is accounted for in the model by low nanophytoplankton to diatoms ratios (Fig. 6b). Accordingly, the overwhelming part of productivity reduction in the northernmost Pacific (Fig. 3d) is related to the decline of diatoms. This is well reflected by the increase of the nanophytoplankton to diatoms ratio for PAST relative to PRESENT (Fig. 6a). In turn, this leads to enhanced silicate concentrations in the North Pacific (Fig. 7a). Part of the unutilized silicate is advected southward via the North Pacific Current and the California Current leading also to elevated concentrations along the western coast of North America (Fig. 7a). A further consequence of the strongly diminished productivity is an accumulation of nitrogen in the subpolar gyre of the North Pacific (Fig. 2a). The nitrogen anomaly is strongest in the southwestern area of the gyre and part of the excess nitrogen is injected into the northern California Current. As a result, a strong positive and wedge-shaped productivity anomaly develops in front of western Canada in PAST (see Fig. 3d). The positive anomaly is caused by the increased production of nanophytoplankton productivity (not shown) which dominates in this region (Fig. 6b); north of the wedge lowered iron limits productivity while south of the wedge nitrate is limiting. Altogether, this reflects a slight shift from diatom production to nanophytoplankton in the eastern Pacific north of 40 °N, as indicated by a decline of ~10% of the nanophytoplankton to diatoms concentrations in the upper 20 m (see Fig. 7b).*

  Apart from the northernmost Pacific, the decline in diatom production leads almost everywhere to slightly increased silicate concentrations in PAST (Fig. 7a). Productivity changes in the Southern Ocean remain low (Fig. 3d) for PAST. The reason for this is the strong light limitation around Antarctica (Fig. 4b) and the deep mixed layer which suppresses productivity and subsequently builds up a large pool of unutilized nutrients. Part of the unutilized nutrients is advected further north into the Southern Ocean, driving productivity there. Accordingly, the reduced deposition of nitrogen and iron in this area (Figs. 1a,d) have only a slight impact on productivity. Consequently, this region is relatively robust against external nutrient input maintaining stable productivity. A similar effect is seen for the North Atlantic where vigorous exchange with Arctic waters takes place across the Norwegian-Greenland Sea. By contrast, in the subpolar North Pacific, the import of unutilized nutrients from the Arctic is hampered, as the water exchange with polar waters is limited by the shallow Bering Strait and the Aleutian Arc. Therefore, the North Pacific appears most sensitive to external nutrient inputs."

a)



b)

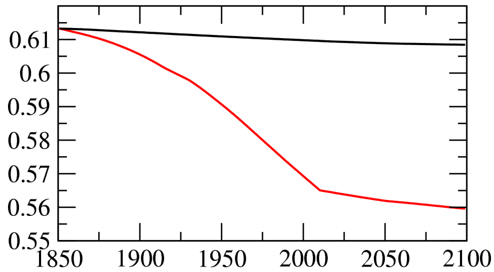


Figure 7: a) PAST to PRESENT relative differences (%) of silicate surface oceanic concentrations of as calculated by the model for the STD simulation; b) Seawater concentration ratio of nanophytoplankton to diatoms in the upper 20m, averaged over the NW Pacific (east of 200°E and north of 40°N). The red line indicates primary production rates for the STD simulation and the black line for the CTRL simulation, respectively.

- **Are phytoplankton (or diazotrophs) consuming critical resources "upstream" that inhibit "downstream" productivity via scarcity or changing nutrient ratios?**

Indeed, we found indications for this in the mid to high latitude North Pacific, where a decline in iron lowers productivity, which leads to enrichment of nitrogen which is subsequently transported southeastward where these waters cause a positive anomaly in nanophytoplankton. A comprehensive analysis is now given in the revised version (see also our reply to the previous comment), e.g.," *The North Pacific turns out to be most sensitive to iron deposition. For the preindustrial period, the lowered input of iron to this region leads to a strong decline of siliceous diatom production leading to an enrichment of silicate, nitrogen, and phosphorus. In turn, this leads to enhanced equatorward transport of nutrients resulting in elevated production rates of calcareous nanophytoplankton in the south-eastern North Pacific. Overall, the North Pacific appears most sensitive to external nutrient deposition mainly due to two reasons: 1) the strongest deposition changes take place in the northern mid to high latitudes, and 2) that compared to the Southern Ocean and the North Atlantic, the exchange with cold and nutrient-enriched polar waters is limited by land by the shallow Bering Strait and the Aleutian arc. By contrast, the southern high latitude ocean contains a large amount of unutilized nutrients that are advected further north (to mid-latitudes) making this region more robust against changes in external nutrient input. In agreement, however, with observational evidence from WOA, PISCES exhibits a widespread surplus of nitrogen compared to phosphorous and with respect to the Redfield ratio. Therefore, the applied changes in phosphorus inputs have nearly no impact on primary production in the model. Note that this applies even to the warm water regions, where reductions* *in atmospheric iron supply limit nitrogen fixation by diazotrophs in both PAST and FUTURE periods.*"

- **Are unutilized nutrients (e.g. Southern Ocean iron in the future) transported away from the surface to reemerge elsewhere and stimulate productivity remotely?**

  Yes, we found the Southern Ocean (and as well the North Atlantic) to be more robust against changes in atmospheric deposition than the N. Pacific. In the Southern Ocean, extremely cold temperatures around Antarctica (thermal isolation due to the ACC) and the widespread lack of iron further delimit productivity and thus nitrogen-enriched water are advected equatorward and maintain vigorous productivity in mid-latitudes where the iron limitation is of minor importance. The additional Fe around Antarctica in FUTURE is deposited around the coast where strong light limitation exists (we show this in the revised version. Therefore, the effect on productivity is low and nutrients are advected equatorward and maintain more or less stable production in the mid-latitudes.

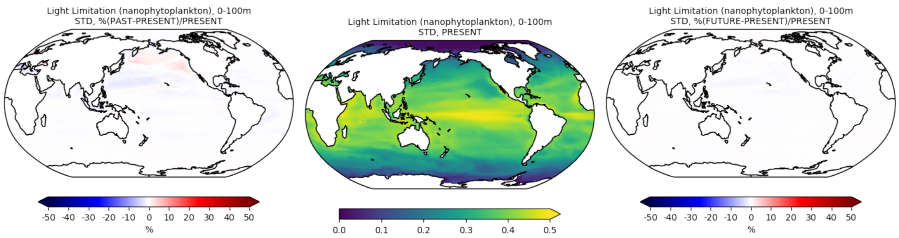
  In the North Pacific injection of nutrient-enriched Arctic waters is effectively suppressed by the shallow Bering Strait and the Aleutian volcanic arc while in the North Atlantic exchange with Arctic waters is maintained by the Norwegian current and East Greenland Current.

  Please find for more details in the revised manuscript, e.g., "*This work documents an overall low impact of atmospheric nutrient deposition scenarios on total marine primary production on a global scale. This is because much of modern productivity is driven by nutrients already recycled in the euphotic zone or by nutrient import from the deep ocean (such as in upwelling regions). Additionally, atmospheric transport appears rather important, as a significant part of nutrient deposition takes place in the northern high latitudes, where light conditions and temperature further limit productivity. Accordingly, even substantial reductions of nitrogen, phosphorus, and iron, ranging between 36 and 51% during the preindustrial period result in an only modest decline of primary production of about 3%. However, substantial local productivity changes of up to 20% were found in regions today limited by nutrients. The strongest sensitivity against atmospheric nutrients is found for the oligotrophic subtropical gyres of the North Atlantic and North Pacific. In these regions, good light conditions and warm temperatures together with low nutrient concentrations predominate. Additional atmospheric nutrient input to this region immediately results in production by increasing the biogenic turnover.*

  The North Pacific turns out to be most sensitive to iron deposition. For the preindustrial period, the lowered input of iron to this region leads to a strong decline of siliceous diatom production leading to an enrichment of silicate, nitrogen, and phosphorus. In turn, this leads to enhanced equatorward transport of nutrients resulting in elevated production rates of calcareous nanophytoplankton in the south-eastern North Pacific. Overall, the North Pacific appears most sensitive to external nutrient deposition mainly due to two reasons: 1) the strongest deposition changes take place in the northern mid to high latitudes, and 2) that compared to the Southern Ocean and the North Atlantic, the exchange with cold and nutrient-enriched polar waters is limited by land by the shallow Bering Strait and the Aleutian arc. By contrast, the southern high latitude ocean contains a large amount of unutilized nutrients that are advected further north (to mid-latitudes) making this region more robust against changes in external nutrient input. In agreement, however, with observational evidence from WOA, PISCES exhibits a widespread surplus of nitrogen compared to phosphorous and with respect to the Redfield ratio. Therefore, the applied changes in phosphorus inputs have nearly no impact on primary production in the model. Note that this applies even to the warm water regions, where reductions in atmospheric iron supply limit nitrogen fixation by diazotrophs in both PAST and FUTURE periods."

- **Are there teleconnections associated with regions of enhanced export and enriched deep water nutrients upwelling elsewhere?**

  Advection by deep waters is generally slow, and significant effects will probably emerge on multi-centennial time scales. Furthermore, diffusive mixing takes place with nutrient-rich deep waters. This makes it difficult to detect in our scenarios. In general, the export of nutrients can take place in regions where light and temperature limit productivity (further constraints relate to iron). The below figure displays exemplary the degree of light limitation for calcareous nanophytoplankton.



  Low values indicate the predominance of light limitation. Outside the polar regions where light/temperature dominates changes reflect mainly changes forced by altered productivity due to the self-shading effect. In the North Pacific light limitation clearly declines in PAST due to the more effective iron limitation. This leads to enhanced nitrogen transports southwards in regions with predominant N-limitation and subsequently enhanced productivity there.

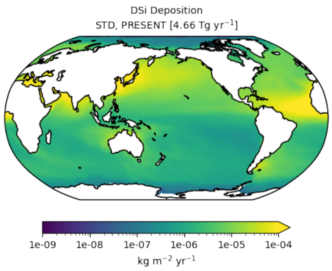
  In the revised version limitations are discussed in a broader and more comprehensive context including changes in other limiting factors (i.e., nutrients, light, Fe). Please find for more details in the revised manuscript, e.g., " *Despite the relatively strong changes in total atmospheric nutrient supply from PAST to FUTURE (Table 1), the impact of atmospheric nutrients on the global productivity rates remains low in the model. This is not unexpected, however, as the atmospheric nutrient supply constitutes only a small fraction of the total ocean nutrient inventory. In addition, oceanic regions that are not nutrient-limited today are less sensitive to external nutrient supply. Finally, a large part of primary production is regenerated by remineralized nutrients from particulate organic matter (mainly detritus) in the upper ocean layer.*

  To further identify the oceanic regions that are particularly sensitive to changes in external nutrient inputs, the limiting factors for local productivity in the model are investigated (Fig. 4). Note that we here focused primarily on changes in PAST compared to PRESENT because, in most of the cases, the changed depositional fluxes in FUTURE are roughly in the same direction as in PAST (but lower in magnitude). Figure 4a displays limitations due to nitrogen or phosphorus. High values indicating low limitation are seen in regions that are subject to intense upwelling, like in the equatorial divergence zones or the western margins of NW and southern Africa and South America (coastal upwelling). Accordingly, these regions are less sensitive to atmospheric deposition as nutrients are supplied from deep ocean layers. Lower nutrient limitation is likewise seen in the mid to high latitudes where limitations by temperature and light (Fig. 4b) limit the growth rates. Exceptions are the North Pacific, the Southern Ocean, and the equatorial Pacific where iron limitation matters (Fig. 4c). Consequently, the model's nutrient sensitivity is largest in the subtropics, in particular in the subtropical gyres where good light conditions and warm waters support high growth rates paralleled by diminished nutrient supply from depth due to Ekman pumping. Furthermore, these regions are far from land nutrient sources and so, a major part of total primary production relates to regenerated production (not directly forced by external nutrient supply). This makes the subtropical gyres sensitive to changes in the external atmospheric nutrient."

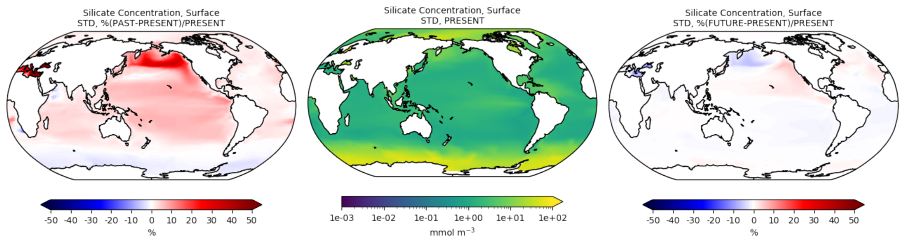
  Please find a more detailed discussion in the revised manuscript.

- **What about silicate (Si) fluxes?**

  Si atmospheric deposition fluxes into the ocean do not change from PAST to FUTURE since they are solely based on present-day dust deposition fields, as simulated from the CTM for the year 2010 (see also our reply in SC8). The atmospheric Si inputs are calculated by assuming a constant fraction of 30.8% Si by weight in the dust. 7.5% of the deposited Si is assumed soluble and thus entered in the dissolved silicate pool of the model upon deposition.

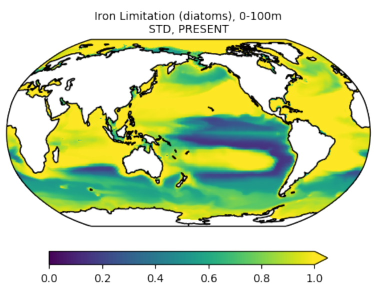


  Simulated changes in PAST and PRESENT oceanic concentrations are therefore related to changed productivity patterns (mainly diatoms). The figures below confirm that due to the lowered productivity in PAST, Si concentrations increase almost everywhere, but stronger in the N-Pacific, and further transport out of the subpolar gyre along the California Current (see below left).



- **How did the composition of phytoplankton functional groups (diatoms vs other phytoplankton) change?**

As an example, we here compare the ratio of nanophytoplankton to diatoms concentration with the iron limitation term in the respective experiments. The above figure shows the ratio of nanoplankton: diatoms (middle) and changes in PAST and FUTURE experiments. The pattern is strongly determined by iron limitation with the strongest impact in the North Pacific where iron and silicate consuming diatoms are diminished compared to nanophytoplankton.



  This likewise explains the higher silicate concentrations in the PAST. The weaker response in the FUTURE with partly decreased iron limitation is related to higher iron inputs in this region compared to PAST and PRESENT. These figures and the respective discussion are now included in the revised manuscript. The following text is added in the revised manuscript: "In the high latitudes, a large part of productivity is related to siliceous diatoms (e.g., Malviya et al., 2016; Uitz et al., 2010) which is accounted for in the model by low nanophytoplankton to diatoms ratios (Fig. 6b). Accordingly, the overwhelming part of productivity reduction in the northernmost Pacific is related to the decline of diatoms. This is well reflected by the increase of the nanophytoplankton to diatoms ratio for PAST relative to PRESENT (Fig. 6a). In turn, this leads to enhanced silicate concentrations in the North Pacific.

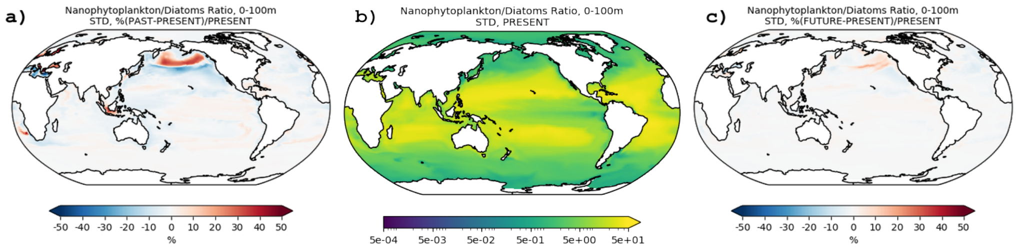


Figure 6: Nanophytoplankton to diatoms oceanic concentrations ratio averaged in the upper 100m for PRESENT (middle), and relative changes for PAST (left) and FUTURE (right) for the STD simulation.

- **Is production limited by a top-down grazing pressure, or a bottom-up resource limitation?**

  Both are true. Grazing by zooplankton delimits phytoplankton production and is most effective during intense blooms. In turn, in oligotrophic regions, the lack of nutrients limits production as well.

- **Some of these issues were touched upon when explaining the counterintuitive higher oceanic P concentrations simulated for the preindustrial era despite lower P deposition, which I found really interesting.**

  Indeed, our simulations demonstrate that the increase in P deposition fluxes into the global ocean from PAST to PRESENT is of minor importance for oceanic productivity. As a result, the present-day phosphate oceanic concentrations are calculated lower, compared to preindustrial times. To further demonstrate this, we performed an additional simulation as for STD, but keeping the DP deposition inputs to preindustrial (PI) levels (namely PIP). As expected, we get almost identical present-day oceanic phosphate concentrations and for primary productions as well. This indicates that marine biogeochemistry is more important in controlling phosphorus concentrations at the surface ocean than the direct atmospheric deposition of phosphorus, as we stated in the manuscript. The following text is added in the revised manuscript: "*As expected, the effect on phosphate concentrations (Fig. S9b) and productivity (Fig. S9d) in this sensitivity simulation remain extraordinarily low, i.e., the relative difference to STD is almost everywhere below ~1%. This overall demonstrates that the changes in phosphorus do not play a significant role in marine productivity from preindustrial to future periods.*"

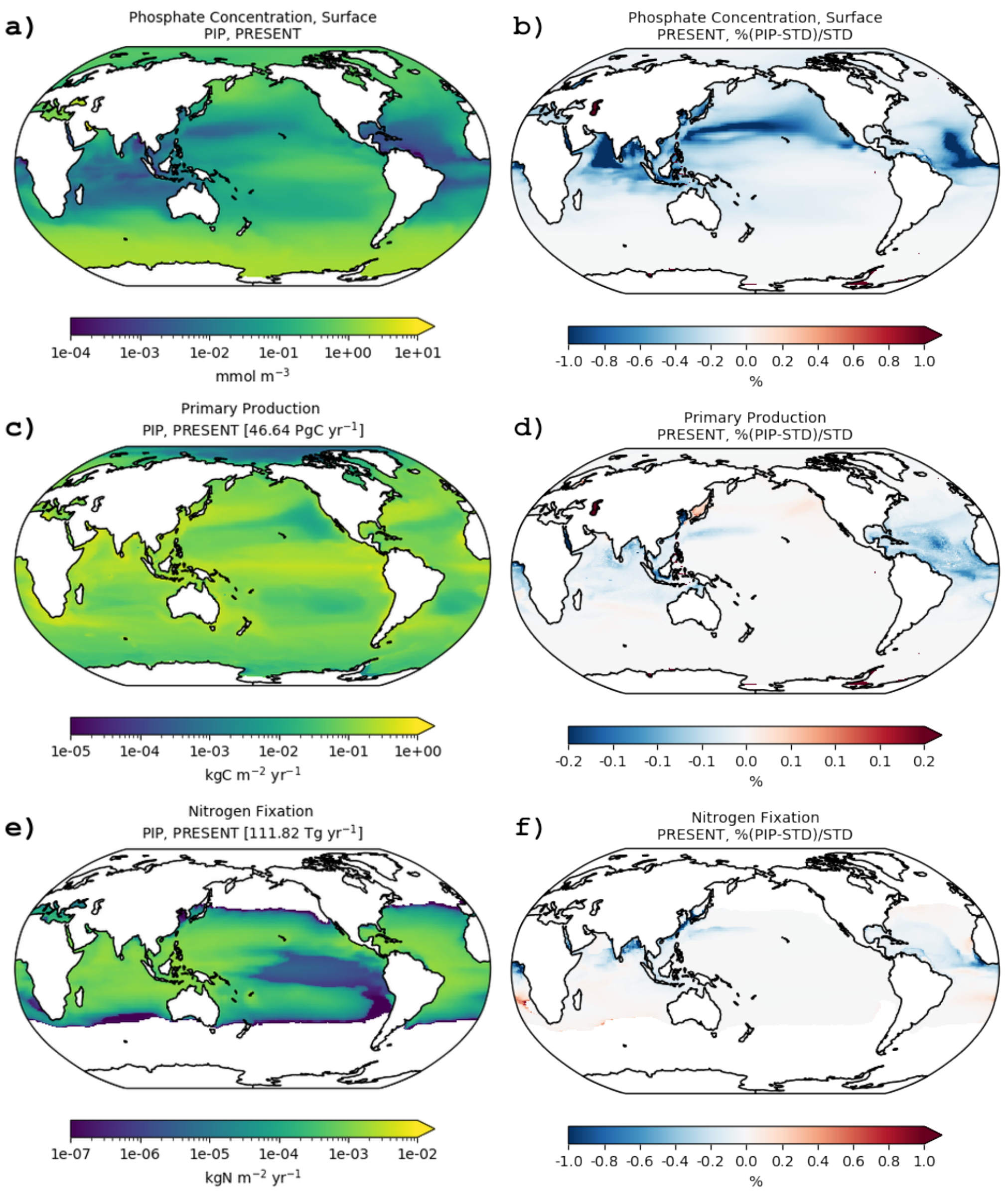


Figure S1: Surface oceanic concentrations (mmol m^{-3}) of phosphate (top row), primary production rates (kg-C m^{-2} yr^{-1}) (middle row), and nitrogen fixation (kg-N m^{-2} yr^{-1}) (bottom row), as calculated by the model for PRESENT for the sensitivity PIP simulation (i.e., as for STD, but keeping phosphorus atmospheric deposition to preindustrial levels) (left column), and the respective relative differences (%) to the STD simulation (right column).

GC2. There are many “moving parts” associated with this study that some idealized experiments might help disentangle the mechanistic role of atmospheric nutrient deposition on ocean biogeochemistry and production. Perhaps substitution experiments with the newly derived N, P, or Fe deposition singly swapped with remaining “standard” PISCES inputs (or combinations of two substituted out of three).

- We agree that more sensitivity experiments would be beneficial for a deeper analysis. This approach is limited, however, by the available resources. Nevertheless, we carried out an additional sensitivity simulation where phosphorous deposition fluxes kept constant at preindustrial levels while all other atmospheric inputs (i.e., N and Fe) changed. This run allows new insight on the importance of N and P macronutrients which is presented in the revised version. Please see our overall reply to SC1.

GC3. I appreciated the signposting of the manuscript structure at the end of the introduction, but I thought the paper would benefit from having separate "results" and "discussion" sections, with integrative diagnostics in the former, and more emphasis on explaining the changes in emergent ocean properties and comparisons with previous studies such as Krishnamurthy in the latter. At the moment, the key messages are very much buried within the qualitative/semi-quantitative description of the results.

- We agree with the reviewer and for this, the manuscript has undergone a major revision, including now a more detailed analysis. As suggested, we separated the discussion from the results in the revised version of the manuscript. For this, the discussion of productivity has completely rewritten and is substantially expanded now. Respectively, in the revised version, the conclusions are rewritten more concisely.

GC4. I also think that the model-data comparisons, although reassuring, interrupted the flow of presentation. One could create a new section on model validation, but I would recommend moving the material and figures to Supplementary information.

- Indeed, our aim was not to repeat the work of previous studies but to show, in short, that our version of the model reproduces the main features from the observations. Thus, a separate section of a model evaluation would be very limited and out of the scope of this work. However, we agree with the reviewer that the model-evaluation figures may interrupt the presentation of this work and for this, the model evaluation part has now moved to the Supplementary material of the revised version, as suggested.

GC5. One comparison that may have been really interesting to include is a comparison of the "CTRL" run to a vanilla PISCES simulation, with the standard atmospheric nutrient fluxes.

- A comparison with the standard atmospheric inputs in PISCES would be of course interesting, but we believe that the value of this study lays on providing new data set of atmospheric deposition inputs for the preindustrial, the present, and future based on realistic atmospheric chemistry and physics (i.e., based on a state-of-the-art atmospheric transport and chemistry model) and plausible scenarios for the future and past. For the standard PISCES configuration, the Fe and P deposition inputs to the ocean are based on the same dust deposition file and based on constant nutrient content and solubilities on the deposited dust aerosols. In contrast, for this work, we provide deposition fluxes based on a detailed mineralogy dataset, online mineral dissolution processes, and atmospheric chemistry for three periods (i.e., namely the years 1850, 2010, and 2100). Such a comparison would be meaningful only for the present-day deposition fields. However, for this work, we intend to rather focus on differences between different periods. Nevertheless, in the case of such a comparison, we do not expect fundamental differences at least on a global scale, as also denoted by current model evaluation compared to previous studies. Though, regional changes could be more important. All in all, we did not provide a comparison with a standard input simulation in this work, since this would be out of the scope of this work.

II. Specific Comments

SC1. P3, line 20: "no-linearly" typo.

- Changed to "*non-linearly*"

SC2. P4, line 13: "It has also been suggested. . ." citation needed, unless it's Krishnamurthy et al. (2010) in which case rephrase for clarity.

- This part is rephrased as "*Krishnamurthy et al. (2010) also suggested that the simultaneous anthropogenic N and Fe deposition can increase oceanic productivity by 1.5 Pg-C yr-1, corresponding overall to a reduction of atmospheric pCO2 level by ~2.2 ppm by the year 2100.*"

SC3. P6, line 7: "five iterations" I think it would be more precise to say you ran the model for 300 years, repeating the 60 year physical forcing five times. Five iterations could technically imply a spin-up of 5x2700s.

- We agree with the reviewer that this statement may be confusing. We rewrote this part by adding a new subsection (i.e., Sect. 2.1); please see also our reply to GC1 of Reviewer #1.

SC4. P6, line 9: Which versions of WOA and GLODAP did you use (if not WOA2013 and GLODAPv2). How was DIC initialized? Also from GLODAP?

- This part is now read as: "*For the initialization of the ocean biogeochemical fields, the climatological fields of oxygen, nitrate, silicate, and phosphate from the World Ocean Atlas 2009 (WOA; Garcia et al., 2010a, 2010b) along with dissolved inorganic carbon (DIC) and alkalinity from the Global Ocean Data Analysis Project (GLODAP; Key et al., 2004) were adopted.*"

SC5. P6, line 25: "no extra optimizations for the iron scavenging parameters" The specific iron cycle configuration is of critical importance to understanding the effect of changing iron input, please can you give more details about this? Did you use particle dependent scavenging? How is organic ligand complexation parameterized (constant or variable ligand concentration)?

- We agree with the reviewer that the iron cycle configuration is of high importance for Fe and other nutrients oceanic concentrations. Since we are mostly focused here on the differences on productivity and nutrients oceanic concentrations solely due to different atmospheric input parameterizations, the simple chemistry model of PISCES (i.e., based on one ligand (L) dissolved inorganic Fe and dissolved complexed iron (FeL)) is just used and not, for example, the complex chemistry scheme that is also available in the model (i.e., ln_fechem = F), as developed by Tagliabue and Arrigo (2006) and Tagliabue and Völker (2011), which is based on five iron species and two ligands and better match with observations. The ligand concentration in the ocean for this work is kept constant, equal to 0.6 nmol L^{-1} and the scavenging rate by dust is equal to 150 d^{-1} mg^{-1} L (see Table 1 in Aumont et al., 2015).
  We propose to add the following part in the manuscript: "*For this work, the simple chemistry scheme based on one ligand (L) dissolved inorganic Fe and dissolved complexed iron (FeL) is used. Additionally, the ligand concentration in the ocean, is kept constant, equal to 0.6 nmol L^{-1} and the scavenging rate by dust is equal to 150 d^{-1} mg^{-1} L (see Aumont et al., 2015 and ref. therein).*"

SC6. P7, lines 1-12: Timeseries of the model nutrient sources would clarify how the experiment was run i.e. I think you did one transient run 1651-2100 and analyze the nutrient concentrations/ecosystem response at three 20-year average periods. In addition, it would be great to show the temporal evolution of globally/regionally-averaged nutrient concentrations and emergent diagnostics during this run. This got me thinking about

whether the "present day" actually represents the peak in atmospheric nutrient deposition, or if that was earlier (70's, 80's or 90's)? There was no real justification for choosing the 2001-2020 average given.

- The revised manuscript (supplement) contains now time series with globally averaged depositional inputs for P, N, and Fe which clarifies how the model was forced. We also reformulated the description of the experiment in the text. The time series clearly demonstrates that the period 2000-2020 is the one with the highest deposition fluxes into the ocean, i.e.,

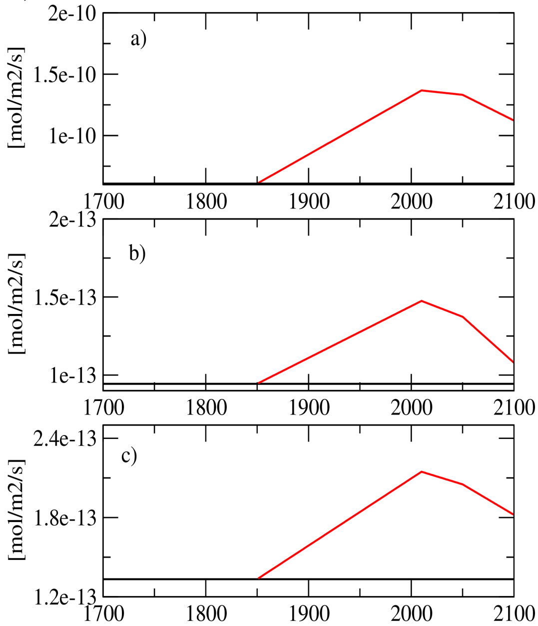


Figure S2: Globally averaged atmospheric deposition fluxes (red lines) of a) nitrogen, b) phosphorous, and c) iron in mol m^{-2} s^{-1}, as taken into account in PISCES. The black line indicates forcing for the control run under preindustrial conditions (i.e., year 1850).

- Indeed, we here performed simulations from 1651-2100, using the first 200 yrs. (i.e., 1651-1850) as a spin-up period for our experiments. For the analysis of the results, we used three 20-year average periods, corresponding to PAST, PRESENT, and FUTURE periods. The simulations with the atmospheric chemistry model comprise yearly simulations for years 1850, 2010, and 2050/2100 (using ACCMIP emissions from Lamarque et al, 2013). The reason is that the atmospheric CTMs are among the most expensive models, so the performance of transient runs over multi centennials is practically impossible. However, considering the typical residence time of tropospheric aerosols of only a few days a 1-year simulation is by far sufficient to bring the atmosphere in equilibrium. Note that for all CTM simulations a one-year spin-up is performed. Afterward, for the ocean depositional forcing, a linear interpolation between the years of the atmospheric run is applied. A more detailed explanation is now provided in the revised version, in the new Sect. 2.2. i.e.,
  "*Simulations with the atmospheric transport and chemistry model are, nevertheless, extremely expensive. Therefore, limitations in available computational resources made it necessary to reduce the CTM simulations to representative single years for 1) the preindustrial state (before 1850), 2) the present-day state (representing the year 2010), and 3) a mid-century (2050), as well as, an end of century (2100) state. However, as the typical residence time of tropospheric aerosols is in the order of a few days, the atmospheric depositional fields used in PISCES represent a well equilibrated atmospheric chemistry and deposition flux, without the need of time transient simulations.*

For the ocean biogeochemistry model spin up (i.e., from 1651 to 1850) the preindustrial field (the year 1850) was applied. After the 200 years spin-up period, the atmospheric deposition input data for the STD and ORG simulations were linearly interpolated from preindustrial to present-day conditions (i.e., the year 2010) to smoothly capture the transition from past to the modern conditions (e.g., Krishnamurthy et al., 2009). Respectively, the deposition data from the present day were linearly interpolated to the projected estimates (i.e., the years 2050 and 2100). Note that for all temporal and spatial interpolations of this work, as well as for the drift calculations applied for this work, the Climate Data Operators (CDO v.1.9.8) software, as provided by the Max Planck Institute for Meteorology, is here used (https://code.mpimet.mpg.de/projects/cdo/embedded/cdo.pdf; last access 29/02/2020). An example of the globally averaged N, Fe, and P atmospheric deposition data as simulated by the CTM and applied in PISCES is presented in Fig. S2. Overall, the here discussed simulations should be considered as idealized sensitivity experiments to estimate the response on the ocean surface properties to changed atmospheric deposition."

SC7. P7, line 12: Will these datasets be available online for ESM groups to experiment with?

- We thank the reviewer for this comment. The atmospheric deposition datasets used for this study (past, present, and future) will be available in Zenodo. A relevant statement is added to the Data availability section at the end of the manuscript.

SC8. P11, line 18: How do dust and aerosol emissions, that are not considered, vary over the time period in question? I think this is touched upon in the "summary".

- The deposition data we used for this study come from a CTM simulation using anthropogenic and biomass burning emissions (gases and aerosols) for the past (1850), present (2010), and future projected (2050/2100) eras. However, due to the nature of CTMs (i.e., offline models), these simulations do not consider changes of the meteorology for the preindustrial era or projected meteorology. Thus, dust emissions that are wind-driven, besides the impact of land-use changes, do not vary in these simulations either. Overall, changes in the deposition fields applied in PISCES for this study, represent changes in nutrient concentrations due to anthropogenic and biomass burning emissions as well as the respective impact of atmospheric chemistry (i.e., atmospheric processing). To make more clear, the following part is now added in the new discussion section (i.e., now Sect. 5): "*All changes in nutrient deposition fluxes here accounted for are solely driven by changes in the anthropogenic and biomass burning emissions, along with the changes in insoluble to soluble conversions rates due to atmospheric processing. Thus, the atmospheric deposition fields used in this study did not account for any changes in dust and bioaerosol emissions. Instead, they were kept constant to the present-day atmosphere (i.e., the year 2010), although several studies suggest that dust fluxes may be sensitive to climate change and the land-use changes (e.g., Ginoux et al., 2012; Mahowald et al., 2010; Prospero and Lamb, 2003), and thus could be an important driver of the atmospheric nutrient cycles.*"

SC9. P11, line 26: "cooler water temperatures. . ." caused also by high latitude upwelling?

- The main effect is the cooler mean climate in the high latitudes. The imprint upwelling (N-Pacific) or deep (and convective) mixing (e.g. Labrador Sea North Atlantic) also affects the pattern of SST in the model.

SC10. P12, line 5: "leads to more efficient export." N supply may certainly lead to increased rates of export in nitrate-limited oligotrophic regions, but if the nutrients are

drawn down to the same low levels, for example in the gyres, is the export actually more efficient?

- We agree with the reviewer. We replaced the word "efficient" with "*increased*".

SC11. P12, line 33: It would be an even more convincing model-data comparison if the authors took advantage of the extensive GEOTRACES iron dataset (https://www.geotraces.org/geotraces-intermediate-data-product-2017/) with 6 years of cross calibrated additional data from a concerted international effort.

- For this work, we only chose the previous GEOTRACES version because it facilitates comparison with previous studies (e.g., Aumont et al. 2015). As also stated in GC4, we use here the GEOTRACES dataset to demonstrate that our simulations produce realistic oceanic concentrations compared to previous studies, and for this, in the revised version we moved the model evaluation in the supplement (please see our reply in GC4).

SC12. P13, line 21-25: side note about Redfield ratios might be better placed with the model set up.

- The following sentence has been added to the new Sect. 2.1 (i.e., model set-up): "*The model simulates the biogeochemical cycles of carbon and the main nutrients (N, P, Fe, and Si) and includes external nutrient sources from atmospheric deposition, rivers, sea ice, sediment dissolution, and hydrothermal vents, and a constant Redfield ratio (i.e., C:N:P = 122:16:1) for growth of phytoplankton*".

SC13. **P14, line 14: Why does nitrogen fixation decrease?**

- We agree with the reviewer that this should be better explained. For this, we have analyzed it in more detail in the revised manuscript and further relate it to the decreased iron concentration in the PAST (and the FUTURE experiments), i.e., "*Note, however, that nitrogen fixation in PISCES is restricted to warm waters (i.e., above 20 °C). Therefore, the strong reductions of nitrogen deposition in the mid to high latitude North Pacific in PAST have no direct impact on nitrogen fixation. In the subtropical Pacific reduced nitrogen fixation rates mainly reflect the diminished iron input (Fig. 1d). On a global scale, the model calculates overall only a small decrease (~0.2%; Table 1) in preindustrial nitrogen fixation rates compared to present-day, mainly as a result of the decreased soluble iron inputs in the subtropical North Pacific (Fig. 1d). For the future conditions, the model likewise calculates a modest decrease in the global nitrogen fixation (~1%; Table 1) along with decreased iron inputs to the ocean (Figs. 1c,f, respectively) resulting overall in some lower rates of up to 10% in the Equatorial Pacific Ocean (Fig. 3c).*"

SC14. P14, line 22: "with the projected decrease of the global inorganic nitrogen and iron inputs. . ." Nitrogen fixation should be promoted by lower N:P ratio (i.e. decreased N and increased P) so is the lower fixation rate due to iron limitation? Is it possible to show maps of resource limitation from the model for phytoplankton/diazotrophs, e.g. the limiting terms in Equation 6 in Aumont et al. (2015)?

- This is true; in PAST simulation, nitrogen concentrations slightly increase or do not change while phosphate increases strongly. Only iron decreases, overall demonstrating the importance of iron deposition. We have unfortunately not outputted the limitation term for diazotrophs (only for nanophytoplankton and diatoms).

SC15. P15, line 32: "all dissolved organic matter is assumed to be instantaneously remineralized. . ." I think this is incorrect. Equation 32 in Aumont et al. (2015) shows how dissolved inorganic matter (for carbon and other species related by fixed Redfield ratios) is separately modeled as a pool supplied by phytoplankton and zooplankton exudation and remineralized aerobically or anaerobically by bacteria over a timescale of the order of months to years.

- We thank the reviewer for attracting our attention to this issue. We rephrased this part as: "*Note that as for the riverine organic fractions in the model (see Aumont et al., 2015), we assume here an instant transformation of the atmospheric dissolved organic nitrogen (DON) and organic phosphorus (DOP) inputs to the respective inorganic fractions in the water column.*"

SC16. P16, line 19: "in contrast to the rather balanced nitrogen fixation rates. . ." a 2% change in primary production also sounds rather balanced to me.

- We agree with the reviewer and we removed this part.

SC17. P16, line 20-28: 15-20% increases occur relatively widely in the ocean, so what causes the counterbalancing decline in productivity? Why are the decreases confined to these bands in the Pacific?

- In ORG increased iron input in the sub-polar gyre increases diatom production leading to more consumption of nitrate. Subsequent transport of nitrogen diminished waters further to the south cause a decrease in productivity further south. In the tropical north Pacific, we find a small zonal dipole pattern of decreased (north) and increased (south). The boundary between decreased and increased bands matches the sharp boundary from iron limitation to non-iron limitation (see example below). We suppose increased iron input south (where iron limitation is) stimulates the production and diminishes nitrogen. Advective mixing of the N-diminished waters with water further north decreases productivity leading to the dipole pattern as presented in the old Figure 4 (i.e., in the submitted version).
  This analysis is now included in the revised version, i.e., "*Primary production increases almost in all ocean basins for the ORG simulation (Fig. 8d), except some parts of the Subpolar Pacific Ocean. In particular, higher rates are calculated in the subpolar Atlantic Ocean (up to 15%). In the N-limited oceanic regions, the increased ORG atmospheric nitrogen deposition (Fig. S3b) directly increases the production rates (Fig. 8d). Such a case is the western subtropical North Pacific, where atmospheric N deposition supports an extra production of up to 15%. The production rates are also increased in the subtropical South Pacific and Atlantic Oceans up to nearly 20% in the ORG simulation. In total, the primary production increased from ~46.7 Pg-C yr-1 for the STD to ~47.8 Pg-C yr-1 for the ORG (Table 1). Figure 8d points out to regions in the Pacific where production decreased. For the North Pacific, however, this represents the same mechanism as described above for the differences in primary production rates between PAST and PRESENT. For the ORG simulation, the increased iron input in the Pacific subpolar gyre increases diatom production leading to higher consumption of nitrate (Fig. S10b). Subsequent transport of nitrogen diminished waters further to the south cause a decrease in productivity further south. The boundary between decreased and increased bands matches the sharp transition from iron limitation to nitrogen limitation (Figs. 4a,c). Increased iron input south of the boundary (i.e., where iron limits) stimulates the production and diminishes nitrogen. However, the advective mixing of the N-diminished waters with waters further north decreases productivity north of the boundary (i.e., where N limits). Overall, the result is the dipole pattern as demonstrated in Fig. 8d.*"

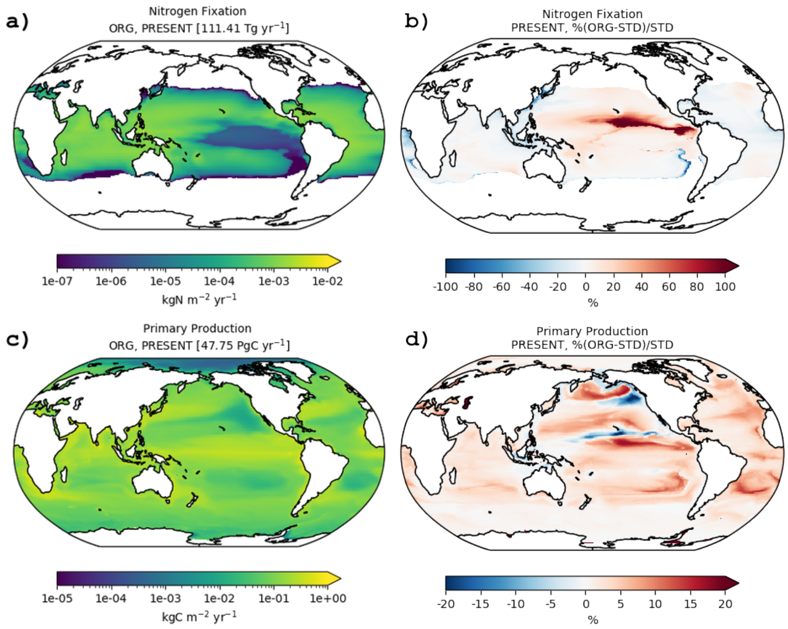


Figure 8: Nitrogen fixation (kg-N m^{-2} yr^{-1}) and primary production (kg-C m^{-2} yr^{-1}) rates as calculated by the model (a,c) for the ORG simulation for PRESENT (2001–2020 average), and the respective relative (%) differences (b,d) compared to the STD simulation.

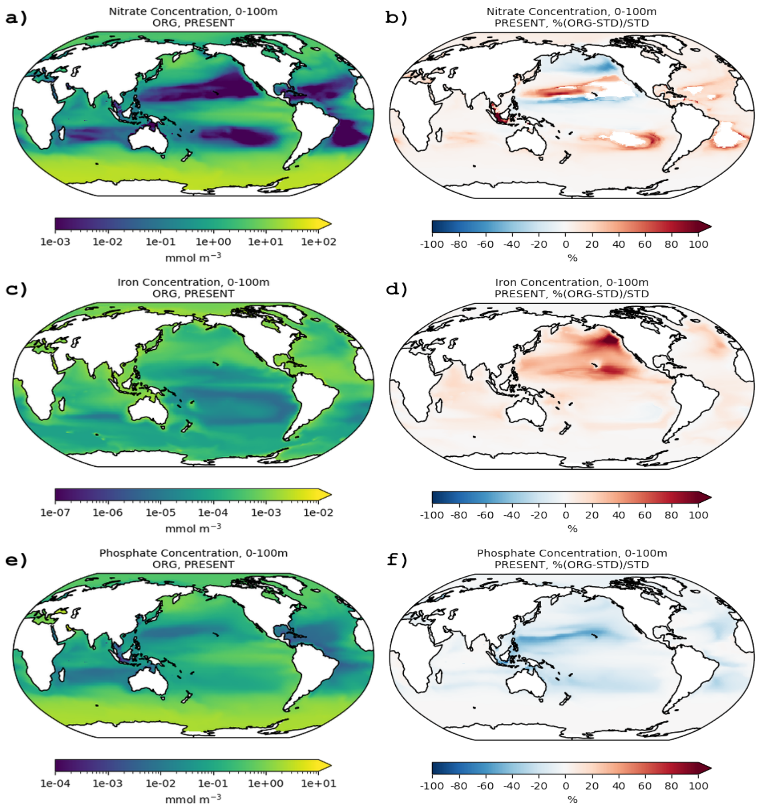


Figure S3: Oceanic concentrations averaged over the upper 100m (left column) of nitrate (a), iron (c) and phosphate (e) as calculated by the model for the ORG simulation for PRESENT (2001–2020 average), and the respective percentage differences (b,d,f) compared to the STD simulation (right column).

SC18. P17, line 13-20: Salinity restoring and mixed layer dynamics was never mentioned in the main text, so surprised to see it prominently in the "Summary" section.

- For this work salinity restoring was only applied during the OMIP run from which the physical ocean forcing for the offline PISCES runs were generated. The salinity of the biogeochemical offline runs is, however, constant, representing only the yearly cycle on a daily basis. To avoid any confusion, we removed this part from the text, since the prolongation of the run for the RCP8.5 scenario is not that relevant for this study. Note, however, that a complete description of the forcing data used for this study is now added in Sect. 2.1 in the revised version.

SC19. Figures: It would be preferable to use a perceptually uniform color palette for the CTRL maps, as opposed to the rainbow/jet colormap currently shown (see here for details: https://blogs.egu.eu/divisions/gd/2017/08/23/the-rainbow-colour-map/, not to mention the accessibility issue surrounding red/green vision deficiency).

- We thank the reviewer for attracting our attention to this issue. We replotted all figures using standard perceptually uniform colormaps, such as Viridis, (see https://bids.github.io/colormap/)