A state-of-the-art parameterization of atmospheric nutrient deposition fluxes in the global ocean*

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INTRODUCTION

✓ Atmospheric deposition of trace constituents, both of natural and anthropogenic origin, can act as an external source of nutrients for the open ocean and thus affect the marine ecosystems.

✓ Human activities have heavily perturbed the atmospheric chemical composition but the impact on marine biogeochemistry and is still not fully understood.

The Modelling Tool

➤ The state-of-the-art biogeochemistry model PISCES (Aumont et al., 2015), enabled here within the European Earth System Model (ESM) EC-Earth (http://www.ec-earth.org/), is used to investigate the impact of atmospheric deposition fluxes of N, Fe and P on the marine productivity.

➤ PISCES 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.

➤ PISCES includes two types of phytoplankton, namely nanophytoplankton and diatoms, and it simulates the chlorophyll concentrations and the growth of phytoplankton based on nutrients' availability (i.e., DP, DN, and DFe for nanophytoplankton and DP, DN, DFe, and DSi for diatoms), temperature and light.
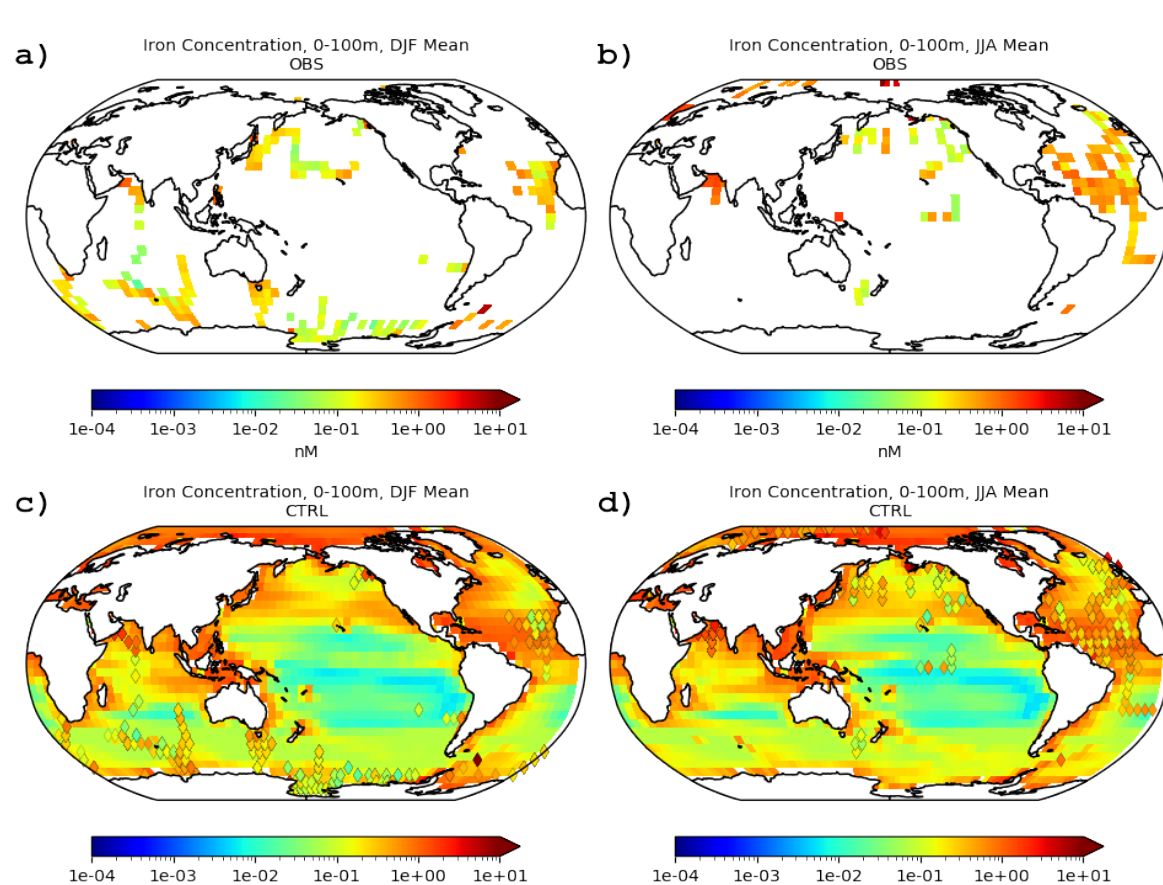
MODEL EVALUATION

Oceanic Nitrate Concentrations


Oceanic Iron Concentrations
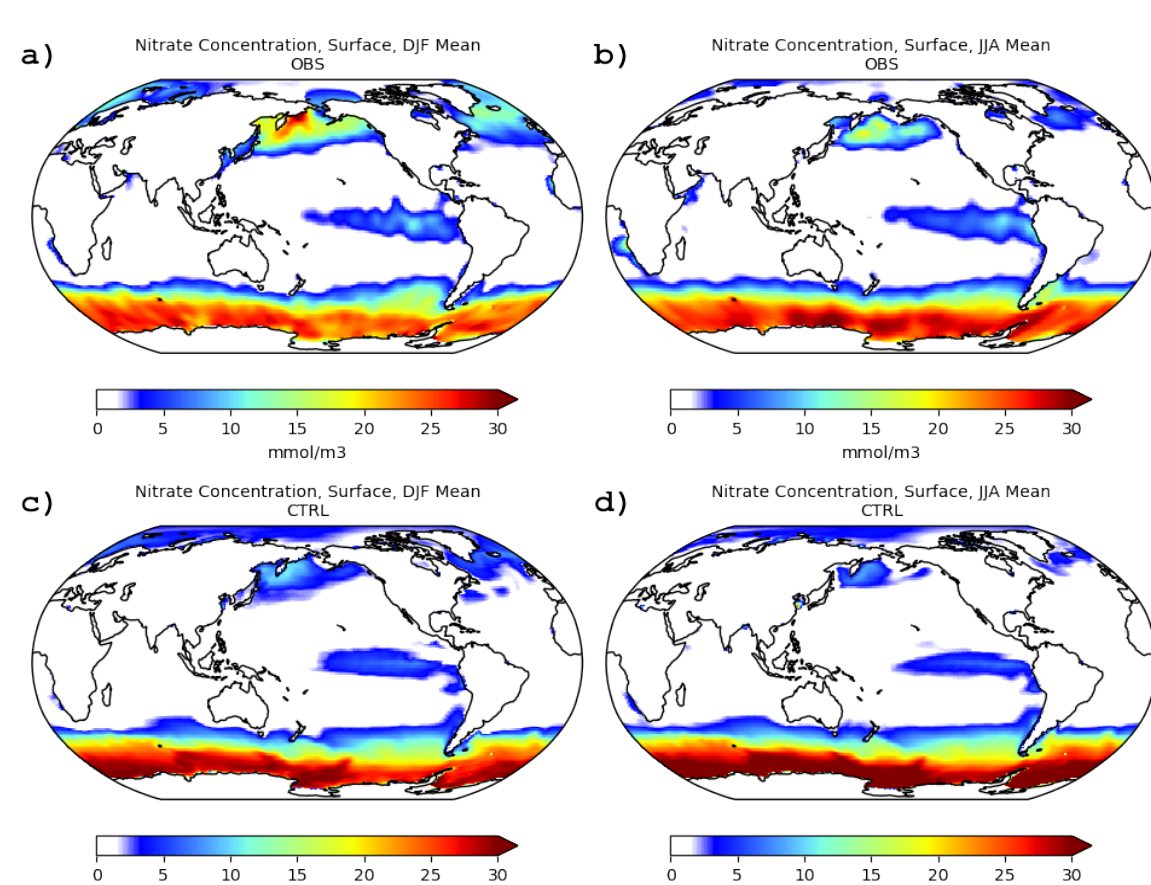
Surface nitrate concentrations (mmole m-3) for the boreal winter (DJF; left column) and summer (JJA; right column) seasons as compiled from the World Ocean Atlas (WOA; Garcia et al., 2010b) (a,b), the simulated concentrations for PRESENT as simulated for CTRL (c,d).

Iron concentrations (nM) averaged over the upper 100m for the boreal winter (DJF; left column) and summer (JJA; right column) seasons (a,b) as compiled by Tagliabue et al. (2012) (OBS), the respective simulated concentrations for PRESENT (c,d) as simulated for CTRL (diamond symbols represent observation data).

Biogeochemistry responses to atmospheric organic nutrients
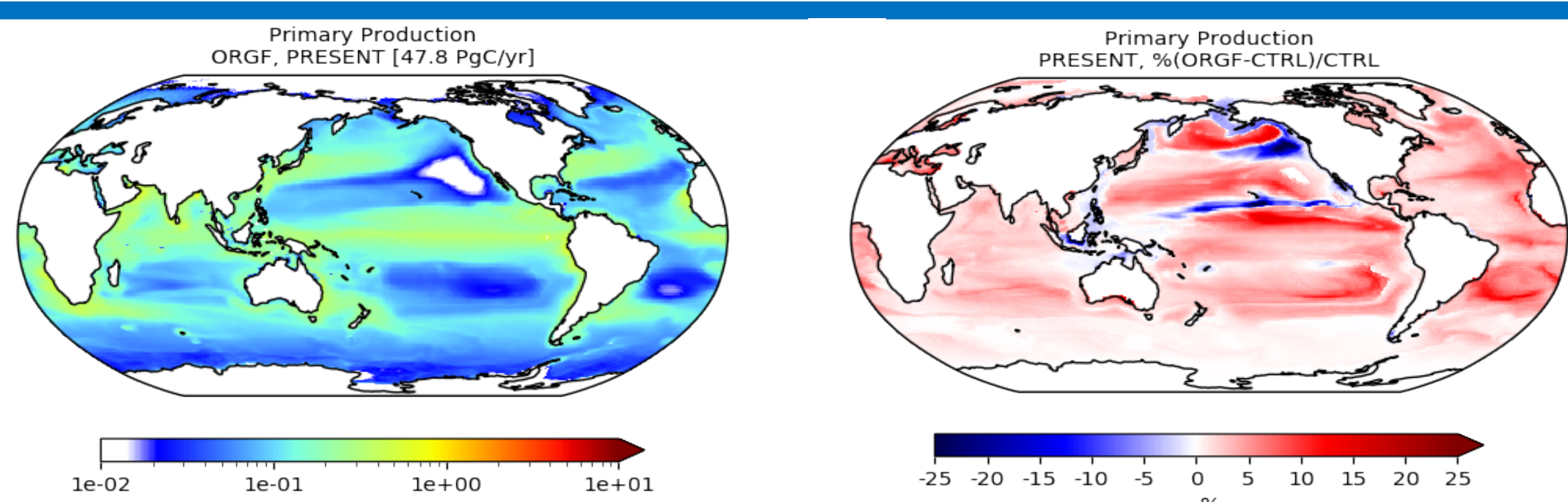
➤ The primary production rates increased from ~46.7 Pg-C yr^{-1} for the CTRL to ~47.8 Pg-C yr^{-1} for the ORGF.

➤ This increase may correspond to a decline of atmospheric pCO2 of ~1.3 ppm, solely when accounting the organic fraction in atmospheric inputs in the model.

➤ Primary production increases almost in all ocean basins for the ORGF simulation.

➤ High rates are calculated in the Subpolar Atlantic Ocean (up to 15 %).

➤ In the N-limited oceanic regions, the increased ORGF atmospheric nitrogen deposition directly increases the production rates.

➤ In the western subtropical North Pacific, the atmospheric N deposition supported an extra production up to 15%.

➤ The production rates are increased in the open subtropical South Pacific and Atlantic Oceans up to nearly 20% in the ORGF simulation.

AIM

I. To investigate the effect on ocean biogeochemistry in the context of atmospheric forcings for preindustrial, present, and future periods (BASE simulation).

II. To estimate the contribution of the organic forms of atmospheric nutrients in the oceanic productivity calculations (ORGF simulation).

Atmospheric Input Parameterizations

The atmospheric nutrient inputs are derived from the global atmospheric CTM TM4-ECPL and are employed as external forcings in PISCES.

➤ For the calculation of the atmospheric N-cycle, the CTM uses primary emissions of NOx, NH$_3$, marine amines, and emissions of particulate organic nitrogen (ON) from natural and anthropogenic sources (Kanakidou et al., 2016, 2018).

➤ The atmospheric Fe cycle is parameterized considering Fe emissions associated with minerals in dust and combustion processes. The CTM accounts for acid- and organic ligand-solubilizations of dust aerosols, as well as for the ageing of the Fe-containing combustion aerosols via atmospheric processing (Myriokefalitakis et al., 2015, 2018).

➤ The atmospheric P-cycle is calculated based on emissions of insoluble mineral P, phosphate, and insoluble and soluble organic P (OP) from natural (i.e., dust, bioaerosols, sea spray and, volcanic aerosols) and combustion aerosol emissions. The CTM accounts for the acid solubilization of dust particles, along with the ageing of the OP-containing aerosols (Myriokefalitakis et al., 2016).
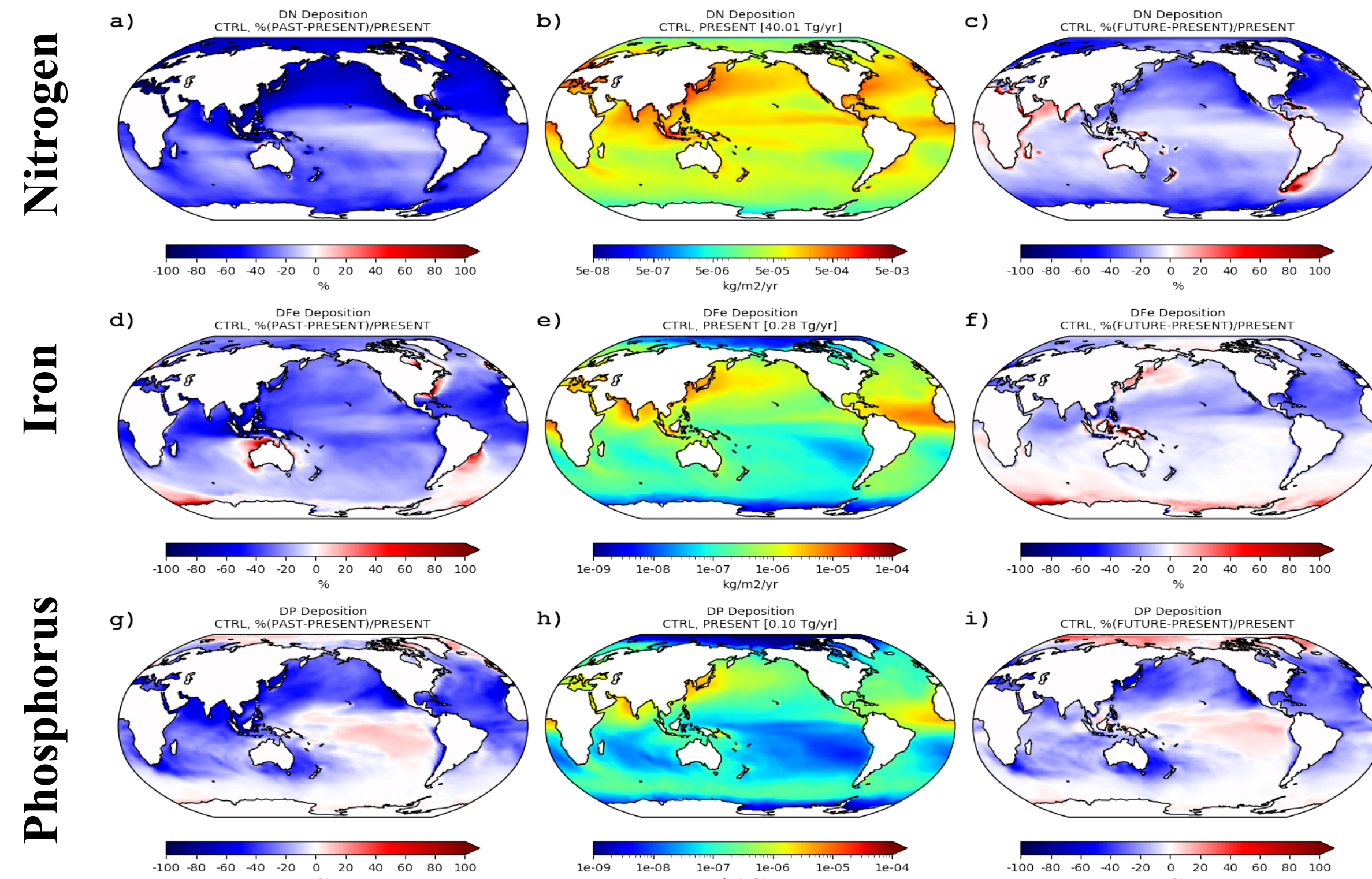
CONCLUSIONS

i. State-of-the-art global nutrient deposition fields are here coupled to the biogeochemistry model PISCES to investigate the effect on ocean biogeochemistry

ii. Present-day atmospheric deposition fluxes of inorganic N, Fe, and P over the global ocean are accounted equal to ~40 Tg-N yr^{-1}, ~0.28 Tg-Fe yr^{-1} and ~0.10 Tg-P yr^{-1}. The resulting globally integrated primary production of roughly 47 Pg-C yr^{-1} is well within the range of satellite-based estimates and other modeling predictions.

iii. Preindustrial atmospheric nutrient deposition fluxes are lower compared to present-day (~51%, ~36%, and ~40% for N, Fe, and P, respectively), resulting here in a lower marine primary production by ~3% globally.

iv. Future changes in air pollutants under the RCP8.5 scenario result in a modest decrease of the bioaccessible nutrients input into the global ocean compared to present-day (~13%, ~14% and ~20% for N, Fe and P, respectively), without significantly affecting the global projected primary production in the model.

v. Sensitivity model simulations indicate that the contribution of nutrients' organic fraction results in an increase in primary production by about 2.4%. Although the relatively weak response of marine productivity on a global scale, stronger regional effects up to ~20% are calculated in the oligotrophic subtropical gyres.

vi. This work provides a first assessment of the contribution of the organic forms of atmospheric nutrients in marine productivity estimates.