Modeled Impact of Dynamic Dust Deposition on Pacific Ocean Biogeochemistry

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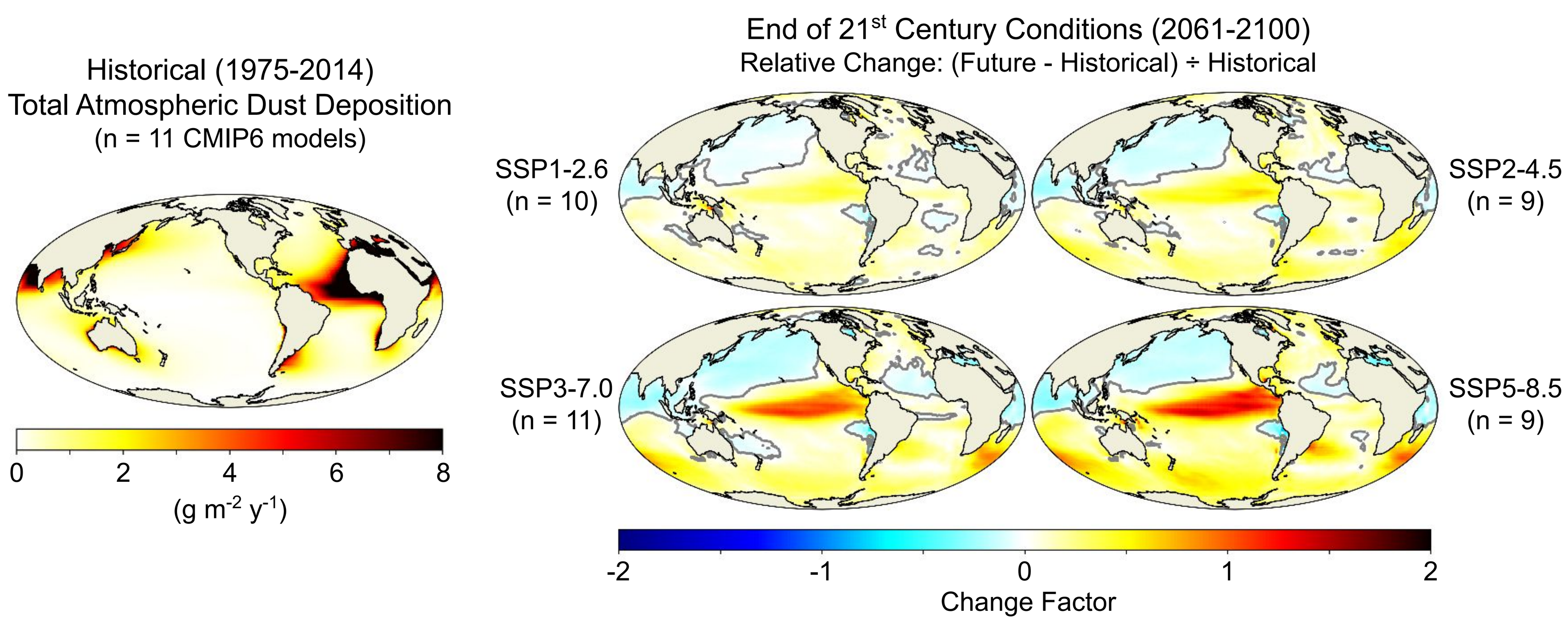
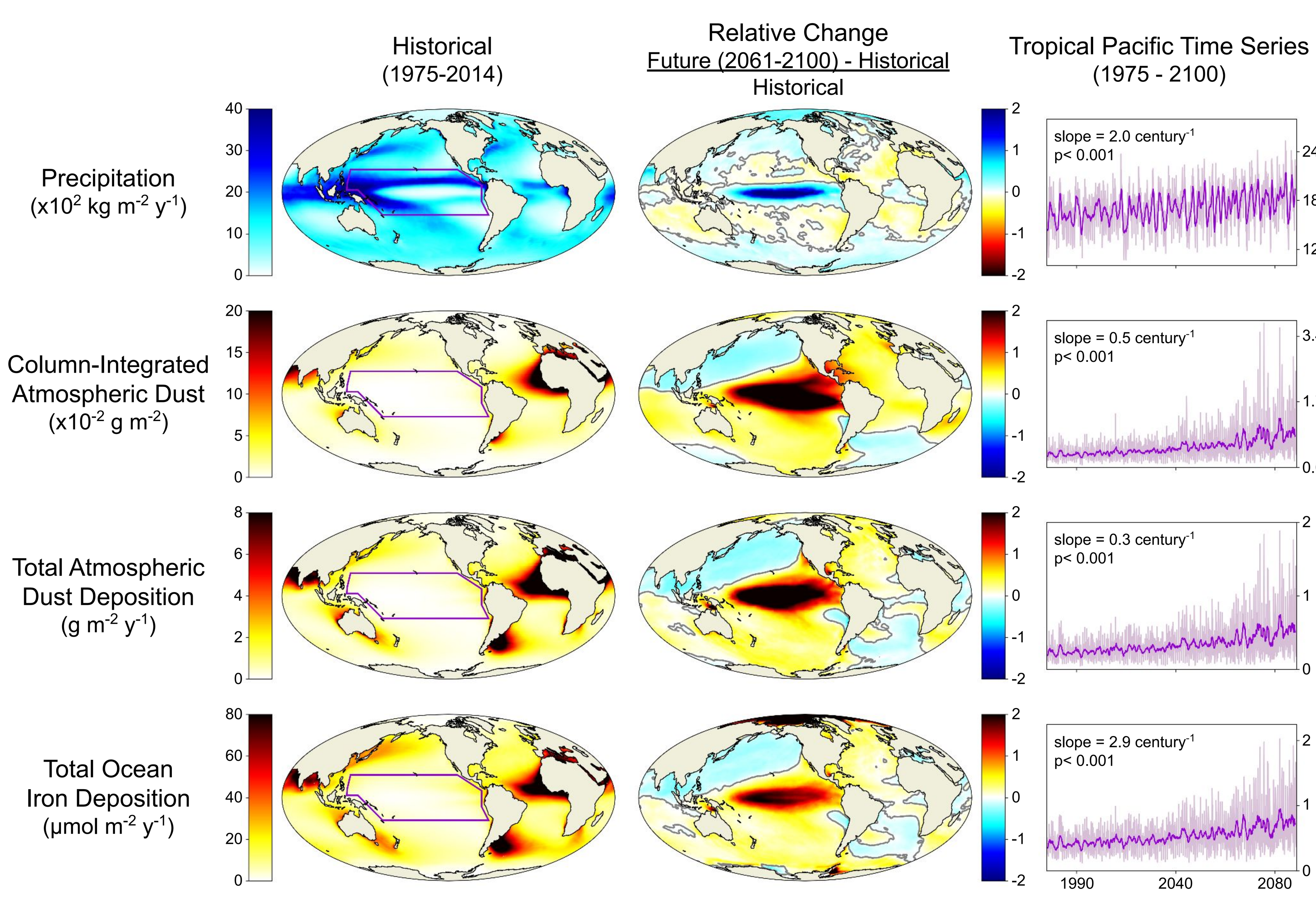
CMIP6 models project increasing atmospheric dust deposition to the equatorial Pacific Ocean under elevated radiative forcing futures

Shared socioeconomic pathways (SSPs[1]) describe possible future scenarios given factors such as global development, policy decisions, and the resultant greenhouse gas emissions and radiative forcing over the next century. Several modeling centers contributed output from historical and SSP projection experiments to the Sixth Coupled Model Intercomparison Project (CMIP6) that included diagnostics for dust deposition. Here we show the multi-model (n = number of models) mean historical and future change in the total flux of dust (i.e., wetdust + drydust deposition) from the atmosphere, with deposition increasing over the Pacific Ocean under higher SSPs.



Changes in dust and iron deposition to the ocean are connected to changes in precipitation and atmospheric dust levels

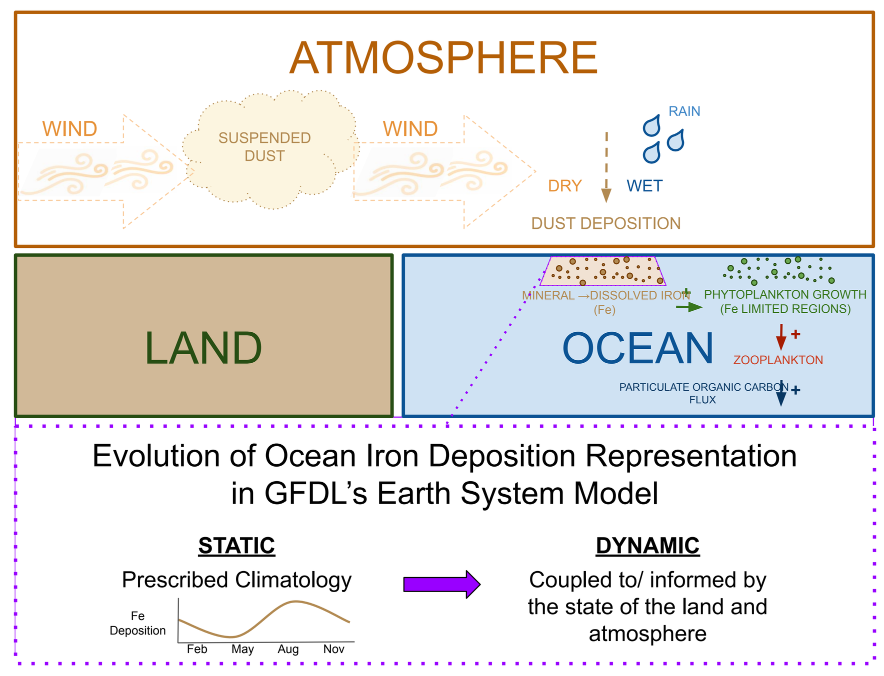
Here we demonstrate the mechanistic and connected nature of the atmospheric processes that affect dynamic dust and iron deposition to the ocean using output from GFDL's ESM4[6]. The relatively large increase in iron deposition to the Pacific Ocean under SSP5-8.5 future conditions is associated with elevated precipitation and atmospheric dust levels. The timeseries (right column) illustrate statistically significant trends in the respective diagnostics that are spatially averaged over the region outlined in purple in historical mean plots.



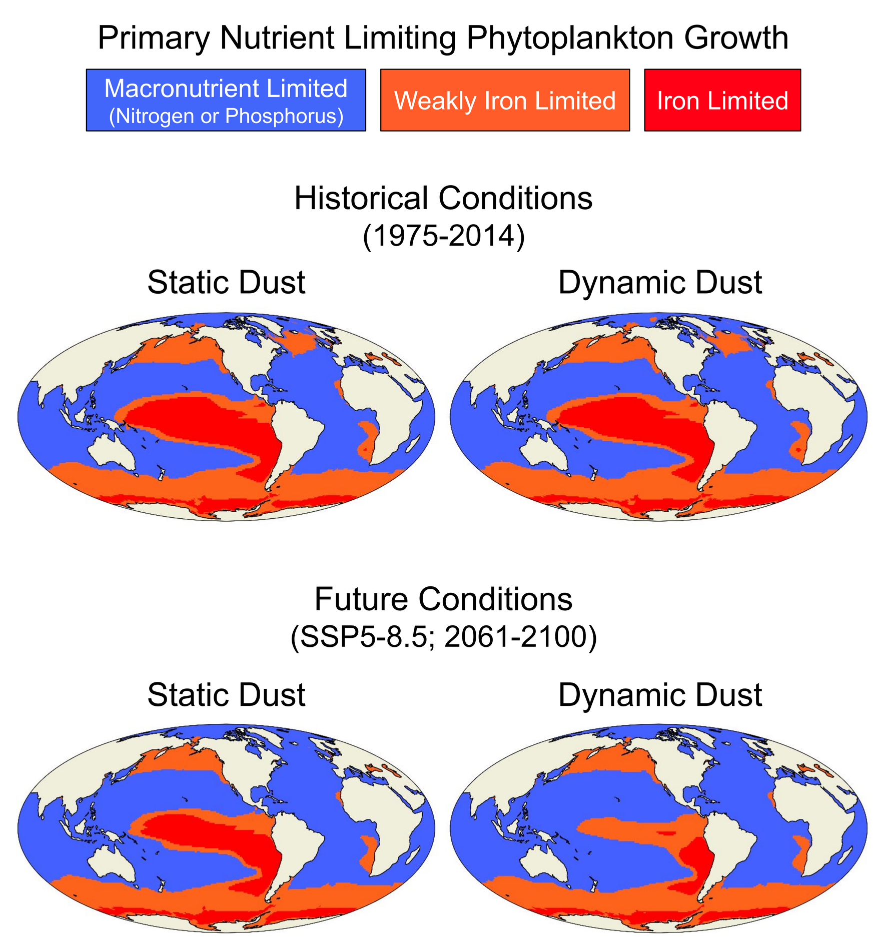
Dynamically representing dust deposition communicates variability due to changing land use and atmospheric conditions to the ocean

Earth System Models (ESMs) simulate processes and interactions across land, atmosphere and ocean systems. The schematic on the right illustrates some of the processes involved in an ESM's representation of dust transport: dust sourced from the land model is advected through the atmosphere, over the ocean, and deposited to the ocean surface. Dissolution of these mineral aerosols releases biologically-available iron, which stimulates phytoplankton growth and subsequent stages of the biological pump in iron limited regions of the ocean such as the eastern equatorial Pacific[2].

Several ESM contributions to CMIP6[3,4,5,6] implement dynamic coupling of atmospheric dust deposition. This is in contrast to earlier CMIP ESMs that parameterized iron deposition as a preindustrial or historical climatology[7], which omits the role of interannual and multidecadal dust variability in ocean biogeochemical (BGC) processes[8]



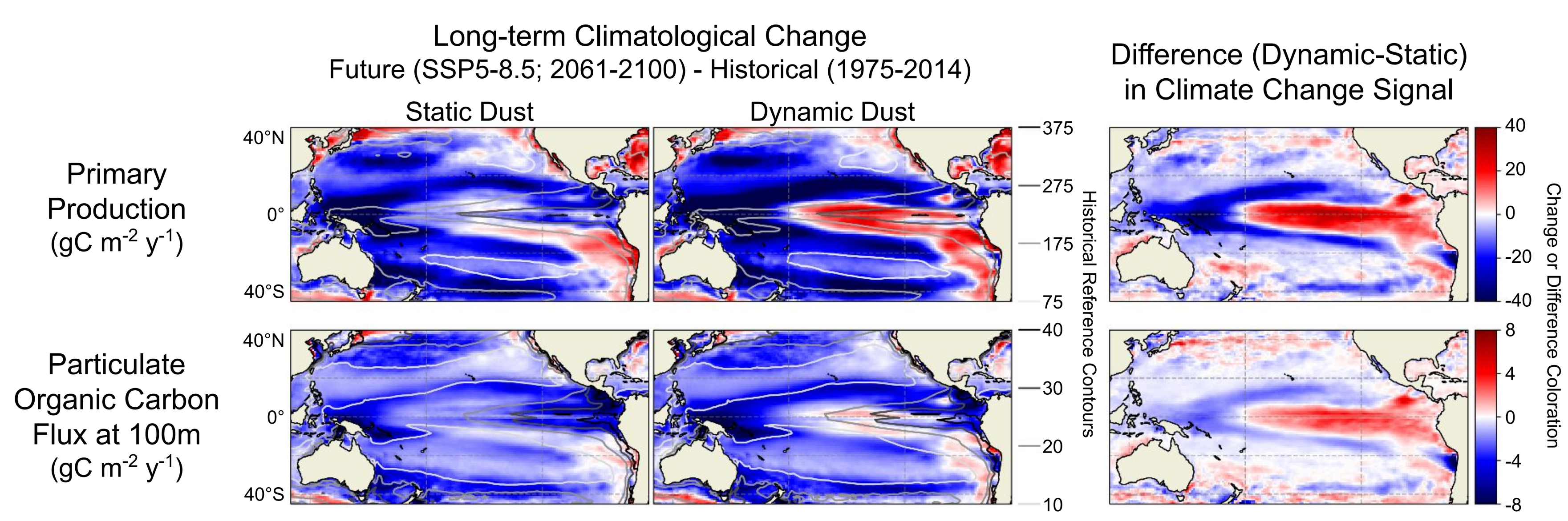
Dynamic vs. static dust deposition affects projections of Pacific phytoplankton nutrient limitations and related BGC diagnostics



To investigate the effect of dynamic dust (DD) deposition on GFDL's ESM4 projections of ocean BGC, we ran complementary ESM4 "static dust" (SD) experiments wherein deposition of iron and lithogenic material to the ocean was prescribed as a preindustrial climatology rather than dynamically informed by the atmosphere.

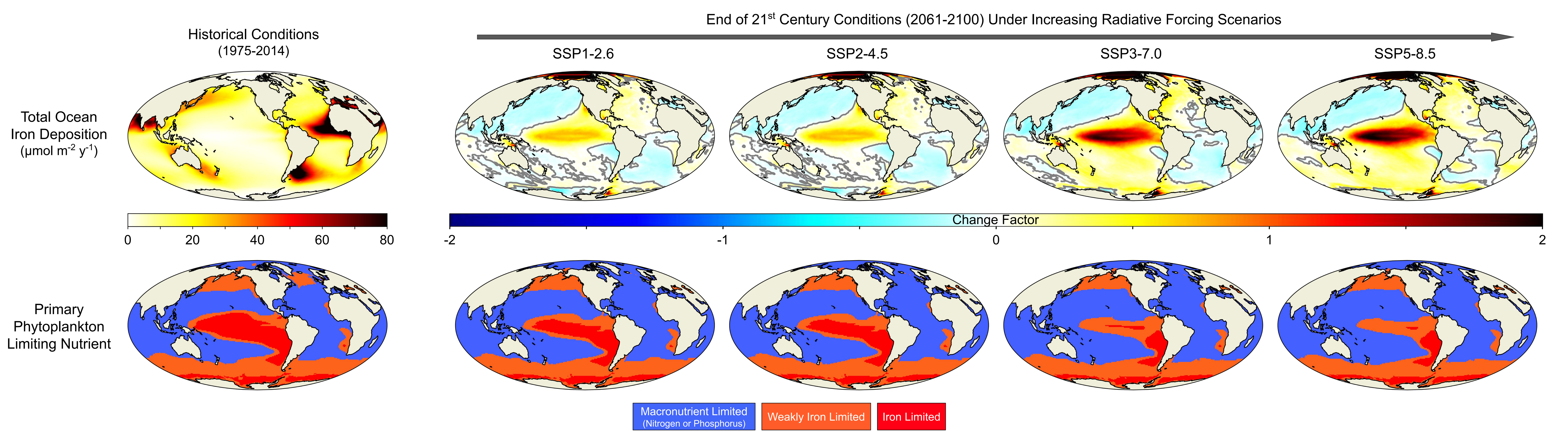
Spatially, the distribution of the primary nutrient limiting phytoplankton growth (left) is roughly the same between SD and DD under historical conditions. However, under a high radiative forcing scenario (SSP5-8.5), the DD simulation projects a latitudinal and eastward contraction of iron limitation in the equatorial Pacific that is not exhibited to the same extent in the SD simulation.

Changes in primary production and particulate organic carbon flux in the equatorial Pacific (below) echo this pattern. Relative to the SD simulations, DD drives more positive changes in the eastern equatorial Pacific where iron deposition continues to stimulate phytoplankton growth in iron limited areas. This region is outlined by greater declines where macronutrients have become most limiting due to both the higher availability of iron and reduced concentrations of nitrogen and phosphorus due to their upstream consumption where phytoplankton growth is elevated[9,10].



Dynamic dust deposition permits greater variability in tropical Pacific nutrient limitation under different radiative forcing scenarios

ESM-evolution towards more holistic representation of land-air-sea interactions has important implications for projecting potential fates of marine ecosystems in a changing climate. Under future scenarios wherein land use, elevated temperature and changes in precipitation substantially alter the transfer of mineral aerosols to the surface ocean, dynamic representation of dust/iron deposition to the ocean is crucial for anticipating basin-scale distribution of primary production and nutrition availability for higher trophic level organisms, including lucrative fisheries.



Additional Methods

CMIP6 model output used for the multi-model mean figure (top left) for historical conditions and relative changes in total atmospheric dust deposition under [a]SSP1-2.6, [b]SSP2-4.5, [c]SSP3-7.0, [d]SSP5-8.5 are listed below; With the exception of GFDL ESM4, model output was acquired through the World Climate Research Programme database:

EC-Earth3-AerChem[c], CanESM5[a,b,c,d], CESM2[a,b,c,d], CESM2-WACCM[a,b,c,d], GFDL-ESM4[a,b,c,d], INM-CM4-8[a,b,c,d], INM-CM5-0[a,b,c,d], IPSL-CM5A2-INCA[a,c], MIROC6[a,b,c,d], MRI-ESM2-0[a,b,c,d], NorESM2-LM[a,b,c,d]

All other figures were generated using output from GFDL ESM4. For the static dust simulations, only projections under SSP5-8.5 were generated.

References

[1]O'Neill et al. 2016. *Geoscientific Model Development*
[2]Moore, et al. 2013. *Nature Geoscience*
[3]Hajima et al. 2019. *Geoscientific Model Development*
[4]Sellar et al. 2019. *Journal of Advances in Modeling Earth Systems*
[5]Danabasoglu et al. 2020. *Journal of Advances in Modeling Earth Systems*
[6]Dunne et al. 2020. *Journal of Advances in Modeling Earth Systems*
[7]Séférian et al. 2020. *Current Climate Change Reports*
[8]Lim et al. 2022. *Geophysical Research Letters*
[9]Moore et al. 2004. *Global Biogeochemical Cycles*
[10]Hamilton et al. 2020. *Global Biogeochemical Cycles*