Initial DECK analysis of the carbon cycle in GFDL's CM4 contribution to CMIP6

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Abstract

As part of the currently ongoing sixth Coupled Model Intercomparison Project (CMIP6), modeling centers have focused on improving the resolution from nominally 2 degree atmospheres and 1 degree oceans in CMIP5 to nominally 1 degree atmospheres and 1 to ¼ degree oceans in CMIP6. Similarly, they have made great strides in comprehensiveness, and fidelity including improving surface temperature, wind patterns and variability, and ocean boundary currents in of these physical models which will allow for more accurate and robust determination of ocean biogeochemical interactions. The experimental design of CMIP6 (Eyring et al., 2016) includes not only a standard set of Design, Evaluation, and Characterization of Klima (DECK) experiments, but includes two dedicated Intercomparison efforts of ocean biogeochemical cycling through the Ocean Model Intercomparison Project (OMIP; Griffies et al., 2016; Orr et al., 2016) and experiments with fully coupled ESMs through the Coupled Climate-Carbon Cycle Model Intercomparison Project (C4MIP; Jones et al., 2016). These sets of experiments will provide an unparalleled comprehensiveness in terms of historical experiments of ocean heat, carbon and transient tracer uptake in the historical context with ocean only and fully coupled models as well as experiments designed to improve the mechanistic attribution of climate and chemistry driven changes. GFDL's CM4 contribution to CMIP6 includes a ¼ degree MOM6 ocean with 75 hybrid layers and a second generation Biogeochemistry with Light, Iron, Nutrients and Gas (BLINGv2). As an initial analysis, we compare the GFDL CM4 ocean carbon results with advanced observations, syntheses, and inverse modeling products including GLODAPv2 effort to synthesize shipboard ocean carbon observations, the SOCAT effort to supply updated climatologies and time dependent analysis of ocean pCO2 and air-sea CO2 fluxes from surface underway sampling, individual inverse modeling studies and larger, programmatic efforts like the Global Carbon Project.

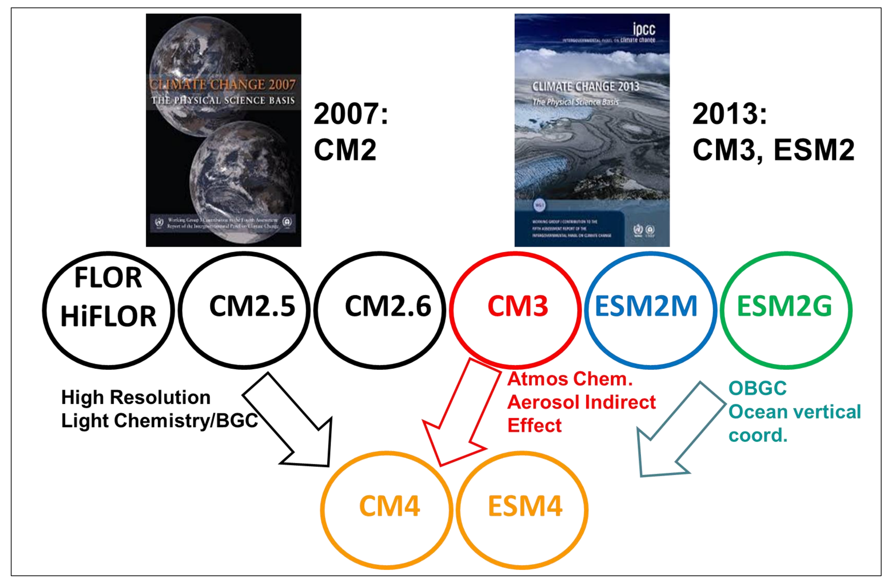


Figure 1: *Chart of the origins of CM4. Additions from prior models were used to create CM4. CM2.5 included a 1/4° ocean whereas CM2.6 included a 1/10 ° ocean.*

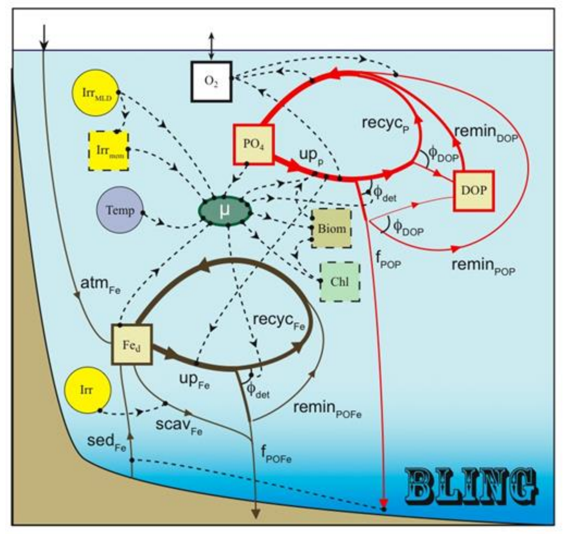


Figure 2: *Visual scheme of BLING interactions, with the most current being the second version BLINGv2 which is used in CM4. Squares outlined with solid lines show prognostic tracers. Environmental state variables are identified as circles; whereas diagnostic quantities are defined by boxes outlined with dashes. Prognostic qualities are shown as solid lines. Dashed lines on the other hand show important dependencies.*

CMIP6 experimental design

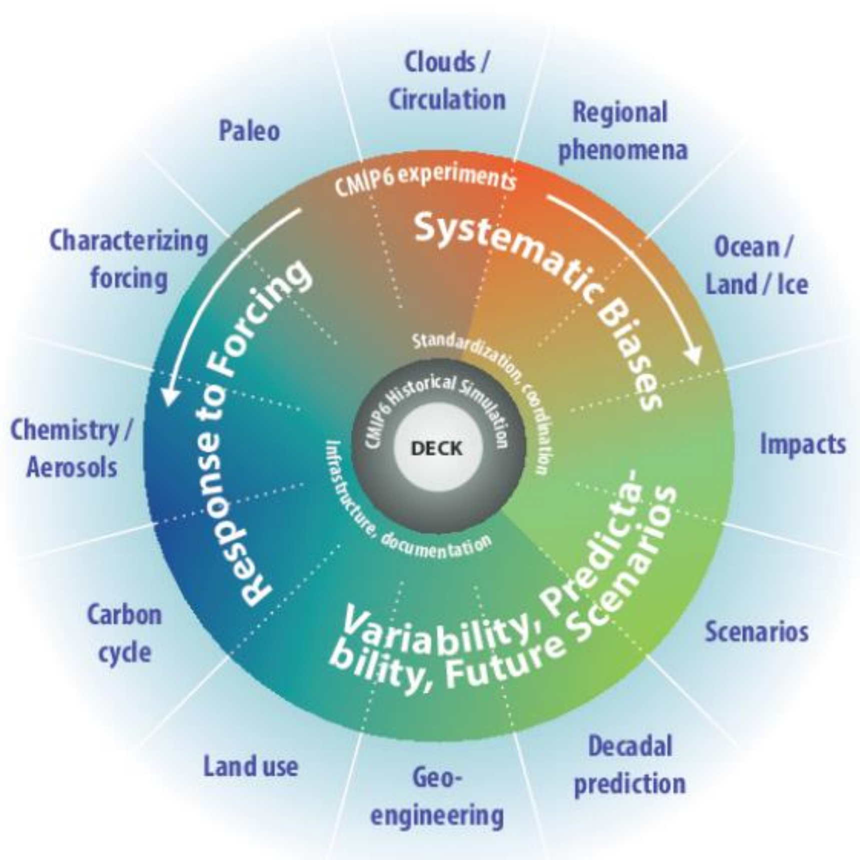
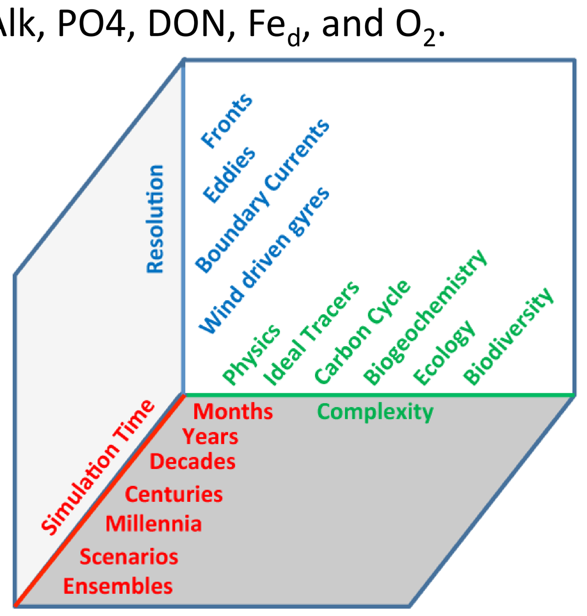
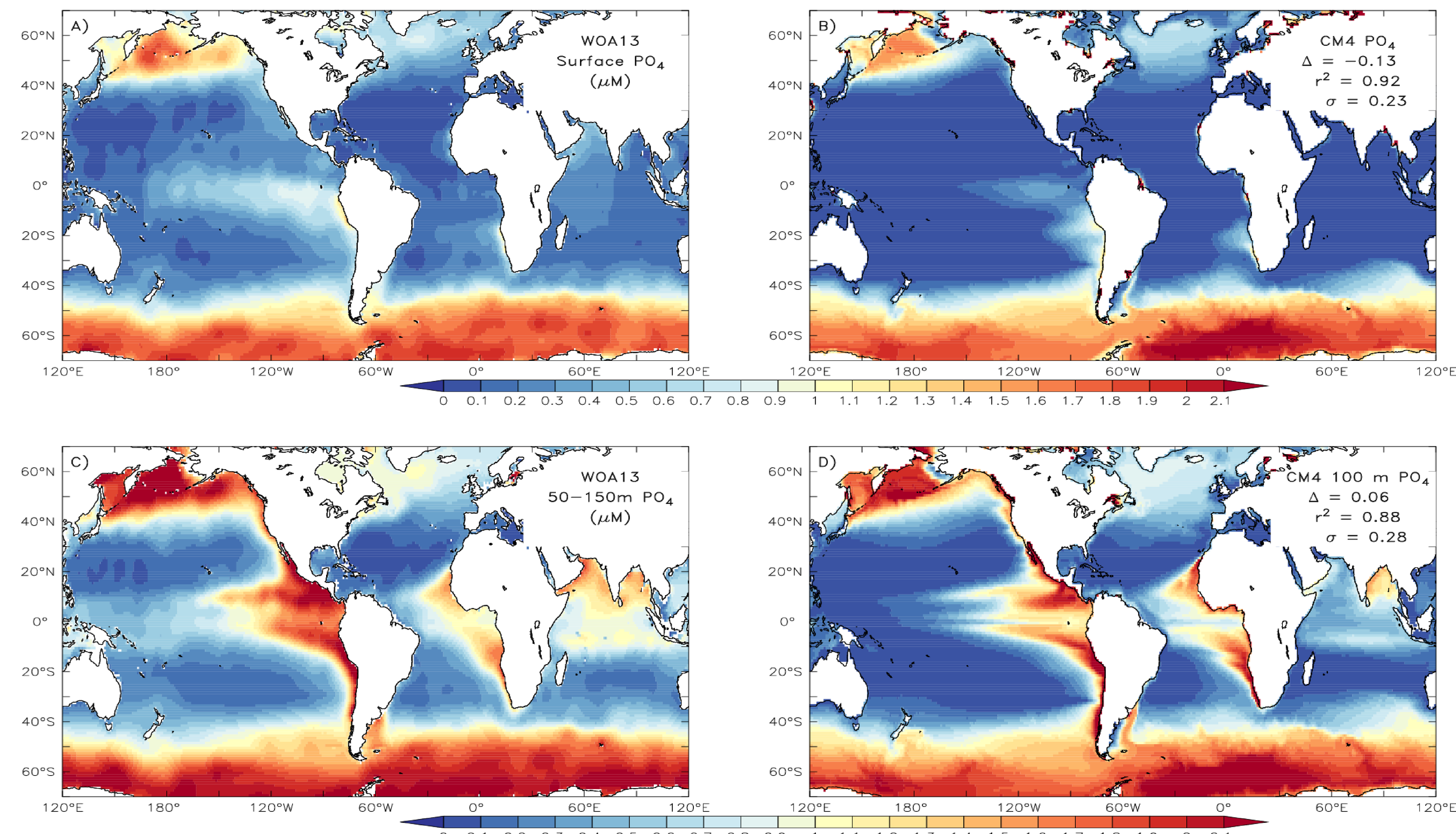


Figure 3: CMIP/CMIP6 experiment design flow. CMIP DECK experiments and the historical CMIP6 simulation are the core ring, along with the "standardization, coordination; infrastructure, documentation" showing the standardized functions. The middle ring reveals CMIP6 broad science topics which are further defined by MIP topics that are addressed by the CMIP6-Endorsed MIPs (outer ring). The schematic is based on the scientific scope for CMIP6; the WCRP Grand Science Challenges: melting ice and global consequences; clouds, circulation and climate sensitivity, regional sea level change and coastal impacts, water for the food baskets of the world, weather and climate extremes, carbon feedbacks in the climate system, near-term climate prediction (Eyring et al. 2016).

Challenges in Carbon Cycle Complexity

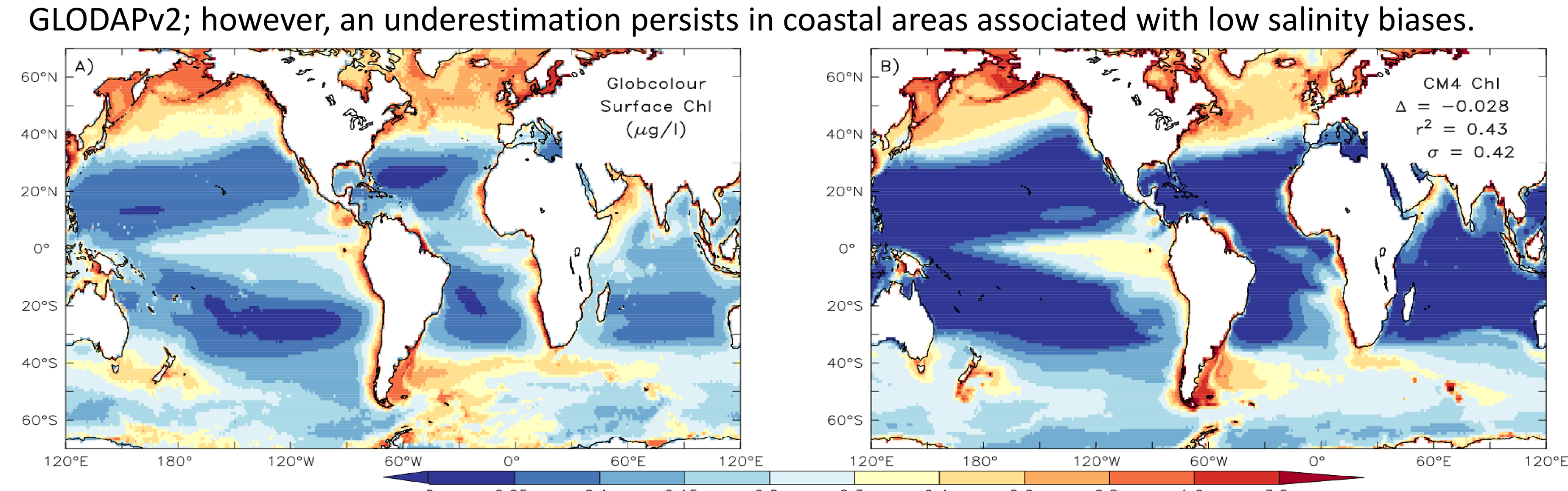
Model robustness varies in accordance to many parameters which can also affect the carbon cycle. Based on previous analysis, enhanced complexity, resolution and simulation time does not always coincide with a more accurate carbon cycle. Therefore, CM4 includes a smaller configuration, BLING (6 tracer) DIC, Alk, PO4, DON, Fe_d, and O_2.

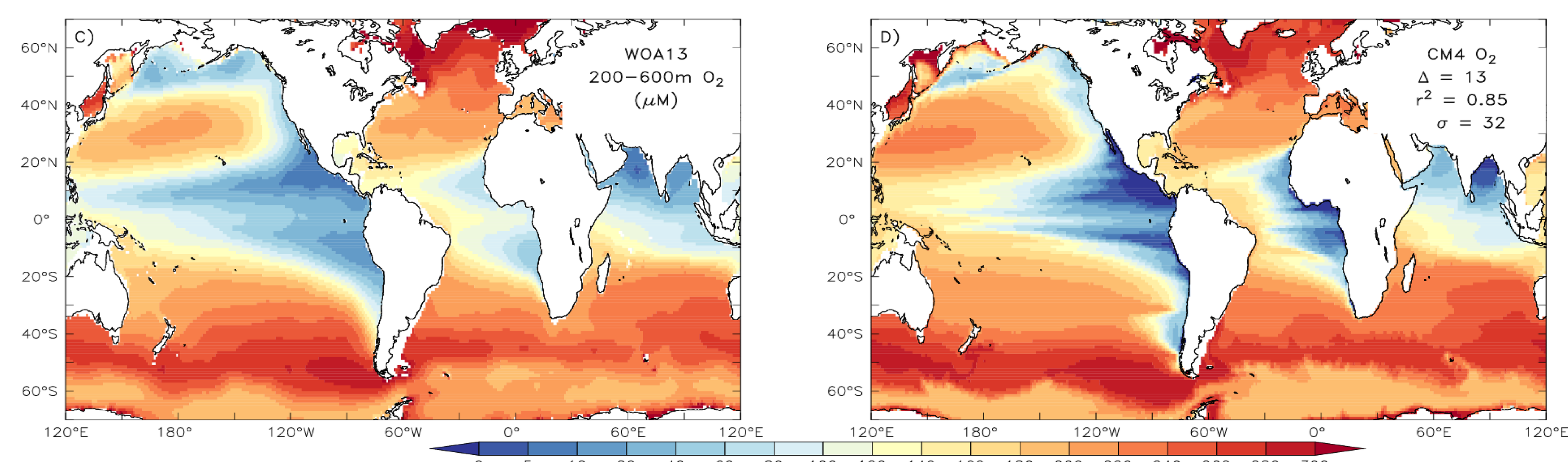


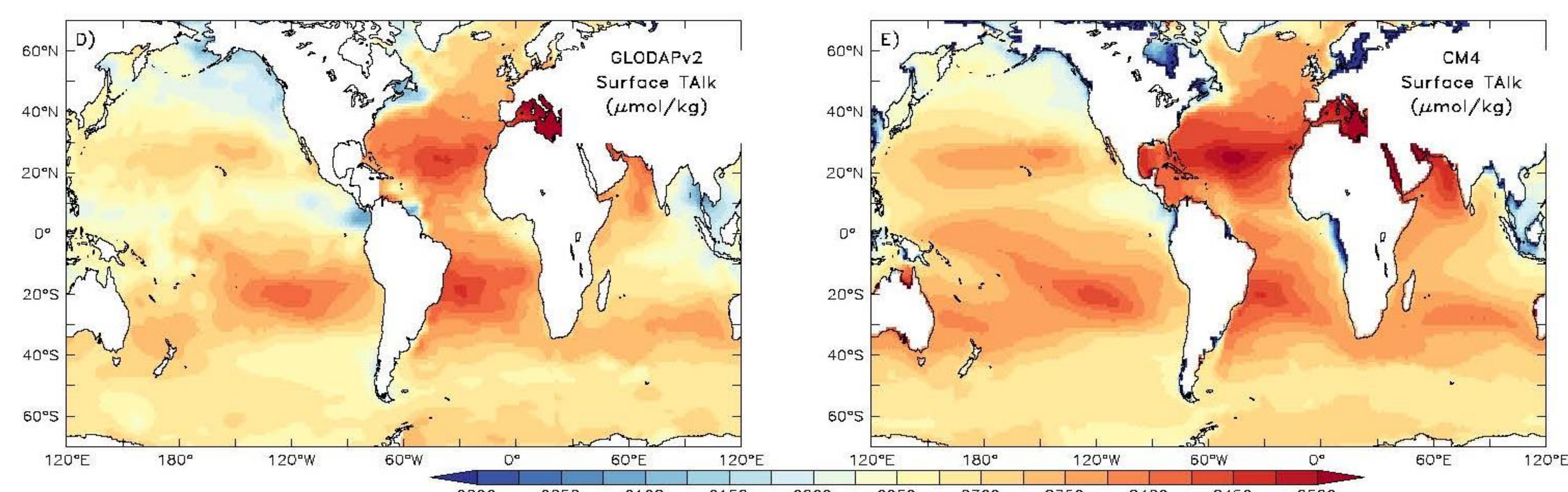


Comparisons of CM4 Tracers with Globcolour, WOA and GLODAPv2

Comparison of CM4 with surface PO4 from WOA illustrate a general comparativeness across biogeographical provinces except for a general low bias in tropical regions. Similarly, comparison with the multi-satellite Globcolour surface chlorophyll (chl) product reveals also similar patterns and highlight good comparativeness in in coastal areas. CM4 underestimates chl in oligotrophic with respect to chlorophyll. However, the model does represent the inter-hemispheric distinction between high chlorophyll northern subpolar regions compared to moderate chlorophyll in the southern ocean with peaks centered at 40S. CM4 reflects well resolved oxygen concentration values similar to the World Ocean Atlas (WOA), capturing 85% of the variability. The major bias in oxygen values is underestimation in the eastern ends of all three tropical basins. In terms of alkalinity, CM4 represents oligotrophic areas well, when compared to GLODAPv2; however, an underestimation persists in coastal areas associated with low salinity biases.







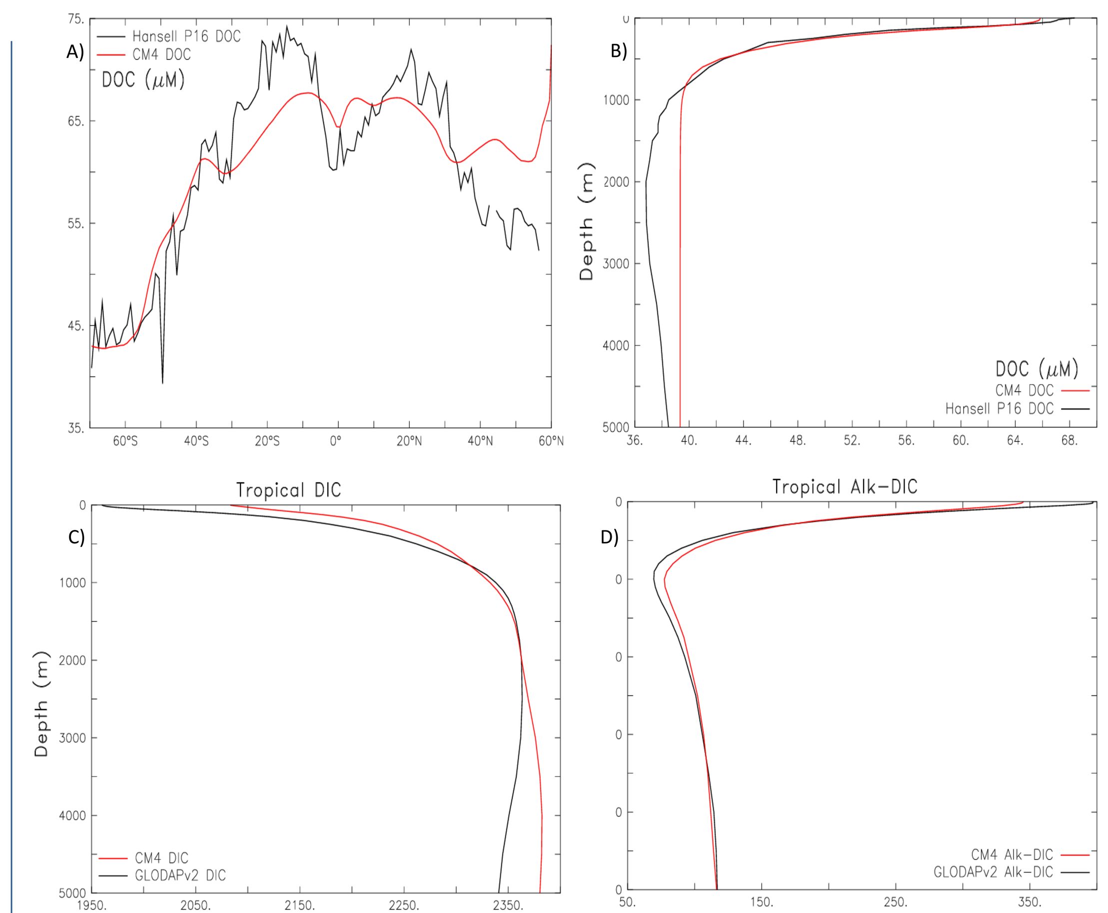


Figure 7: *A) DOC by depth in CM4 follows Hansell P16 DOC values until 30°N, after which an increase is seen in CM4. B) When DOC is plotted over depth, concentration decreases from the surface, and continues through the photic zone. Hansell P16 DOC values agree with CM4 until ~1000 m, after which CM4 experiences a sharper change in slope. Nevertheless, the values are within +/-5 µM of one another. C) GLODAPv2 and CM4 DIC values in the tropics, show the highest amount of variability in the photic zone, and follows a similar pattern to CM4 and Hansell P16 DOC; after 1000 m, there is a decrease in variability. However, after ~2200 m CM4 values deviate from GLODAPv2. On the other hand, when taking into account alkalinity with DIC of both GLODAPv2 and CM4 values highly agree.*

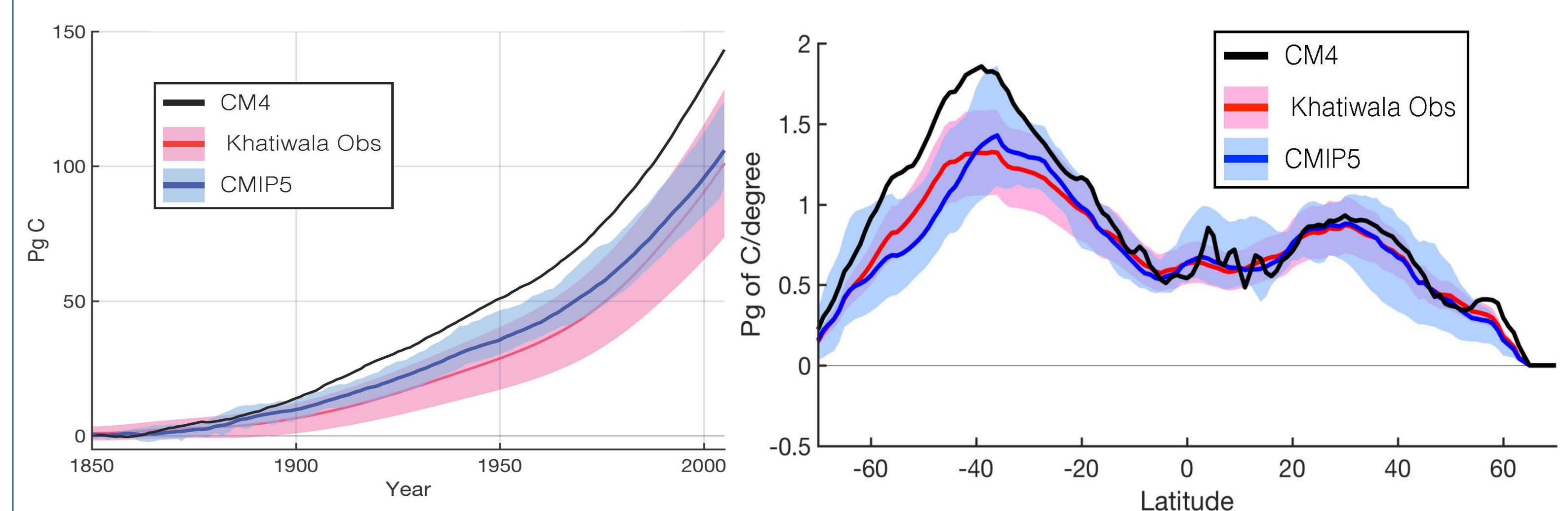


Figure 8: *A) Time series of C_{ant} referenced to the 1850 pre-industrial state, showing CMIP5 models (blue), Khatiwala et. al. (2013) observations (red) and CM4 (black). The grey envelope shows the uncertainty in the observational estimate and the blue envelope shows the CMIP5 model spread. B) Total C_{ant} per degree of latitude in the year 1995 (averaged between 1985 and 2005).*

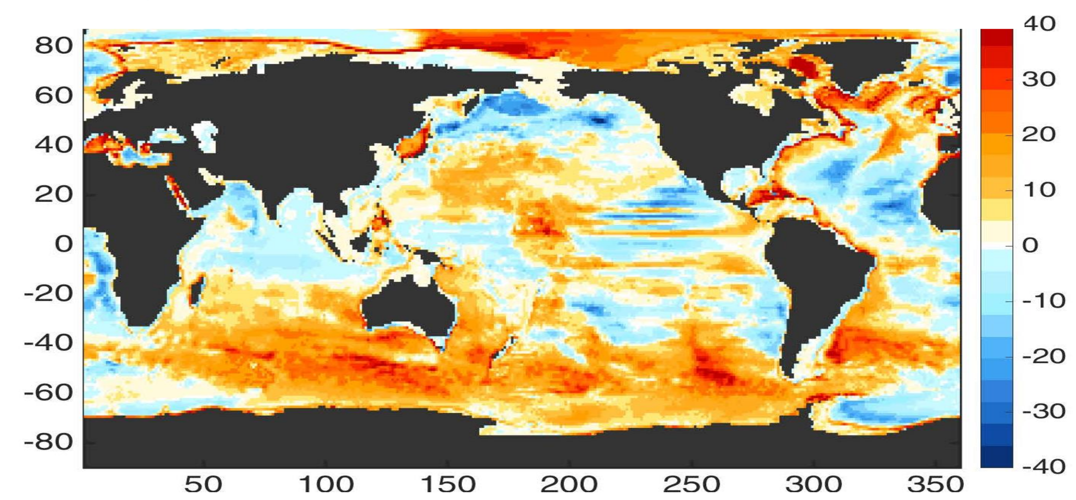


Figure 9: *Difference in column-integrated C_{ant} in the year 1995 between CM4 and the CMIP5 mean. CM4 appears to have a very high uptake of Cant, higher than both Khatiwala observations and CMIP5 values. Most of the differences are due to high uptake in the Southern Ocean. However, CM4 is mostly consistent with both CMIP5 models and observations north of ~30°S.*

Summary

Initial analysis of GFDL's CM4 model biogeochemistry fidelity primarily focuses on surface conditions, as the model takes time to reach equilibrium in abyssal areas. CM4 analysis exemplifies a large improvement from past BLING contributions to CMIP models through a combination of improved resolution and algorithmic development. Through comparisons of CM4 data with WOA, GLODAPv2, Globcolour, Khatiwala observations, CMIP5, and Hansell dissolved organic carbon, high general agreement can be seen. Nutrient additions to CM4 benefits the carbon cycle by accurately resolving chlorophyll and oxygen concentrations in larger areas which in turn effects concentrations of DIC, DOC, anthropogenic carbon and alkalinity. In terms of anthropogenic Carbon uptake, CM4 agrees well with observations except for an enhanced uptake in intermediate waters of the Southern Ocean which we attribute to the ¼ degree model lack of sufficiently resolving the role of eddy-induced restratitification.

References

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