Reviewer 1

General comments

The study provides insights on how CO2 system in the ocean responds to CO2 mitigation, and its interactions to ocean circulation in the near term. The results are needed for monitoring the climate-carbon feed back in different regions of the global ocean. The manuscript is clear and well written. However, as the authors identified the limitations of the work, I found it is necessary to look at those limitations more closely. In addition, I am wondering why only the short term effects, not the long term effects were studied.

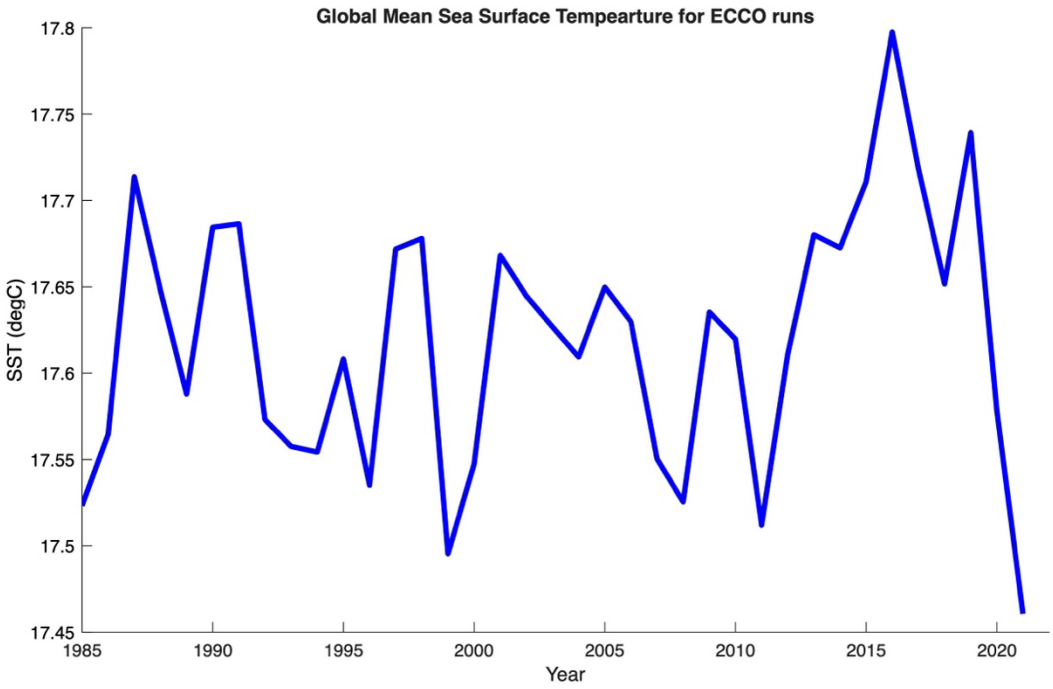
We thank the reviewer for these comments. Below we will respond to the specific question about our discussion of limitations of the results. Only the short-term effects of the response are analyzed and discussed in this paper because of the limitation of the model run length. ECCO can only be run out to recent years because it is a data-assimilative hindcast model. Thus, we were limited to a roughly 20-year period for our investigation. We chose to apply mitigation in the year 2000 because it followed along from the Montreal Protocol meetings where such efforts were pledged. Our motivating question was, what if those commitments were upheld and mitigation truly began soon after (i.e., the year 2000).

As an ecological modeler, my opinions maybe biased toward how planktonic systems play a role in it. This part is ignored due to the lack of feedback of mitigation to the ocean physics in this study. Ideally, mitigation would slow down warming, or even cool down the ocean over long term. That would increase mixing, and thus nutrient supply, primary production and biological CO2 pump, and solubility pump at lower temperature. If you imagine increased primary production, and decreased respiration under cooling, CO2 budget due to biological changes may not be trivial. Globally, the increase in CO2 uptake due to increased primary production may not be high as the authors argued, but locally, in some normally low productivity areas, the increase could be significant.

We thank the reviewer for these detailed discussions of the biological feedback potentials in such mitigations. We have revised the manuscript to reflect this potential for large impact on primary production at local-scale.

I would recommend the publication of this manuscript after minor revisions. However, I would suggest the authors show how sea water temperature changes over time in baseline simulation, just like you displayed CO2 flux and pCO2 in baseline in Figure 1.

We thank the reviewer for this suggestion and here we show a timeseries of changing sea-surface temperature in the ECCO-Darwin model runs. We do not feel that this timeseries provides much additional interpretation information for the discussion in the manuscript so it will be added to the supplementary figures.



I would encourage the authors add another simulation of the mitigation scenarios using (downscaled, if needed) forcings derived from the output of Earth System Models. Without this, the scope of this work, and contribution to this area would be unfortunately limited.

The suggestion from the reviewer is an interesting idea, but unfortunately outside the scope of this work. We cannot apply output from the ESMs into the data-assimilative ECCO-Darwin model. Many other pieces of research look at mitigation in the ESM framework, and we have referenced these throughout our manuscript.

Specific comments

• Line 145: atmospheric CO2 forcing: better to use pCO2. We have changed the text as suggested.

• The paragraph between lines 286-293, and Figure 5: there are some mismatches between panels referenced and texts. Net diffusion is in Figure 5(e), not (d). Net advection is in Figure 5(d), not (e). We thank the reviewer for identifying this mix-up. We have revised and double checked all other figure references in the manuscript.

• Line 296: ”DIC gain and loss from circulation largely compensates when integrated globally”, but why is the globally integrated circulation value is positive: 0.132 Pg C year−1? This text refers to the 3 globally-integrated terms: -1.43, 0.132, and -1.56 Pg C year-1 for DIC tendency, circulation, and air-sea CO_2 flux. As compared to the other 2 terms (tendency and air-sea CO_2 flux) which are both an order of magnitude smaller, we summarized that the changes seen from

the circulation component are being modulated because of the compensation between gain and loss. This is shown in Figure 5e where there are only a few spots on the map showing large magnitude changes. The value is positive because the gain of DIC is slightly larger than the loss and this is occurring predominantly in the boundary waters at the northern edge of the Southern Ocean, as well as along other frontal boundaries.

• Figure 5: The color scale is saturated. Maybe the color limit can be expanded to 1.5 x 10−5. We thank the reviewer for this suggestion and adjusted the color scale on this figure.

• Figure 5d: DIC advection in the mitigation scenario increased comparing with baseline. I have to wonder why. As you used the same physics between baseline and mitigation, so the U, V, and W of the current should be the same between baseline and mitigation. Then the increased flux should be due to increased DIC concentration under mitigation. Mitigation under SSP1 should have reduced CO2 uptake and thus lower CO2 concentration than with baseline, rather than increase. Please clarify. We thank the reviewer for this comment. Yes, the ocean physics is the same in all our simulations. While lower atmospheric CO_2 results in less CO_2 uptake, in some places the DIC advection is increasing (example, equatorial pacific) because the difference in air-sea uptake of carbon is largest there and thus the advection term is redistributing gradients induced by these changes.

• Figure 5 legend: align the order of panels in the text with the figure. We have revised this section discussion to try to more clearly walk through the discussion in the order than the components are shown in the figure.

• Line 383: The reference should be Williams et al. (2024), not 2023. We thank the reviewer for this correction and have revised the manuscript.

Reviewer 2

The manuscript tests the effect of changes in atmospheric CO2 on oceanic carbon uptake using a model, while keeping other parameters such as circulation, temperature, and sea ice identical. The broad conclusions are physically sensible: lower atmospheric CO_2 reduces the air–sea gradient, uptake declines rapidly, and the resulting DIC anomaly is redistributed along upper-ocean ventilation pathways. I suggest some revisions to improve clarity.

The manuscript should explicitly define "mitigation", as this word can be misleading. As implemented here, mitigation is not an emissions intervention but a prescribed atmospheric CO_2 concentration trajectory. The model does not simulate emissions, policy actions, carbon-dioxide removal, enhanced marine productivity, or the coupled feedback of altered ocean uptake on atmospheric CO_2. This distinction is essential because different mitigation strategies could produce different ocean responses. Please define the term consistently in the abstract, introduction, and methods and consider modifying the title to describe the imposed concentration forcing accurately. We thank the reviewer for this comment and have edited the text to clarify that the "mitigation" that is causing changes in these experiments is simply a reduced atmospheric carbon level and therefore specific responses to various potential mitigation methods that would result in these reductions are not considered. We have also edited the title from "Quantifying the Near-term Response of the Ocean CO_2 Sink to Emissions Mitigation" to "Quantifying the Near-term Response of the Ocean CO_2 Sink to Reduced Atmospheric Carbon Concentrations"

Please show the biological DIC-budget terms rather than asserting that biological differences are negligible. Enhanced biological consumption and export could lower surface-ocean pCO_2, partially restore the air–sea gradient, and modify the inferred response. We thank the reviewer for this comment and have added text in the manuscript to discuss how local impacts of biological impacts from changing DIC could be significant but that on a global scale they are negligible as compared to the other components discussed.

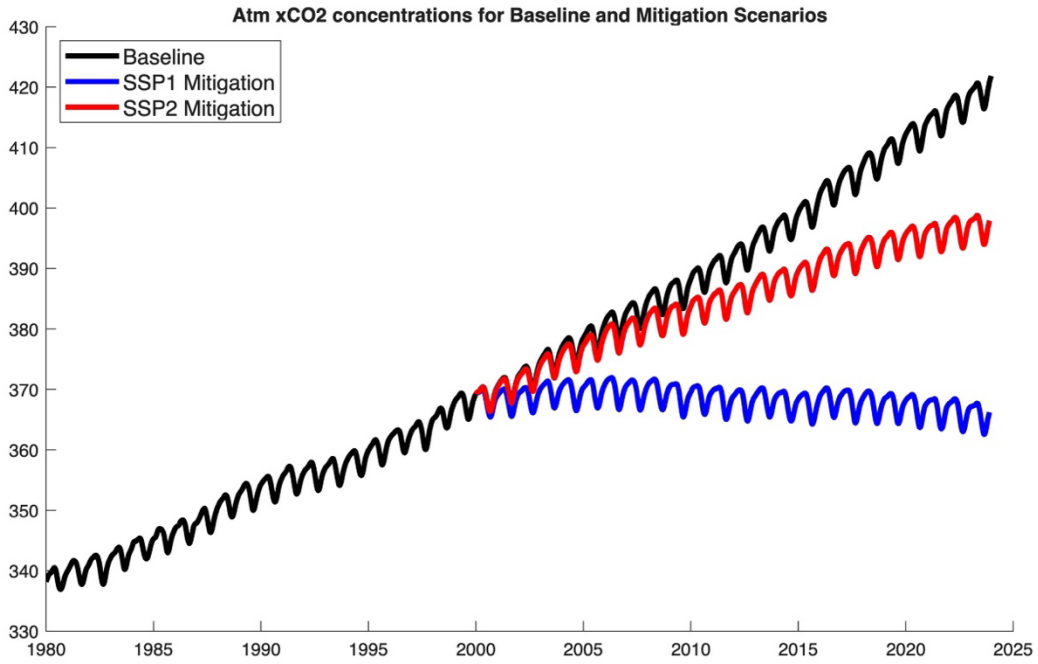
Some language incorrectly implies that circulation changes between runs. Physics is identical, so mitigation does not alter circulation in this experiment. Advection-budget differences arise because the same velocity field transports different DIC distributions. Statements about "the dynamic response of ocean circulation" (line 112) should instead refer to tracer redistribution by fixed circulation. We thank the reviewer for this insight and have adjusted the text according as: "Each simulation uses identical physical and biogeochemical initial conditions. Differences among scenarios and the baseline therefore reflect the dynamic response of carbonate chemistry to changes in atmospheric CO_2 concentration alone."

High-latitude and boundary-current systems show the largest modeled responses, but their strong natural variability and sparse observations may obscure the mitigation signal. Because the study does not perform a signal-to-noise or time-of-emergence analysis, it cannot conclude that these signals would be detected earliest in the real ocean. We appreciate the reviewer's

comments here. The model performs well across the globe as compared to independent data (as well as other models). Therefore, sparse available observations in these high latitude regions would not cause the large response in the model — they are due solely to the perturbation response of the model's ocean carbon chemistry to changes in atmospheric CO_2 concentrations.

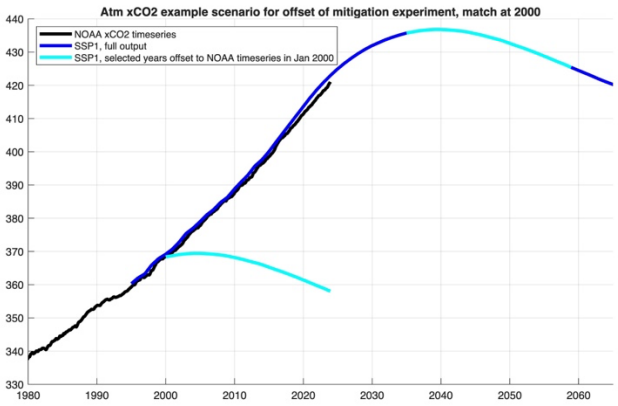
Explain exactly how the atmospheric CO_2 scenarios were constructed. The backward shifting of SSP1-1.9 and SSP1-2.6 concentration trajectories is insufficiently documented. Please provide the transformation, original and shifted years, treatment of the January 2000 transition, and complete atmospheric CO_2 time series. Clarify whether the scenarios represent lower concentrations, lower growth rates, or actual concentration declines. This information is necessary for reproducibility and interpretation.

We thank the reviewer for this suggestion. A supplementary figure has been added with the complete global mean atmospheric CO_2 timeseries for each scenario, and is shown here.



In order to create these timeseries, we start with the monthly global xCO_2 values downloaded from the Global Monitoring Lab website (https://gml.noaa.gov/ccgg/trends/gl_data.html, Lan, X., Tans, P. and K.W. Thoning: Trends in globally-averaged CO2 determined from NOAA Global Monitoring Laboratory measurements. Downloaded: May 20, 2024). This timeseries extends from 1979-2023. We utilize the "trend" column which does not include a seasonal cycle on the xCO_2 values. The monthly atmospheric CO_2 concentration values for each SSP scenarios are from the MAGICC7 live tool (available at https://live.magicc.org/, described in Meinshausen et al (2011), with updates in Meinshausen et al. (2020)).

To apply a simulated atmospheric CO_2 expected post mitigation, we selected the year 2035 from the SSP scenarios, which is when the reductions of atmospheric CO_2 are beginning to be observed in the global timeseries. We take values for Jan 2035 from each SSP scenario and subtract the NOAA global mean xCO_2 value for December 1999; this is now our offset value. We subtract this value for each SSP scenario and translate the resulting curve to begin in Jan 2000, concatenating it to the NOAA timeseries beginning in that year. See example figure here for SSP1.



Lastly, we utilize the latitudinally-varying seasonal cycle of xCO_2 available from the marine boundary layer file from NOAA (Lan, X., Tans, P., Thoning, K., & NOAA Global Monitoring Laboratory. (2024). NOAA Greenhouse Gas Marine Boundary Layer Reference – CO2. [Data set]. NOAA GML. https://doi.org/10.15138/DVNP-F961, Downloaded April 4, 2024, available at https://gml.noaa.gov/ccgg/mbl/data.php). We apply this spatially-varying seasonal cycle to the adjusted timeseries for Baseline and each Mitigation scenario timeseries to simulate observed seasonal variability on top of the declining xCO_2 trends at the timestep required for input to the ECCO-Darwin model.