Response to the reviewers

We thank the reviewer Prof. Scott Doney for his very helpful and constructive comments. In the following we address the comments point by point.

The manuscript presents an analysis of an ensemble of coupled global climate-carbon cycle model simulations for the recent historical period through the end of this century. The models' Arctic Ocean inorganic carbon systems are analyzed to quantify the growth of the anthropogenic carbon inventory and the underlying driving factors related to ocean thermocline ventilation and freshwater/alkalinity trends. The approach follows on prior studies using an earlier generation of Earth System Models (CMIP5) identifying substantial changes in CMIP6 model dynamics and the performance of a pair of so-called emergent constraints relating changes in carbon uptake and acidification to surface density (a metric of ventilation rates for mesopelagic ocean). Overall this is a well-constructed manuscript both in terms of the underlying analysis methodology and presentation, and this work is relevant to a number of science communities involved in climate and ocean carbon cycle science as well as marine ecology related to the impacts of ocean acidification. My recommendation is for minor edits to address my comments below that are primarily requests for clarifications on the methodology and results in the text.

1.1 — Line 6 "the inter-model uncertainty of projected end-of-century Arctic Ocean Omega arag/calc"

Should this be the temporal change of saturation state comparing preindustrial minus end of century? This relates to the model bias correction described in Lines 120-125 using the GLODAP data. Would be useful to describe in abstract the data-based bias correction that is applied to the models.

Also need to clarify in Abstract when the text is describing the water-column (or whole Arctic) change or when discussion trends for particular depth levels (e.g., surface, mesopelagic).

Reply: Line 6 will be changed in the revised manuscript to as follows:

" Compared to the previous model generation (CMIP5), the inter-model uncertainty of projected changes over the 21st century in Arctic Ocean $\Omega_{arag/calc}$ averaged over the first 1000 m is reduced by 44-64%."

Lines 12 and 13 will also be changed for clarification to:

"Even under the low-emissions shared socioeconomic pathway SSP1-2.6, basin-wide averaged Ω_{arag} undersaturation in the first 1000 m occurs before the end of the century."

1.2 — Line 18-20 "In CMIP6, models generally better simulate maximum sea surface densities in the Arctic Ocean and consequently the transport of Cant into the Arctic Ocean interior, with simulated historical increases in Cant in improved agreement with observational products."

Perhaps description of improvement in model ocean physics would be better placed in abstract on Line 5 before discussion of carbon system.

Reply: This will be changed as suggested.

1.3 — Line 42-42 "Due to freshening and increasing Cant concentrations, the Arctic Ocean is projected to be the first large-scale ocean region to become undersaturated with respect to the metastable CaCO3 polymorph aragonite (Omega arag < 1) (Steinacher et al., 2009)."

Clarify if referring to Steinacher et al. results on trends in Arctic surface ocean or full depth ocean.

Reply: Steinacher et al. results refer to the entire watercolumn. This will be clarified in the revised manuscript:

"Due to freshening and increasing C_{ant} concentrations, the Arctic Ocean is projected to be the first large-scale ocean region to become undersaturated with respect to the metastable $CaCO_3$ polymorph aragonite ($\Omega_{arag} < 1$) throughout the entire water column (Steinacher et al., 2009)."

1.4 — Line 55 In the section on emergent constraints, is there any evidence that variations in extent of sea-ice loss affects local air-sea anthropogenic CO2 uptake and thus inventory?

Reply: At present, the air-sea CO_2 uptake plays a minor role for the Arctic Ocean C_{ant}. Indeed, most of the C_{ant} enters the Arctic Ocean with Atlantic waters, which are already saturated with respect to C_{ant} (Terhaar et al., 2020b). These waters then sink into the deeper ocean in the Barents Sea (Midttun, 65 1985; Rudels et al., 1994, 2000; Jeansson et al., 2011; Smedsrud et al., 2013, Terhaar et al., 2019b).). The strong relationship between the sea surface density in the Barents Sea and the end-of-century Arctic Ocean C_{ant} inventory (Figure 2) indicates this will not change in the near future.

1.5 — Line 84 "sedimentation now explicitly simulated in 10 out of 14 ESMs" Does "sedimentation" here refer to gravitational particle sinking? Or does this refer to fluxes at the water-sediment surface? Please clarify.

Reply: In the revised manuscript the sentence will be changed to:

"In particular, the treatment of organic matter carbon cycling has generally evolved, with remineralization of particles in sediments now simulated in 10 out of 14 ESMs."

1.6 — Line 87 "Furthermore, the external carbon and nutrient sources" How many of the CMIP6 models include dissolved inorganic carbon and alkalinity concentrations in river fluxes? It would be useful to expand Table 1 or add a Table 2 to display the differences in model treatment of freshwater inorganic carbon chemistry.

Reply: The information will be added to Table 1 as suggested.

1.7 — Line 104, Section 2.2 Some more detail is needed on the specific models and simulations used for the ocean biogeochemistry CMIP6 ensemble. For example, did all the coupled models follow the protocols outlined in:
Orr et al. 2017: Biogeochemical protocols and diagnostics for the CMIP6 Ocean Model Intercomparison Project (OMIP), Geoscientific Model Development, 10, 2169-2199, doi:10.5194/gmd-10-2169-2017

Reply: More specific information about the models and simulations,e.g. spin-up length and riverine input, will be added to the revised manuscript as suggested.

1.8 — Also, given the importance of river input into the Arctic, some additional discussion is needed on the model treatment of river freshwater, inorganic and organic carbon, and alkalinity.

Reply: As suggested, the riverine carbon and alkalinity fluxes will be added to Table 1. Furthermore, additional text will be added about the model treatment of riverine freshwater, carbon and alkalinity.

1.9 — Line 115-118 "To quantify the effect of freshening on changes in AT, the AT anomalies for each model were further decomposed into changes resulting from freshening and from the combined effect of other bio-geochemical processes by calculating the temporal evolution of salinity corrected alkalinity with a reference salinity of 35 following Lovenduski et al. (2007)." A salinity correction implicitly assumes a freshwater end-member for alkalinity. For the Arctic was a non-zero end-member used to account for non-zero river alkalinity?

Reply: A zero end-member was assumed for freshwater. This is correct for models with no alkalinity in freshwater but an overestimation for models with alkalinity in freshwater. Unfortunately, the information about alkalinity in freshwater is not available for most models. Moreover, with the available model output it is impossible to quantify the contribution of land ice melt, sea ice melt, precipitation minus evaporation, and riverine input to freshwater changes. For simplicity, we assumed a zero alkalinity end-member. This will be explained and discussed in the revised manuscript.

1.10 — Line 241-243 "The resulting constrained estimate for the rescaled Arctic Ocean Cant inventory decreases from the low-emission scenario to the high-emission scenario from 12.3 to 10.7 Pg C." Perhaps would be useful to clarify again that the rescaled constraint only informs the actual emergent constraint that is in Figure 2.

Reply: As suggested, this will be clarified in the figure and the figure legend.

1.11 — Line 251 "surface salinitities" Should be "salinities"

Reply: This will be changed in the revised manuscript.

1.12 — Line 356 "dramatically reduced in CMIP5" Should this read "dramatically reduced compared to the uncertainties in CMIP5"?

Reply: Yes it should. This will be changed in the revised manuscript.