Reply on Reviewer 1

The mansucript attempts to project global changes in carbonate production using a habitat suitability model coupled with a climate model. The methods regarding how carbonate production is calculated, and the exact methods forcing changes in net carbonate production under climate change need to be made explicit here in the methods. Currently, the reader must go through a number of other papers to determine why the results of this mansucript have played out how they have and what the authors have actually done. I also found the writing to not be very direct. Clarifying points that are trying to be made, and explaining clearly why, would make this mansucript more accessible to a general reader. This mansucript needs to be revised before its suitably could be assessed, but likely would provide the reader a useful alternative to other existing models of changes in carbonate production under climate change.

We thank the reviewer for their comments. As suggested we have tried to add more information so that it is easier to understand without reading the other papers.

I give specific comments below that hopefully will assist the authors:

Line 39 onwards: What does the plus/minus indicate? Standard error, range, standard deviation? And is this the variability globally spatially or variability in any one location depending on the model outcomes?

The plus/minus indicates the standard deviation of the multi-model global change, more precisely the intermodel standard deviation, we have added precision in the new manuscript:

"Climate models indicate that under the high-emission scenario SSP5-8.5, sea surface temperatures will increase by 3.47 ± 0.78 °C, while the surface pH will decrease by -0.44 ± 0.005 by the end of the century (multi-model global mean change values of 2080–2099 relative to 1870–1899 ± the intermodel standard deviation, Kwiatkowski et al, 2020)."

Line 53: The role of carbonate ions in seawater has largely been disproven, see Comeau et al. (Comeau et al. 2018) and the various opinion/discussion papers, e.g., Cyronak et al (2015), Jokiel (2013).

The text here has been revised to reflect the general impact of acidification and not carbonate ions specifically. We agree that this part of the module could be improved in the future, as more data become available to derive a function of carbonate production from pH or DIC instead of saturation state. In the section on caveats and missing processes we have added more discussion:

"The calcification process which enables organisms to produce their external calcium carbonate skeleton requires more energy as the oceans take up anthropogenic carbon and acidify."

“For example, the relationship between Ω_{ar} and the rate of calcification is complex (Chan and Connolly, 2013; Jokiel, 2016; Eyre et al., 2018). As corals can control their internal pH value and seem to be more sensitive to pH, carbonate production might need to depend on pH instead of saturation state (Comeau et al., 2018).”

Line 69: And some used pH instead of saturation state, which is likely more appropriate for most calcifying taxa (including corals).

With have added pH in the manuscript:

“Among the models used to evaluate the impact on coral reefs during the next century globally, some considered the impact of future temperature change (Donner et al., 2005), others the impact of Ω_{ar} or pH change (Kleypas et al., 1999, Eyre et al., 2018), and some both variables simultaneously (Silverman et al., 2009; Frieler et al., 2012; Couce et al., 2013; van Hooidonk et al., 2016; Cornwall et al., 2021; Cornwall et al., 2023).”

Line 84: Please define GCM if it has not already been done so. But, does it need an acronym?

As it is not used elsewhere we agree there is no need for an acronym, it has thus been replaced by “Global Climate Models”.

Line 86: Some intro to this model is required for the reader.

The description of the model is given in the method section: “2.2.1 iLOVECLIM carbon-climate model”. We have indicated this in the manuscript: “To account for this uncertainty, we use different versions of the iLOVECLIM climate model (see section 2.2.1) spanning the range of climate sensitivities in climate models.”

Line 120: There needs to be some more details here and further on regarding how this model is working for this to be a stand alone paper. Citing the previous paper and not including any details here means the reader must go through the Bouttes et al 2024 paper with a fine tooth comb to understand some very important aspects of this paper (probably the two most important parts of the methods) 1) how carbonate production is calculated and what controls it within the model, and 2) how temperature and ocean acidification impact carbonate production in this model. If space is an issue, remove the previous text that describes components of the model that are not as important for understanding the results here please.

As suggested we have added more details on the computation of carbonate production in the module:

“Carbonate production can take place provided that:

- The temperature is between 18.1°C and 31.5°C and exceeds 18.1°C throughout the year.
- The salinity is between 30 and 39
- The phosphate concentration is below 0.2 µmol L^{-1}
- The depth Z is shallower than the maximum coral production depth (Z_{max}) which depends on attenuation of light in the water column:

$$Z_{max} = \frac{\log\left(\frac{I_{min}}{PAR}\right)}{K_{490}} \quad (1)$$

where I_{min} is a fixed parameter (the minimum light intensity necessary for reef growth), PAR is the photosynthetically active radiation at the surface (computed by the iLOVECLIM climate model) and K_{490} is the diffuse attenuation coefficient at 490 nm taken from the Level-3 binned MODIS-Aqua products in the OceanColor database (available at: http://oceancolor.gsfc.nasa.gov). The production depth is defined as the depth at which light is at the Imin level.

In habitable zones, coral reef carbonate production P is computed on a vertical subgrid with a 1 m resolution from the available photosynthetically active radiation (PAR), temperature T, aragonite saturation state Ω_{ar}, surface area S_{avail} and a topographic factor TF, following:

$$P = g_{max} \times f_R(PAR) \times f_T(T) \times f_O(\Omega_{ar}) \times S_{avail} \times TF \times f_B(t;\ t_{bleach}) \qquad (\mathbf{2})$$

Where g_{max} is the maximum value (fixed) and $f_B(t;\ t_{bleach})$ a function for the bleaching.

The two main potential drivers of production changes in the future are temperature and saturation state, as they will evolve in the future. In the coral module, the temperature function $f_T(T)$ is a linear function of temperature (T), °C, fitted for the temperature range of coral reef habitability (f_T(T) = 0 at T = 18.1°C and f_T (T) = 1 at T = 31.5°C; f_T(T) = 0 outside the range of 18.1–31.5°C):

$$f(T) = -1.38 + 0.077 \times T \qquad (3)$$

Following Langdon and Atkinson (2005), the saturation state function $f_O(\Omega_{ar})\ is$:

$$\text{if } \Omega > 1\ f_O(\Omega) = \frac{\Omega - 1}{K_{omega}} \qquad (4)$$
$$\text{Else } f_O(\Omega) = 0$$

with K_{omega} is a normalisation parameter (K_{omega} = 2.86)."

Paragraph around line 140: Please in clear language explain to the reader why this part of the methods is important? How does ESC matter in the context of coral reef carbonate production over absolute changes in temperature and pH? There is more details on this than on how carbonate production is estimated.

The ECS determines the simulated warming for a fixed amount of CO_2 emissions. Higher ECS leads to higher ocean warming, with large impacts on coral reefs. The ECS has very limited impact on ocean pH change as this is primarily driven by ocean carbon uptake, which is almost entirely determined by the concentration of atmospheric CO_2, with limited influence of simulated warming.

In the manuscript we have added:

"The simulated ocean warming in response to atmospheric CO_2 emissions and the resulting impact of this on coral reefs, is strongly dependent on the equilibrium climate sensitivity (ECS) of a given model."

Line 173: Its difficult to determine the speed and extent to which corals will gain increased tolerance to higher temperatures. However, this method is just as good as those previously used.

Paragraph around line 200: Other than using the NOAA guidelines for bleaching, and possible reef habitability, how do these projections of coral presence/absence actually function? A grid either has coral carbonate production at full value or 0 if the grid is habitable? Again, not enough detail on what are the most important aspects of the model outputs for this manuscript here.

The coral reefs are present if the net carbonate production is positive. Simulated carbonate production is dynamically simulated as a function of light, temperature, saturation state, surface area and topography and can vary between 0 and g_{max}. This is now described in detail in section 2.1.2 . The paragraph referred to by the reviewer here describes idealised simulations where some of the variables (temperature or saturation state) have prescribed fixed values in order to evaluate their respective impacts on carbonate production.

Line 330: Is global mean net erosion that same as complete cessation? If some locations still have positive net carbonate production, then perhaps this statement is misleading, as to me this means all locations stop producing carbonate.

Complete cessation means there is no net carbonate production (P=0) and is not the same as mean net erosion (P<0). Erosion is not explicitly accounted for in the model with negative P currently not permissible. We have modified the text here to avoid this confusion:

"By 2100, Cornwall et al. (2021) projected a decline in global mean net carbonate production of 77% for RCP2.6 with negative global net production (erosion) and no reefs able to accrete at rates equivalent to projected sea level rise for RCP8.5. With our coupled climate-coral model net erosion is not currently permissible, however we do project complete cessation of net accretion by 2100 for SSP5-8.5 (in the absence of thermal adaptation)."

Line 355: No model can project changes in in situ temperature on specific reefs at enough resolution anyway, so perhaps this does not matter.

Higher resolution models are capable to simulate temperature extremes closer to observations, so it could improve results. We plan to test this in the future.

References used here:

Comeau, S., C. E. Cornwall, T. M. DeCarlo, E. Krieger, and M. T. McCulloch. 2018. Similar controls on calcification under ocean acidification across unrelated coral reef taxa. Global Change Biology **24:** 4857-4868.

Cyronak, T., K. G. Schulz, and P. L. Jokiel. 2015. The Omega myth: what really drives lower calcification rates in an acidifying ocean. ICES Journal of Marine Science **73:** 558-562.

Jokiel, P. L. 2013. Coral reef calcification: carbonate, bicarbonate and proton flux under conditions of increasing ocean acidification. Proceedings of the Royal Society B: Biological Sciences **280:** 1764.