Response to the referee #2's comments on "Importance of El Niño reproducibility for reconstructing historical CO2 flux variations in the equatorial Pacific" by Watanabe et al.

Thank you very much for invaluable comments and suggestions on our original manuscript. Following the comments, we have revised the manuscript. In addition, following the comment we received personally from the National Oceanographic Centre, UK. (The supplement of the reply to referee #1 includes their comments and our replies), we have combined Section 3.2 and 3.3 in the original manuscript and reorganized. We think the revised manuscript is now more readable. We hope that the revised manuscript meets your approval and will be suitable for publication in the journal.

Reply to comments:

(Referee #2) "This paper describes the benefits of advanced data assimilation method in advanced CMIP6-class climate model compared to CMIP5 model. The model results and their mechanisms have been well described in this manuscript. I would recommend this paper is acceptable in this Ocean Science Journal with some support analysis based on comparison using observations to verify the assimilation skills, which could be much elevating the values of this paper.

Thank you very much for your comments.

L52. Can we discard the biological pump on the results, especially in the La Nina states? Author represented NINO3-CO2F correlation coefficients, which means both El Nino and La Nina events. As we know, decreasing the phytoplankton in El Nino event could affect the CO2F variability modulated by DIC solely but I wonder whether the strong positive bloom in La Nina event could absorb the CO2 into the ocean. If then, the better performance of the phytoplankton assimilation skill can be a key to elevate the better CO2F skill. Composite analysis between CO2F at El Nino and La Nina and taking difference of them to see the asymmetry would elevate the biological influence on CO2F in this model. If then, you may provide supporting figures of chlorophyll skills in this model using satellite-derived chlorophyll concentration using such as ESA-CCI (https://esa-oceancolour-cci.org) or GlobalColour in Hermes (http://hermes.acri.fr).

Thank you for your suggestion. We here examine the effect of the biological pump on CO_2

flux in the equatorial Pacific. First of all, we investigated whether NEW-assim captures the historical variations in the bloom magnitude associated with ENSO. Figure R1a shows the timeseries of simulated surface chlorophyll concentration anomalies averaged over the Niño3 region (hereafter NINO3-Chla) and NINO3-SST anomalies in NEW-assim. NINO3-Chla anomalies derived from the observational dataset Ocean Colour Climate Change Initiative (OC-CCI) dataset, Version 4.2, European Space Agency, is also shown. Here, monthly anomalies were calculated with respect to the 1998–2005 monthly mean climatology because OC-CCI dataset is only available since September 1997. The results of NEW-assim shows that NINO3-Chla increased during La Niña, and the correlation coefficient between NEW-assim and the observed values was estimated to be 0.60, indicating that NEW-assim is able to capture the variations in primary production associated with ENSO. It should be noted here that the variation of NEW-assim is larger than the variation of the observed values. Since NEW-assim captures the historical variations in the bloom magnitude associated with ENSO, we next calculate the average of NINO3-CO2F for El Niño, La Niña, and others (neutral), respectively (Figure R1b). Here, following Japan Meteorological Agency, "El Niño event" is defined as a phenomenon in which the five-month running mean of the NINO3-SST anomaly exceeds +0.5°C for six consecutive months or more, and "La Niña event" as a phenomenon in which the five-month running mean of the NINO3-SST anomaly is below −0.5°C for six consecutive months or more (Figure R1a). The anomaly of NINO3-CO2F averaged during El Niño periods is −0.43 $\mu gCO_2\ m^{-2}\ s^{-1}$, and that averaged during La Niña periods is 0.36 $\mu gCO_2\ m^{-2}\ s^{-1}$. The absolute value of NINO3-CO2F anomaly averaged during La Niña periods is 15% smaller than that of El Niño periods, which can be explained by the biological pumps during La Niña periods. However, the standard error bar of NINO3-CO2F during La Niña periods overlaps that during El Niño periods, so that the difference in NINO3-CO2F is not significant and we did not include these results in the revised manuscript. Further studies are needed to quantify the effect of biological pump.

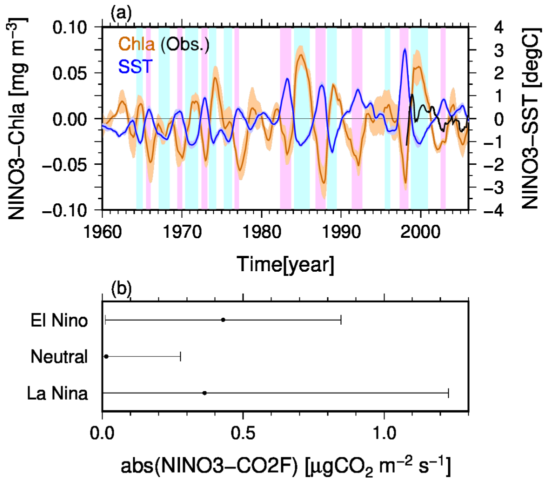

Figure R1. (a) Timeseries of the detrended NINO3-Chla for NEW-assim (orange line) and observations (black). The blue line is the timeseries of the detrended NINO3-SST anomalies in NEW-assim. Values plotted are the one-year running mean and shading shows the ensemble spread (1σ). The El Niño and La Niña periods is indicated by light magenta and light cyan, respectively. (b) Absolute values of monthly mean NINO3-CO2F anomalies averaged over El Niño, La Niña, and other (neutral) periods, respectively, during the period from 1960 to 2005 simulated with NEW-assim. Error bars indicate the standard deviations of monthly mean NINO3-CO2F anomalies. Note that they are not the standard deviations of the absolute values of monthly mean NINO3-CO2F.

L142. What about observational skills in the region for CO2F associated with ENSO compared to NEW-assim skill -0.41? This can be depending on the definitions of regional and temporal scales but as you cited Dong et al (2016) represents above 0.6 skills in many CMIP5-class model (it seems like opposite sign for CO2F). Of course they do not have assimilation but do you think the ENSO-CO2F skill is generated by some limitations coming from assimilation? Otherwise you may add comparison between OLD and NEW model correlation (or regression) skill of ENSO-CO2F without assimilation (freerun) to argue this issue as a table likewise arranging skills of OLD, OLD-assim, NEW, NEW-assim and with skill of available SST reanalysis and psudo observation data of CO2 flux at least single observation dataset such as using Landschutzer et al 2016 (link: https://www.nodc.noaa.gov/ocads/oceans/SPCO2_1982_2015_ETH_SOM_FFN.html), opened to public or data-based estimates of carbon cycle variability (http://www.bgc-jena.mpg.de/CarboScope/?ID=oc), which is needed by personal contact to access. If then, you may add some figures and discussions in chapter 3.1 for comparison of ENSO-related CO2F skills between in observation, OLD, and NEW model in spatial and temporal scales. If the results are significant, this could be providing the most benefit in this paper and persuading rest of results being reasonable. According to this, you may see some figures and references in Hongmei Li et al. 2019 as you cited."

Thank you for your suggestion. In order to discuss the correlation coefficients between CO2F and SST in each experiment, we have added Table 1 in the revised manuscript. We have recalculated the correlation coefficients between CO2F and SST in NEW-assim, and it was estimated to be –0.50. The absolute value of the correlation coefficient in NEW-assim is less than the absolute value of the correlation coefficient of NEW (–0.85). This is because model nature are somewhat distorted by the temperature analysis increment even in NEW-assim. In the revised manuscript, we have added the following sentence in Lines 246–248:

"Because the ENSO characteristics in NEW are not perfectly consistent with observations, model nature, namely responses of vertical velocity and DIC concentration in ENSO, are still distorted by the temperature analysis increment even in NEW-assim. This indicates that further model improvements are needed."

To compare the maps for the correlation coefficients between CO2F from SOM-FFN and that from the NEW-assim or from OLD-assim, we have added the new figures in the revised manuscript (Figure 1a and 1c). CO2F in NEW-assim (Figure 1a) is positively correlated with SOM-FFN in the equatorial Pacific. On the other hand, CO2F in OLD-assim shows a negative correlation with SOM-FFN there. In Lines 146–152 in the revised manuscript, we have added the description of these figures. The description on SOM-FFN has been added in Sect. 2.3 in the revised manuscript.