"Contrasting projection of the ENSO-driven CO_2 flux variability in the Equatorial Pacific under high warming scenario"
by P. Vaittinada Ayar et al.

We first would like to thank the anonymous reviewer for her/his thorough reading and very positive and constructive comments. We tried to take them into account as much as possible. A detailed point-by-point reply to these comments is provided below. Changes in the manuscript are indicated in blue.

Answer to Referee #3 :

Major comments :

- *Even though the authors are looking at the response of coupled models, the authors have ignored any changes or even providing statements about the atmospheric response (except Lines 340-344). There is no mention of changes in trade winds and/or changes in conditions of the air-sea interface due to the weakening of the easterly trade winds (during El Niño, for example). To me, this is a key ingredient that is missing from the study. This is a CMIP-based study and since the tropical ocean-atmosphere are strongly coupled with each other, the authors do need to provide qualitative statements about how atmospheric conditions across the ESMs (preserved vs. reserved) evolve that impact the oceanic ENSO response. Quantitative analyses regarding changes in atmospheric winds across the study time periods (or a figure or two) would be better, but I recognize that a quantitative evaluation of dynamical wind response is not a trivial task.*

  Authors' response : Thank you for this comment. In response to reviewer #1 request, we have calculated the simulated wind-solubility coefficient ($k * K_0$) during different ENSO phases and how they evolve in the projections for the two model groups. This information, together with the respective surface wind anomalies, are now presented in Fig. R1. It shows that both model groups are able to simulate the weakening of easterly trade winds during El Niño, and vice versa during La Nina under the contemporary period. In addition, the anomaly amplitudes are generally stronger in the preserved models, which is consistent with the higher amplitude of CO_2 fluxes variability in the preserved models (see Table 3 and Fig. 5). However, for the respective groups the amplitude of the surface wind anomalies between ENSO phases is not changing between given the periods, suggesting that the wind variability can only marginally contribute to CO_2 fluxes variability and can not explain the behaviour of the reversed group models.

  Figure R1 has been added to the supplementary material and this question has been addressed in lines 243-251 of the revised manuscript as :

  In addition to surface ocean pCO_2, CO_2 flux is estimated using atmospheric pCO_2 and wind solubility coefficient $k * K_0$ as :

$$\text{fgco2} = k * K_0 * (p\text{CO}_{2o} - p\text{CO}_{2a}) \quad (4)$$

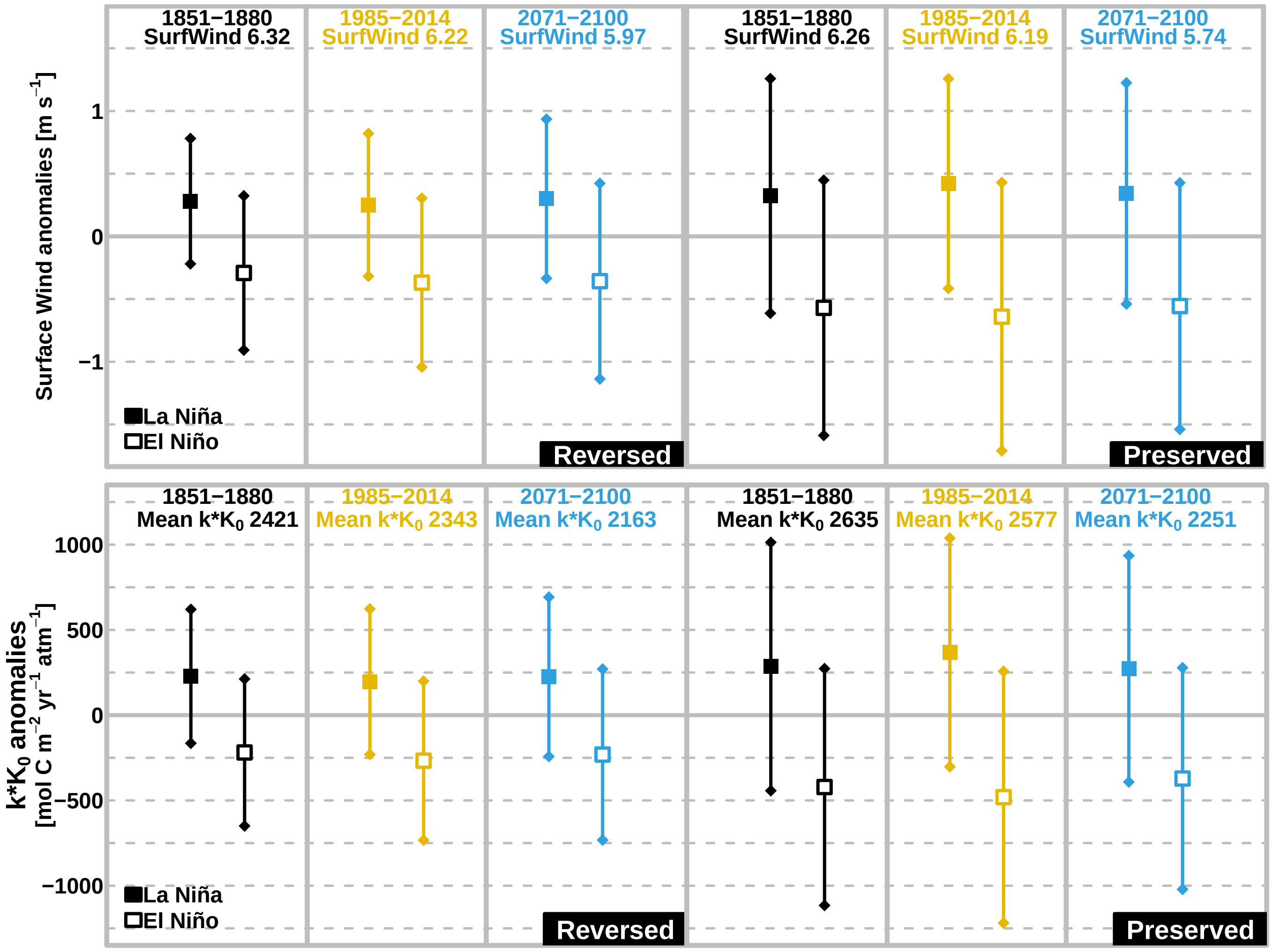

FIGURE R1 – El Niño and La Niña surface wind (*top* in m s^{-1}) and $k * K_0$ (*bottom* in mol C m^{-2} yr^{-2} atm^{-1}) mean anomalies for the reversed (*left*) and preserved (*right*) ESMs over the early historical (1851-1880), contemporary (1985-2014) and future (2071-2100) periods in the EP domain. Vertical bars represents ± one s.d. of the anomalies for the respective periods, groups of models and ENSO phases.

k represents the gas transfer velocity and K_0 the solubility coefficient [cf. WANNINKHOF, 2014]. The anomalies of surface wind and product of $k * K_0$ for each period, group of models and ENSO phase are depicted in Fig. S8 of the supplementary material. The amplitude of both anomalies between ENSO phases is larger for the preserved models than the reversed ones, which partly explains the higher amplitude of CO_2 flux variability variation between ENSO phase for the preserved models than the reverse ones (see Table 3 and Fig. 5). However, for the respective groups the amplitudes between ENSO phases are not changing between given the analysed periods. This means that the wind variability can only have a marginal contribution to CO_2 fluxes variability and can not explain the behaviour of the reversed group models.

- *The authors should consider evaluation of the models for specific ENSO cases - strong El Niño or strong La Niña years. Figure 5 provides a first indication that the "preserved" ESMs agree better with the observations than the reversed ESMs. But the comparison is noisy, and it may be better to examine specific strong and very strong ENSO events between 1950-2014. Approximately 10 such events can be identified for both El Niño and La Niña conditions that should allow robust statements on which of the two groups of ESMs (preserved vs reserved) validate better against observations.*

  Authors' response : Thank you for this comment. Models have been selected according to the correlation between annual CO_2 flux anomalies and Niño 3.4 index. We agree if the comparison is solely based on Figure 5, it is noisy. However the aim of our study is to identify common responses or pattern or changes in ENSO-CO2 flux variability among CMIP6 models. To keep it simple, we have applied one s.d. of Nino34 index to classify El Nino (Nino34>1s.d.) or La Nina (Nino34<1s.d.) months. As suggested, we have now explored whether or not we can get clearer comparison when taking into account only extreme ENSO events, (i.e. using 1.5 s.d. criteria). Figures RX and RY show contemporary SST and CO2 flux anomalies from observations and models using 1.5 s.d. criteria for distinguishing El Nino vs La Nina events. Except for one model (CNRM-ESM2-1), we do not see any significant difference in the spatial patterns when compared to Figs. S1 and S2 in the manuscript.

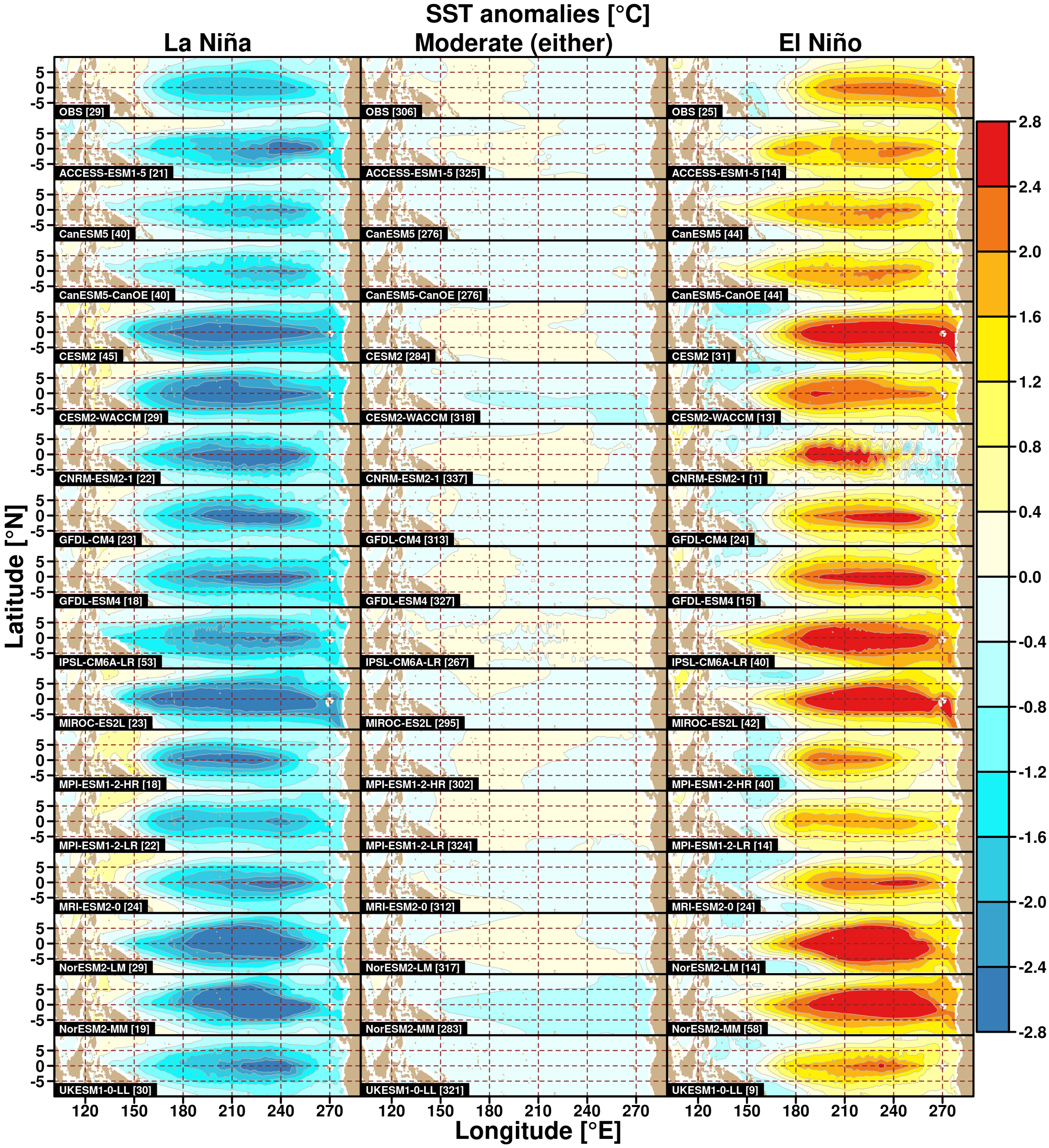

FIGURE R2 – CMIP6 ensemble SST (in °C) average anomalies over the 1985-2014 contemporary period for the La Niña, El Niño and the moderate regimes.

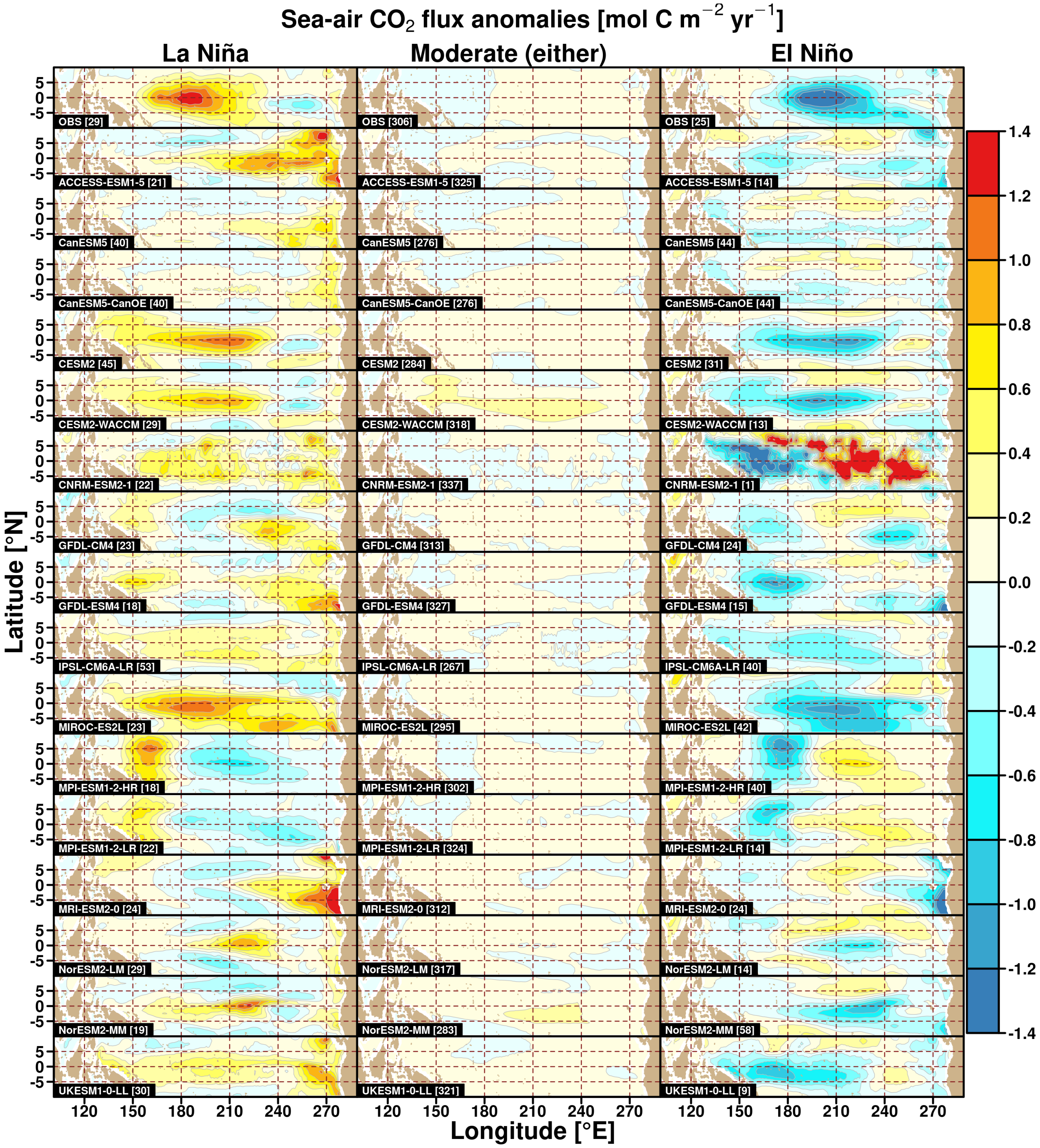

FIGURE R3 – CMIP6 ensemble sea-air CO_2 fluxes (in mol C m^{-2} yr^{-1}) average anomalies over the 1985-2014 contemporary period for the La Niña, El Niño and the moderate regimes.

Minor comments :

- *Line 2 – change to 'over the tropical ocean less carbon is released during El Niño. . . '*

  Authors' response : Done

- *Line 56 – it is hard to interpret what the authors mean by the phrase 'an end member future projection'. While it becomes clear eventually that the authors are referring to the high-emission scenario, maybe add a sentence or two here to clarify this phrase for the benefit of the reader.*

  Authors' response : Modified in line 59 of the revised manuscript as :
  in future projection run under a high warming scenarios

- *Line 97 – please check the grammar and punctuation*

  Authors' response : Done

- *Lines 145-146 and Lines 337-339 - it is a bit strange that while the authors define a classical Niño 3.4 domain (Lines 99-100), the study area is subsequently shifted to different longitudes. This matters because not all El Niños are similar and whether we are looking at an EP or a CP El Niño should have implications for the findings of this study. Did the authors consider evaluating the model simulations based on different El Niño types ?*

  Authors' response : Niño 3.4 domain is only used to compute Niño 3.4 index. This index is used to categorised month into El Niño or La Niña regime see section 2.2. The EP domain 2°S-2°N and 180°-260°E is identified as the common domain where the models and observation show the largest change in SST between ENSO phases see section 2.5. In this study, the aim is to examine the long-term average of ENSO-related CO2 flux variability and how it response in the high CO_2 future. As such, we think discriminating into more specific El Nino events (e.g., EP vs CP El Nino) is beyond the scope of this paper.

- *I would strongly encourage a modified version of Figure 11 – again, instead of looking at 1850-2100, maybe pick a period or specific strong & very strong ENSO years, for which the authors can plot a 'best estimate' of air-sea CO 2 flux from observations and/or models (for example, see Ishii et al., 2014, Biogeosciences, https ://doi.org/10.5194/bg-11-709-2014). It would be interesting to see which of the ESMs actually fall in the region where surface CO_3^{2-} concentration obs. and the most optimal estimate of air-sea CO2 fluxes overlap. Can we identify a subset within the 16 CMIP6 ESMs that validate better against the observations ? This study has already laid the foundation for providing this key message, thereby really helping the improvement of future ESMs and CMIP simulations.*

  Authors' response : Thank you for this comment. We would like to clarify that Figure 11 is meant to illustrate if historical carbonate concentration can provide a constrain on the projected cumulated CO_2 fluxes over the historical and future period. In that case choosing specific strong or very strong ENSO year would not be helpful although it would provide similar insight that models, which overestimate the surface carbonate ion concentration tend to simulate high cumulative CO2 fluxes (see Figure R4 below). Figure R4 which is similar to Figure 11 but we added on the left panel the cumulated CO_2 flux over the observational period. It provides us the same relationship between carbonate and cumulated CO_2 fluxes over the 1850-2100 period. Over contemporary period, the majority of the models (10/14) are underestimating the observed cumulated sea-air CO_2 fluxes but reversed models simulate the largest underestimation.

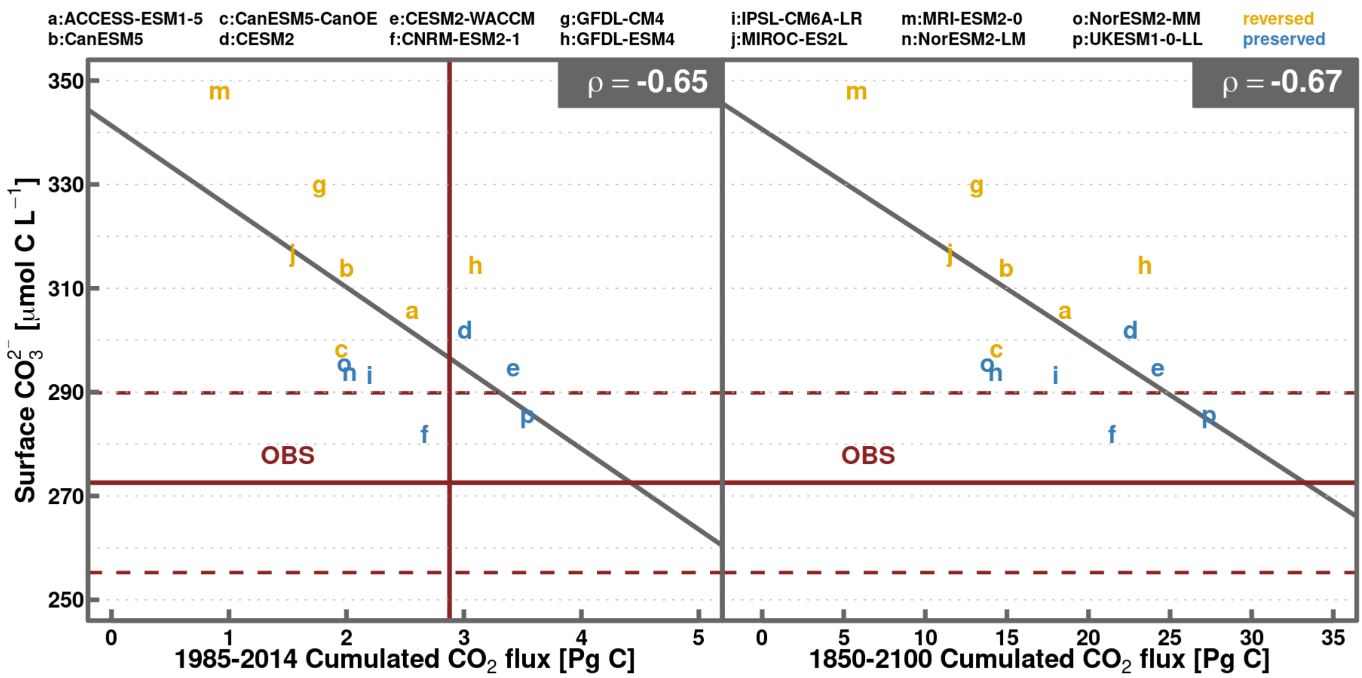

FIGURE R4 – Average contemporary surface CO_3^{2-} concentration (in μmol C L^{-1}) plotted against the cumulated sea-air CO_2 fluxes (in Pg C) in the EP region from 1985 to 2014 (*left*) and 1850 to 2100 (*right*). ρ is the correlation and reversed ESMs are marked in yellow and preserved ones in blue. The observations are given in brown lines with dashed lines being the carbonate observation error.

Figure R4 is the new Fig. 11 of the article and additional discussion has been added in lines 334-339 of the revised manuscript as :

Figure 11 shows contemporary surface carbonate concentration against the cumulated sea-air CO_2 flux ~~from 1850 to 2100~~ over the 1985-2014 and 1850-2100 periods over EP for all the models except the MPI models. ~~The correlation at~~ Correlation at 0.65 and 0.67 ~~indicates~~ indicate that the carbonate concentration is a good indicator of the buffering capacity of the model : the higher the carbonate the lower the cumulated CO_2 outgassing (ie. more carbon uptakes). The preserved ESMs are less biased in terms of carbonate concentration and cumulated CO_2 flux over the contemporary period, which tend to indicate that their behaviour should be more reliable.

WANNINKHOF, Rik (**2014**). “Relationship between wind speed and gas exchange over the ocean revisited”. Limnology and Oceanography : Methods. Vol. 12. no. 6, p. 351-362.