Response to Reviewer #3

(Note: referee comments are in italic font, and our replies are in normal font)

In this paper, the authors used an interesting diagnostic method to examine the sources of the systematic SST bias in the tropical Atlantic Ocean for the Community Earth System Model version 1 (CESM1). The NCAR coupled model demonstrates substantial errors in this region with a temporal-spatial pattern that is typical of many other climate models. The authors' emphasis is on the roles played by the systematic errors inherent in the uncoupled atmospheric and ocean-sea ice components in the coupled simulations. The analysis indicates that the uncoupled errors in the ocean sea ice model contributes significantly to the eastern equatorial Atlantic warm SST bias in CESM1, implying major flaws in the simulated oceanic processes. The method of analysis they developed is quite novel and is promising as useful tool of error diagnosis generally for coupled models. The paper is also well written and easy to read. However, I have difficulty in reaching the same conclusions as the authors have drawn on several points. In the following, these points, as well as some other comments, are listed for the authors to consider in a minor revision of the paper.

Reply: We would like to thank the reviewer #1 for the thoughtful comments. The manuscript is now revised following the reviewer's suggestions.

1. Lines 112-121: The authors highlight here the merits of diagnosing the systematic error sources through an initial value approach. It is useful to also point out here that the strategy of focusing on the initial development of the SST bias using ensemble initial value experiments has been proposed and used successfully in previous studies (e.g., Huang et al. 2007; Toniazzo and Woolnough 2013; Voldoire et al. 2014).

Reply: Thank you very much for pointing out these references. The papers are now discussed in section 2 and referenced.

2. Lines 208-218: In this paragraph, the authors seem to argue that, the bias of the shortwave radiative flux in the southeastern Atlantic may not be a major source of the SST error because it is largely compensated by the bias of the long-wave radiation (if observed SST is prescribed). This interpretation may be misleading because this implied compensation might not materialize due to air-sea feedback. In a coupled system, if a positive SST error is generated by *the shortwave bias, the increased SST may lead to a reduction, instead of an increase, of the longwave radiation. The net effect may be an enhancement of the initial SST bias by net radiative heat flux change, instead of damping it. This scenario is consistent with the CESM1 bias (left column, Fig. 6), which shows distinctive positive tendency from August to October in the southeastern Atlantic (presumably because of the lack of low cloud), even though the coupled bias center does not line up with those in the right columns.*

Reply: Thank you for the valuable suggestion. These sentences about the longwave compensation are now removed.

3. Lines 237-259: In this part of discussion, the authors do not say explicitly how the oceanic SST bias (delta Tm in Eq (3)) is estimated. My guess is that it is the residue of all other terms. Sometimes it is also not clear whether the total delta T or just the delta Tm is discussed in the figures or texts. For instance, does the implicit SST bias for OCN refer to total delta T or delta Tm? A clear definition in this paragraph can clarify this issue.

Reply: Tm in Eq (3) is already defined in Eq (2). It is the difference in ocean mixed layer temperature between EXP_OCN and the observation.

4. Lines 228-236: The authors have discussed the effects of using interactive bulk formulae to calculate the turbulent evaporative and sensible heat fluxes in the OCN runs, which is equivalent to a nudging to prescribed local air temperature. A diagnostic strategy is developed to reduce the influence of this problem. However, I wonder a switch to delta Tm can totally mitigate this shortcoming. For instance, since the left-hand side of EQ. (2) is small because of the nudging, the two terms on the right-hand side largely balance each other. One may argue that some of the error in delta Tm is also a response to the nudging and not totally due to independent processes of ocean physics. Therefore, some transient errors, e.g., the initial cooling in the Gulf of Guinea, may be partly forced by this uncoupled initialization strategy and not totally caused by inherent deficiency of the ocean model physics, as the authors argued.

Reply: As the reviewer pointed out, the left hand side of Eq (2) is indeed small because the model-simulated surface temperature is strongly damped to the prescribed air temperature and specific humidity. However, we would like to stress that the implicit SST bias in EXP_OCN is the first term in the right hand side of Eq (2), not “delta Tm” in the left hand side of Eq (2). We agree with the reviewer that the implicit SST bias in EXP_OCN can be affected by both inherent deficiency of the ocean model physics and the ocean model initialization strategy. In our case, an important component of the ocean model initialization strategy is the surface flux fields used (COREv2) for EXP_OCN. The COREv2 surface flux product is not error-free. Therefore, both inherent deficiency of the ocean model physics and the COREv2 surface flux bias could contribute to the implicit SST bias. This point about the COREv2 surface flux bias is now discussed in section 6.

5. Could the authors discuss the uncertainty in the observed heat fluxes and its potential effects on their estimates of the SST bias? Since modest heat flux changes can generate relatively large SST bias in some of these regions, how such uncertainty can affect the result is of interest here.

Reply: The reviewer raised a very important point, which is now addressed in section 6. As the reviewer pointed out, our results are not entirely independent from uncertainty in the observed surface flux product used (i.e., COREv2). For instance, if the net surface heat flux in COREv2 is too large, it will contribute positively (negatively) to the implicit SST bias in EXP_OCN (EXP_ATM) according to equations (1) and (3). Although considerable effort was invested to minimize errors, COREv2 is still far from error-free. Therefore, in a more strict sense, equation (3) should be considered as the implicit SST bias in EXP_OCN in reference to COREv2. Similarly, equation (1) should be considered as the implicit SST bias in EXP_ATM in reference to COREv2. Nevertheless, it should be noted that the total implicit SST bias in EXP_ATM + EXP_OCN is independent from the observed surface heat flux product used, and is thus not subject to uncertainty in the observed surface heat flux product used at least in a linear sense (see equation 3).

It order to better understand the impact of uncertainty in the COREv2 surface heat flux fields on the implicit SST bias in EXP_ATM and EXP_OCN, two additional stand-alone ocean sea-ice model simulations are performed by using the surface flux fields derived from the European Centre for Medium-Range Weather Forecasts Interim (ERA_INT) reanalysis, and the Modern-Era Retrospective Analysis for Research and Applications (MERRA) reanalysis.

As shown in Figure 9a, d and g, the implicit SST bias in EXP_ATM referenced to either ERA_INT or MERRA is more negative compared to that referenced to COREv2. On the contrary, the implicit SST bias in EXP_OCN referenced to either ERA_INT or MERRA is more positive compared to that referenced to COREv2. What these mean is that the net surface heat flux into the tropical Atlantic is larger overall in ERA_INT and MERRA than that in COREv2. Nevertheless, the spatial patterns of the implicit SST bias in EXP_ATM referenced to the three surface flux products (i.e., COREv2, ERA_INT and MERRRA) are quite similar. As shown in Figure 9b, e and h, the same conclusion can be drawn for the implicit SST bias in EXP_OCN.

In sum, the overall magnitude of the implicit SST bias can be attributed more to either the atmosphere-land model or the ocean sea-ice model depending on the reference surface flux product used. However, the spatial pattern of the implicit bias in EXP_ATM (EXP_OCN) is largely determined by inherent deficiency of the atmosphere-land (ocean-sea ice) model component. As such, the total implicit SST bias in EXP_ATM + EXP_OCN is only minimally affected by the reference surface flux product used (Figure 9c, f and i). Therefore, we can conclude that the total implicit bias in EXP_ATM + EXP_OCN is a reliable measure of inherent deficiency in an AOGCM.

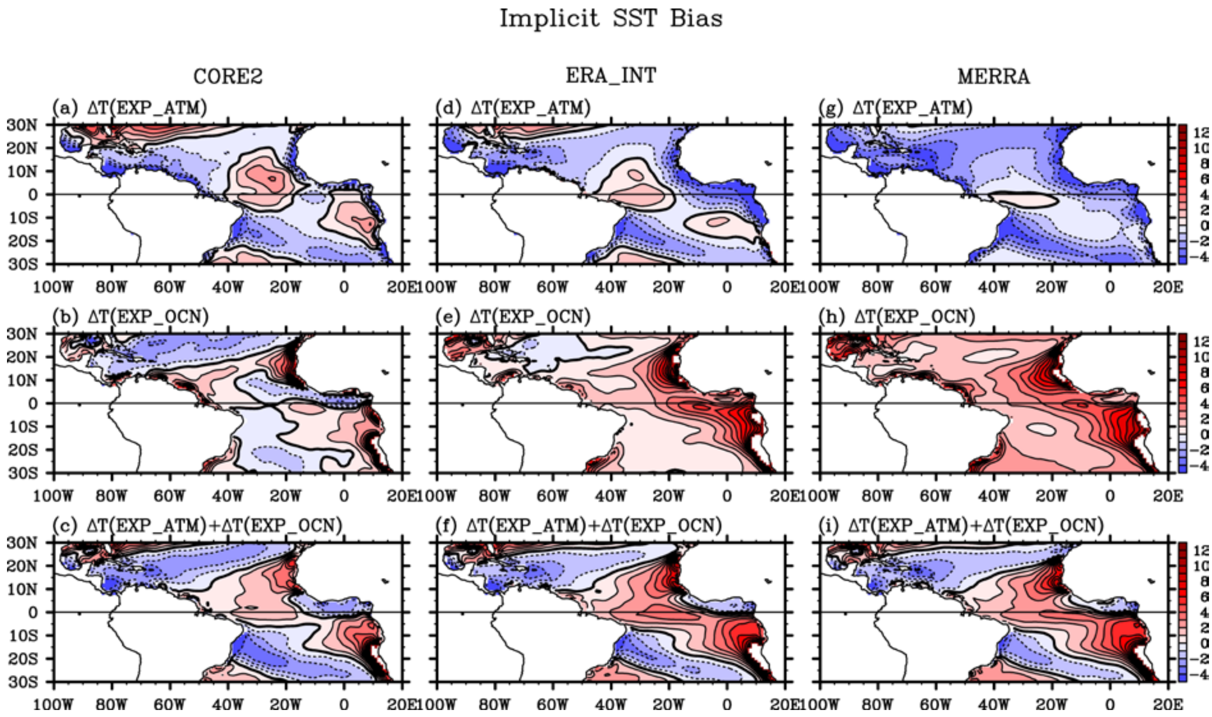

Figure 8. Annually averaged implicit SST bias in (a,d,g) EXP_ATM, (b,e,h) EXP_OCN, and (c,f,i) EXP_ATM + EXP_OCN referenced to (a,b,c) COREv2, (d,e,f) ERA_INT, and (g,h,i) MERRA. The unit is °C.