Response to Reviewer #1

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

The warm bias in the tropical Atlantic Ocean in CGCM is an unresolved problem until now. Through some experiments, this work suggested that the ocean-sea ice model contributes significantly to the eastern equatorial Atlantic warm SST bias in CESM1 due to its spurious ocean dynamic processes. While acknowledging the potential importance of the westerly wind bias in the western equatorial Atlantic and the low-level stratus cloud bias in the southeastern tropical Atlantic, both of which originate from the atmosphere-land model, the authors argued that solving those problems in the atmosphere-land model alone does not resolve the equatorial Atlantic warm bias in CESM1. This is an interesting work. I suggest some following minor revisions for authors' consideration.

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

1. Role of ocean processes:

One of important conclusions of this work is "the ocean-sea ice model contributes significantly to the eastern equatorial Atlantic warm SST bias in CESM1 due to its spurious ocean dynamic processes". However, it is unclear which processes (zonal/meridional advections or upwell) play more important role. It will be a big improvement for the manuscript if some further diagnoses about the contribution of different ocean processes on the bias can be added.

Reply: Since there is no reliable observations to accurately estimate important heat budget terms in the equatorial Atlantic Ocean, it is quite difficult to pinpoint which terms (or processes) contribute more to the spurious ocean dynamic processes. Therefore, our methodology only provides a mean to estimate the integrated effects of the spurious ocean dynamic processes via "implicit SST bias".

However, we do understand the need for further diagnosing the contribution of different ocean processes on the implicit SST bias. Therefore, in response to the reviewer's suggestion, we have added a new figure (Figure 8). The new figure shows the monthly-averaged equatorial temperature bias (averaged for 5S-5N) in EXP_OCN. The green solid (dashed) line shows the corresponding mixed layer obtained from EXP_OCN (observations). This figure clearly shows that the temperature bias near the surface is quite small. However, at the based of the mixed layer, the temperature bias increases up to 6^{o}C. What this suggests is that due to spurious ocean dynamic processes in the ocean model, the upper thermocline water that entrains into the mixed layer during late spring and early summer (e.g., Lee and Csanady, 1999) is too warm. The surface temperature is strongly damped to the observation via the prescribed air temperature and specific humidity in EXP_OCN. However, when the ocean sea-ice model is fully coupled to the atmosphere-land model, the entrainment of the warm upper thermocline layer will produces warm SST bias.

Obviously, this still does not tell us which process or parameterization is responsible for the warm implicit SST bias in EXP_OCN. However, our study in this paper provides the tool to investigate those processes or parameterization. For instance, we can perform multiple experiments using the stand-alone ocean sea-ice model by changing the vertical diffusivity. By computing the implicit SST bias using equation 3 and 4, we can estimate the potential impact of ocean vertical diffusivity in the fully coupled model SST bias. This is an example of what we would like to do in the future studies.

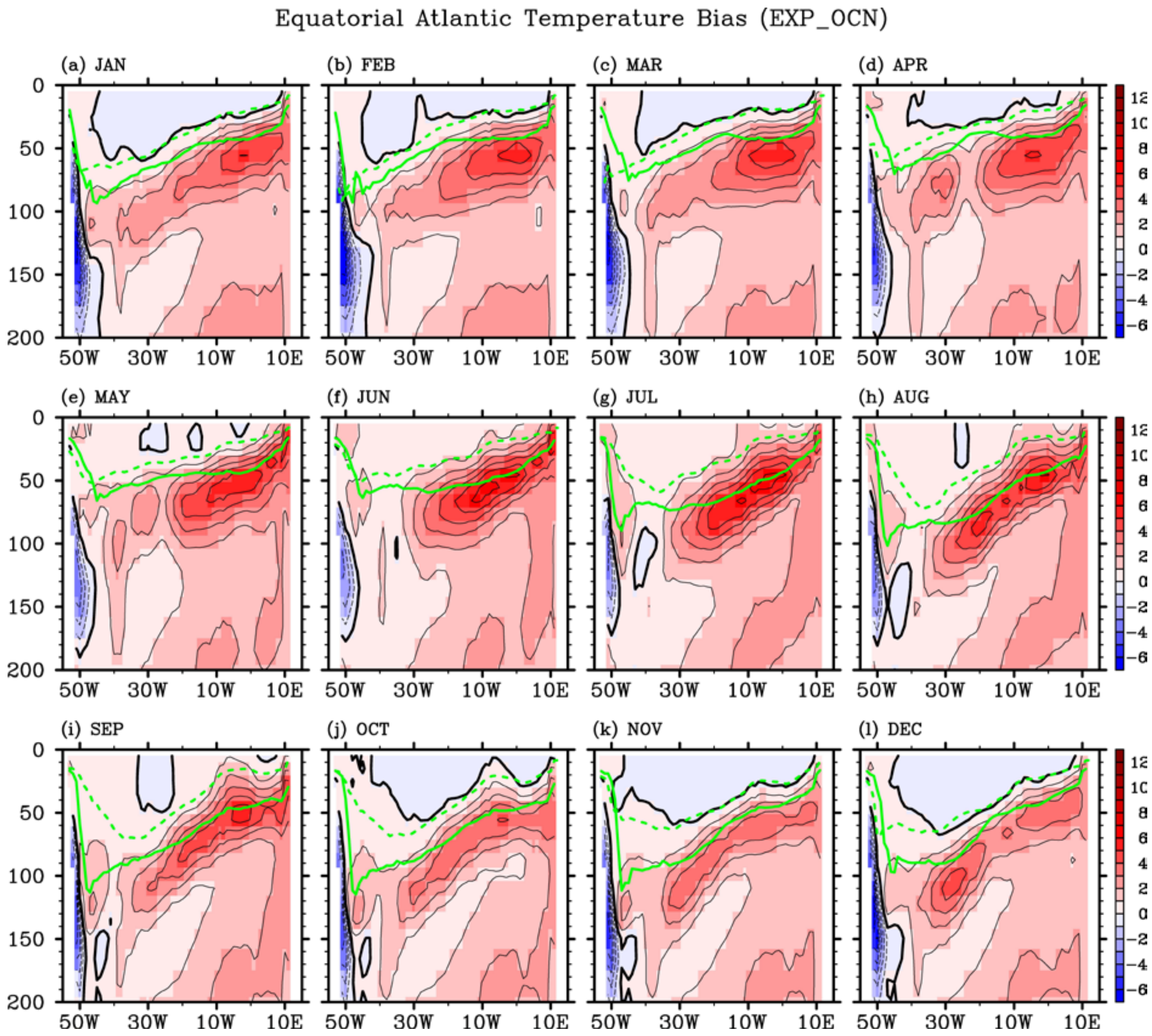

Figure 8. The time-depth evolutions of equatorial temperature bias (shaded) and mixed layer depth (green solid line) averaged for 5S-5N obtained from EXP_OCN. The green dashed line is the mixed layer depth obtained from observations (EN4 from Hadley Center).

2. Importance of coupling in resulting in the bias

It was speculated that the overall bias in the tropical Atlantic may be largely due to air-sea coupling processes. For example, when SST bias presents in the tropical southeastern Atlantic, the climatology reversion layer in the atmosphere boundary will be weaken, then the low-cloud deck may disappear, as a result of reduced low-cloud amount, short-wave radiation increases and SST warm bias enlarges. This is the case at least at NCEP CFSv1 (Hu et al. 2008). Thus, the warm bias may mainly involve air-sea coupling processes. It was noted that the bias in EXP_OCN, and EXP_OCN+ EXP_ATM (Fig. 4a, b) is much larger than that in CCSM4 and EXP_CPL (Figs. 1b, 4c). Does that mean that coupling will reduce the bias? It will be interesting to explain and understand the significant amplitude differences of the biases among these experiments?

Reply: As the reviewer point out, the air-sea coupling process will amplify *the SST bias* in EXP_OCN, which is shown in Figure 3, when the ocean sea-ice model is coupled to the atmosphere-land model. However, Figure 4a shows the *implicit SST bias*, which is very different from the actual SST bias. The implicit bias in EXP_OCN shown in Figure 4a estimates the extent to which the spurious ocean dynamics in the ocean sea-ice model could potentially contribute to the SST bias once the air-sea coupling is initiated. Therefore, it is expected that *the SST bias* in the fully coupled model is weaker than the *implicit SST bias*. For instance, in a region where the total implicit SST bias is positive, once the air-sea coupling is initiated, the model SSTs will increase initially. However, the increased SSTs will in turn enhance the longwave radiative and latent cooling at the surface to reduce the rate of SST warming. Therefore, it is highly unlikely that the SST bias will reach the full extent of the total implicit SST bias. This point is now discussed in section 3.3.

3. Experiment lengths

In page 7, it was indicated that EXP_ATM was integrated 30 years, EXP_OCN 210 years, and EXP_CPL 5 years. What are the considerations using different lengths of the integrations?

Reply: EXP_ATM, EXP_OCN and EXP_CPL were integrated for 30, 210 and 5 years, respectively. The global kinetic energy demonstrated that the atmosphere-land model has reached a quasi-equilibrium state after about 10 years, while the upper ocean in EXP_OCN achieved a quasi-stationary state after about 100 years. EXP_ATM and EXP_OCN were integrated for 30 and 210 years and then the last ten years results were used for initial conditions for the 10-emsemble member EXP_CPL. For EXP_CPL, we focus on the initial development of the tropical Atlantic bias in this study. Therefore, EXP_CPL was integrated for 5 years, and only the first 2-year results were used for our analysis.

4. *Others and typos*

(1) *Lines 53-57, this paragraph just has one sentence, may merge with the following paragraph.*

Reply: Done.

(2) *Line 63: Huang et al. (2007) may also include here.*

Reply: Huang et al. (2007) is now referenced.

(3) *Line 186: may define "COREv2" first.*

Reply: COREv2 is now defined in line 167.

(4) *Figs. 5-6 show season dependence of the bias: grows faster in boreal summer and fall and peaks in November-December. This is consistent with Huang et al. (2007). The seasonal dependence of the bias growth is an important issue and should be discussed.*

Reply: We agree that the seasonal dependence of the bias growth is an important issue. To certain extent, this point is addressed in Figure 6 and 7 and also discussed in the text. In particular, we point out in section 4 that the eastern and southeastern equatorial Atlantic SST bias in EXP_CPL is mainly caused by spurious ocean dynamics in late spring and early summer during which the equatorial entrainment is maximized.