Replies to Reviewer #1:

Dear Prof. Spencer Jones,

Thank you very much for these constructive comments. We have revised the manuscript carefully based on these comments. This manuscipt is improved significantly because of your invaluable suggestions.

"I am dissatisfied with some of the responses to comments I made on this paper. The authors' claims about the importance of local wind forcing in the North Pacific seem to be over-exaggerated. I cannot recommend the paper for publication until these claims are either better supported (which I don't actually believe is possible), or toned down a good deal. The paper has enough material even if the authors remove their claims about the role of local wind forcing, so they should not be afraid to do so.

There are two fundamental questions the authors should think about. Would the PMOC still emerge if Ekman downwelling in the North Pacific did not increase in NoTibet? And would the PMOC still emerge if Ekman downwelling was the only effect of removing Tibet? The authors say that the PMOC is enabled by Ekman downwelling several times in the paper, but they show no evidence that an increase in Ekman downwelling is essential to the establishment of the PMOC (correlation here does not imply causation). Moreover, in modern AMOC/PMOC theory, wind forcing in the North of the basin is a second order effect, especially in simulations with salinity (Cessi 2018).

Responses: Thank you very much for these comments. In this round of revision, we toned down the role of wind forcing in the North Pacific deep water formation (NPDW). We agree with you that the surface buoyance is the most important factor, while the Ekman downwelling plays the secondary role in the NPDW.

At this stage, we can not fully address the two fundamental questions. However, please allow us to express our tentative opinions: (1) the PMOC might not emerge if the Ekman downwelling in the North Pacific did not increase in NoTibet; and (2) the PMOC would never emerge if the Ekman downwelling was the only effect. We think both the Ekman downwelling and surface buoynace are important for the PMOC, but the latter is more important.

Figure R1 can help us understand the NADW formation in Real and NPDW in NoTibet. In Real, the SSD in the North Atlantic can be more than 27.5σ_0 (outlined by solid grey rectangle in Fig. R1a), which is strong enough to enable deep water formation in the North Atlantic, even accompanying the Ekman pumping (black dots in Fig. R1a). However, in NoTibet the SSD in the North Pacific is no more than 26.5σ_0 (outlined by dashed grey rectangle in Fig. R1b), which, we think, is not strong enough to form deep water in the North Pacific. In fact, from Real to NoTibet, the SSD increase ($\Delta\sigma$ ~ 0.5 kg/m^3) (due to the salinity increase) in the North Pacific is not as significant as the SSD decrease ($\Delta\sigma$ ~ 2 kg/m^3) in the North Atlantic. The enhanced Ekamp downwelling (denoted by black crosses in Fig. R1b) may be truly needed for the North Pacific. Figs. R1c and d show the SSD anomaly with global zonal mean value removed. The SSD contrast between the North Atlantic and North Pacific in Real and NoTibet can be seen more clearly. In Real the SSD in the North

Atlantic is 2 kg/m^3 more than the zonal mean (Fig. R1c), while that in the North Pacific in NoTibet is only 0.5 kg/m^3 than the zonal mean (Fig. R1d). Therefore, we would like to say that the physical processes of deep water formation in the North Atlantic and the North Pacific are different. The former involves thermohaline dynamics only, while the latter involves both thermohaline and wind-driven dynamics.

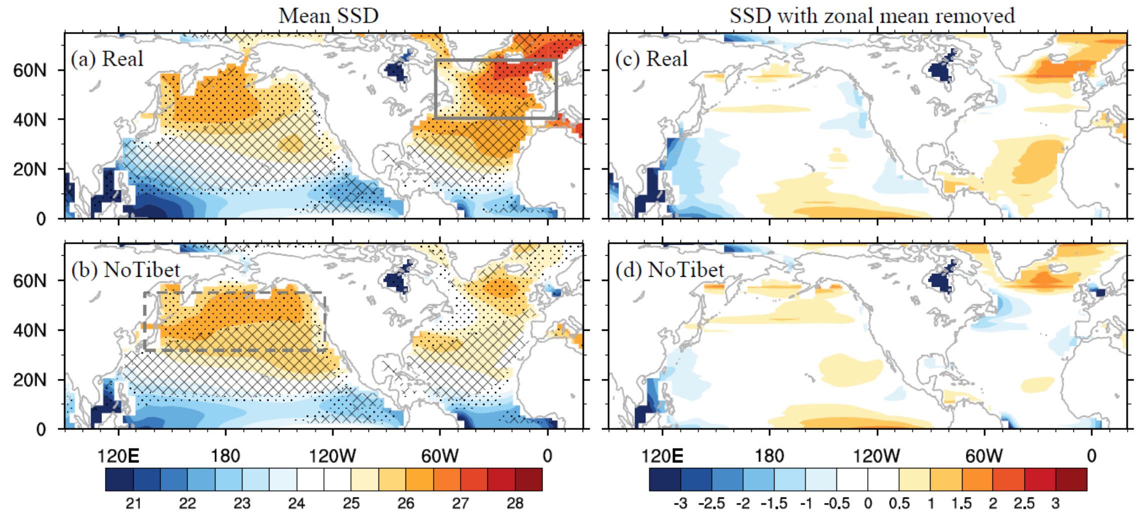

Fig. R1 Mean sea surface density (SSD, σ_0, kg/m^3) in (a) Real and (b) NoTibet. In (a) and (b), the black dots denote Ekman upwelling, and the black crosses denote Ekman downwelling. (c) and (d) show SSD with global zonal mean value removed.

Major points:

1. *In the response to my question 2, you say "the lower southward branch of the PMOC is located between 1000-m and 2000-m depth, which is not related to the wind-driven dynamics. Since the depth of 27\sigma_{\theta} isopycnal level can only reach to 500m in the Pacific, the PV over 26-27\sigma_{\theta} has nothing to do with the PMOC". I agree. But why do you think that PV contours over 26-27\sigma_{\theta} at 40N are related to the PMOC? At 40N the PMOC is still below 1000m. It seems to me that this subduction is either not influencing the PMOC at all, or only influencing the PMOC through the salinity field (see next point). This should be emphasized - at the moment the paper seems to say that subduction along this isopycnal surface is directly forcing a stronger PMOC.*

Responses: Thanks for your comments. In our previous reply to Q. 2, we wrote "the PV over 26-27 in the *South Pacific* has nothing on the PMOC," so we only plotted PV in the North Pacific in Fig. 8.

We totally agree with you that, if we only see the PV over 26-27σ_0, the depth of PV contours can only reach 500 m (see the 27 isopycanl line in Fig. 9a4). But if we look a little bit deeper, say the 27.2 or 27.4 isopycal lines in Fig. 9a4, the depth can extend to 1500 m. In the upper 500 m, both the wind-driven dynamics and salinity effect cause downward subduction; and below 500 m, the salinity effect furthers the downward subdction. The PV dynamics is related to the PMOC, but we did not say the PV dynamics causes the deeper subduction. The salinity effect is more important for the deep water formation (Figs. 9a4, b4, and c4).

Figure R2 shows the evolution of PMOC. The time evolution of PMOC in NoTibet shows that the downward branch of PMOC first occurs in the upper 500 m around 40°N during the first few decades (Figs. R2b and c). This short time scale corresponds to the time scale of wind-driven dynamics since the thermohaline circulation needs much longer time. We do agree with you that the subduction influences the PMOC mainly via salinity effect. The anomalous Ekman downwelling can help the high-salinity surface water penetrate downward much deeper, which eventually leads to the formation of PMOC.

The salinity effect and wind effect cannot be separated in NoTibet. In general, we agree with you that the surface salinity is more important for the PMOC setup. In this revision, we toned down the Ekman downwelling effect and put more emphases on the salinity effect.

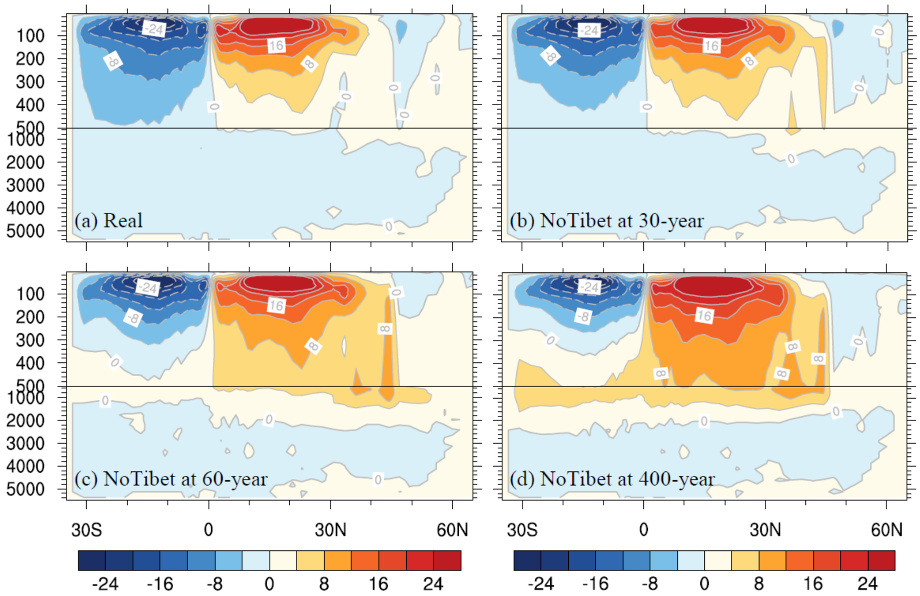

Fig. R2 Mean PMOC in (a) Real, and the PMOC in NoTibet averaged over (b) years 15-45, (c) years 45-75, and (d) the last 100 years. Units: Sv.

2. *I do not believe, either based on the PV field, or on the change in Ekman forcing, that local wind directly forces significant deep water formation in the North Pacific. The North Pacific is not like the Southern Ocean: it is a blocked region, so the Ekman transport is returned near the surface of the ocean. Hence, Ekman pumping near the surface is very unlikely to reach depth (particularly not as deep as 1000m). The Ekman transport in the North Pacific can influence the overturning a small amount by a) transporting heat and salt or b) compensating for some of the northward transport in the upper part of the MOC. The schematic in figure 12 may be correct that increased Ekman downwelling increases the salinity in the eastern North Pacific, but I think that this is most likely a second-order effect.*

Responses: Thank you very much for your comments. We agree with you that the local wind cannot directly force significant deep water formation in the North Pacific. In several places of this revision, we emphasize that the Ekman downwelling plays a secondary role.

In Fig. 12, we change the arrow between ”Ekamn downwelling” and ”SSS in ENP” to a line segment, indicating there is no causality between them. We just want to show that these two effects when combined can lead to more denser water sunduction in the North Pacific.

3. *Line 293: The authors say that the anomalous downwelling regions help push surface water downward to thermocline depth. But this makes no sense: light water that is pushed downwards to thermocline depth will just float back up again due to its buoyancy. You might be able to say that downwelling encourages vertical mixing and enables vertical isopycnals, but I'd need to see evidence that wind-driven vertical mixing goes all the way down to the thermocline in a blocked basin: that seems unlikely to me.*

Response: Thank you very much for this suggestion. It is revised as follows: ”... These anomalous downwelling regions are forced by the anomalous high-pressure systems above (Fig. 4a), which can encourage vertical mixing and subduction process.”

4. *Line 306: How can downward movement of PV at ~500m be influenced by Ekman downwelling at the surface?*

Response: Thank you very much for this comment. We deleted ”which is again assisted by the enhanced Ekman downwelling over there. This subduction process in NoTibet can be well understood by the classical ventilation thermocline theory (Schott et al., 2004).”

5. *Line 333: If the processes are different from the AMOC, can you show some actual evidence that compares the AMOC with the PMOC? (I think the processes are the same and you should just remove this statement)*

Responses: Thank you very much for this suggestion. We toned down this statement and state that ”The NPDW formation can also involve wind-driven dynamics.”

Please also refer to Fig. R1. Since the SSD in the North Atlantic is strong enough, the thermohaline dynamics is enough to the AMOC formation. While in the North Pacific, the SSD is not strong enough, the Ekman downwelling can play a role in the PMOC formation. Of course, we agree with you that the thermohaline process is more important to the formation of PMOC.

Minor points:

6. *Line 370: "this weak NPDW formation" If the water only reaches 300m, there is no NPDW formation.*

Response: Thank you very much for this suggestion. We rewrote this sentence as follows: ”This shallow subduction is far from sufficient to form the NPDW and thus start the PMOC.”

7. *Line 21: "the presence of the TP be" -> "the presence of the TP is"*

Response: Thanks. Revised.

8. *Line 68: "Freshwater input is thought as"-> "Freshwater input is thought to be"*

Response: Thanks. Revised.

9. *Line 83: "the Pacific is featured by shallow wind-driven circulations, say, the subtropical cells"-> "the Pacific features shallow wind-driven circulations, also called the subtropical cells"*

Response: Thanks. Revised.

10. *Line 84: "we find that the deep MOC can develop in the Pacific, namely, the PMOC"->"we find that a deep Pacific overturning (the PMOC) can develop"*

Response: Thanks. Revised.

11. *line 147: "Clearly"->"As shown in figures 2b and 2c,"*

Response: Thanks. Revised.

12. *Line 271: "How and where the surface water sinks to deeper ocean are closely related to ocean dynamics."->"How and where surface water sinks to the deeper ocean is closely related to ocean dynamics."*

Response: Thanks. Revised.

13. *Line 418 says xxx instead of an actual statement*

Response: Sorry for our carelessness. We deleted “suggesting that xxx.”

14. *"Please try to get someone who speaks English well to proofread the manuscript before the next submission. There are more grammatical problems than I listed here, and some of the grammatical changes in this revision actually make the grammar worse rather than better."*

Response: Thank you very much for the suggestion. Our manuscript has been sent to a professional English editing company twice. We hope that the English and grammar in this revision are satisfactory.