Response to reviewer

We would like to deeply thank the reviewer for constructive comments which greatly improve the manuscript. The followings are detailed response to each comment. Corresponding modifications are highlighted in the new submission.

To Reviewer 1,

(1) As cited in the introduction, Oka et al. (2021) investigated NPSTMW using Argo floats observations. They showed that annual-mean volume actually increased in the northeast region (28–40ºN, 140ºE–170ºW) from 2017 to 2019, while that in the other region decreased. The northeast region includes the main formation region of NPSTMW with densities of larger than 1025.2 kg/m3. This is important difference and needs the comparison with Oka et al. (2021).

Response: We thank the reviewer's valuable comment. According to the reviewer's suggestion, we have added the comparison with Oka et al. (2021) in the section 3.1 of the new submission (L216-220): Oka et al. (2021) investigated NPSTMW change in the region (15ºN–40ºN, 120ºE–170ºW) using Argo floats observations. They showed that annual-mean volume increased lightly in the northeast region (28ºN–40ºN, 140ºE–170ºW) from 2017 to 2019, while that in the other region decreased significantly. In fact, the NPSTMW in the whole region have gradually decreased in recent years. Hence, the recent decline of NPSTMW observed in RGA dataset is definitely consistent with the results of Oka et al. (2021).

(2) As shown by Qiu et al. (2020) and Qiu (2023), the stable KE and its northward shift is a combined response to the Kuroshio LM south of Japan and the Rossby wave forcing from the interior wind stress across the North Pacific. The KE northward shift can affect the overlying storm track and basin-scale wind field (Qiu et al. 2020). Is the northward shift of the westerlies, shown by the authors, associated with the stable KE? Or is it due to the PDO? Some additional analyses will be necessary. In addition, are the surface warming and intensified stratification also due to the northward shift of the KE?

Qiu et al. (2020), JC, doi: 10.1175/JCLI-D-20-0237.1

Qiu (2023), Oceanography in Japan, doi: 10.5928/kaiyou.32.3-4_67.

Response: We thank the reviewer's valuable comment. The current stable KE state seems to have begun with the initiation of LM (Qiu et al., 2020), it has also been supported by basin-wide wind forcing (Qiu et al., 2023). The dominant surface wind stress forcing in the midlatitude North Pacific basin is related to the PDO phases (Qiu et al., 2023) (L414-418). The average of temperature tendency anomaly during the cooling season of 2018-2021 (Figure 12b) is positive. It is contributed by the air-sea heat exchange (38.0%), the vertical entrainment through the base of the ML (37.0%), the Ekman advection (17.6%), and the geostrophic advection (7.4%). This result demonstrates that, in the NPSTMW formation region, the weak processes of the air-sea heat exchange and the vertical entrainment play an important role in the ML warming during 2018−2021. This result is demonstrated in section 3.4 of the new submission through the ML heat budget analysis (L359-388).

Qiu, B., Chen, S., Schneider, N., Oka, E., and Sugimoto, S.: On the reset of the wind-forced decadal Kuroshio Extension variability in late 2017, J. Clim., 33, 10813–10828, 2020.

Qiu, B., Chen, S., and Oka, E.: Why did the 2017 Kuroshio large meander event become the longest in the Past 70 years?, Geophys. Res. Lett., 50, e2023GL103548, 2023.

(3) Davis et al. (2011) showed no correlation between NPSTMW and wintertime surface cooling in the RG region, consistent with Qiu and Chen (2006). However, the decline in the NPSTMW volume after 2018 seems to be caused by wintertime surface cooling. Please discuss the correspondence with Davis et al. (2011) and Qiu and Chen (2006).

Response: Thanks. We have discussed the correspondence with Davis et al. (2011) and Qiu and Chen (2006) in the section 4 of the new submission (L486-500): For more than two decades since 1993, the decadal variability of NPSTMW has been modulated by the decadal variability of the KE system associated with the PDO and the westward propagation of the MTD anomalies in the central North Pacific (Qiu and Chen 2006; Rainville et al. 2014; Oka et al. 2015; Cerovečki and Giglio 2016). However, the distant effect is the first baroclinic Rossby wave as the primary message of wind variability from the central Pacific to the NPTMW formation region over a time lag of ~4 years (Sugimoto & Hanawa, 2010). The variabilities of MTD anomalies and KE state due to PDO (a ~4-yr lag) are corresponding to the propagation speed of the first baroclinic Rossby wave. However, Davis et al. (2010) also demonstrated that an interannual signal of the NPSTMW volume variability is also correlated with the PDO with zero time, which implies the connection of NPSTMW to the basin-scale ocean circulation. With this, modulations of upper-ocean properties driven by the varying strength and the position of the westerlies as well as the regional air-sea heat flux pattern are recognized as the significant contributions to the variability of NPSTMW volume on interannual time scales. The results presented in this study shows that there is no significant time lag of the distant effect between NPSTMW variability and the change of basin-scale wind stress pattern (i.e., the PDO phase shift). Meanwhile, the current stable KE state seems to have begun with the initiation of LM (Qiu et al., 2020), it has also been supported by basin-wide wind forcing (Qiu et al., 2023). This suggests that different mechanisms account for the recent NPSTMW decrease on interannual time scales, which resembles the theoretical framework in Davis et al. (2010) not in Qiu and Chen (2006) and Sugimoto & Hanawa (2010).

(4) L173-176. It is hard to see the changes from Fig. 4a. In addition, are these changes statistically significant?

Response: Thanks. Following reviewer's suggestion, we also conducted the Mann-Kendall test on the NPSTMW volume in denser density range (approximately σ_θ>25.2 kg m^{-3}) from 2012 to 2018 following the method of Xu et al. (2022). For the present study, the null hypothesis of no trend is rejected when the absolute value of the standard deviation $|Z| > 1.96$ at the significance level is 0.05. Yes, these changes are statistically significant. There is a decreasing trend for the change of the NPSTMW volume in denser density range ($Z = -3.09$). Particularly, the mean NPSTMW volume in denser density range (approximately σ_θ>25.2 kg m^{-3}) appears to decrease from 11.07×10^{13} m^3 in 2012−2015 to 8.77 $\times 10^{13}$ m^3 in 2018−2021. L220-225 in the new submission

Xu, L., Wang, K., and Wu, B.: Weakening and Poleward Shifting of the North Pacific Subtropical Fronts from 1980 to 2018, J. Phys. Oceanogr., 52, 399–417, https://doi.org/10.1175/JPO-D-21-0170.1, 2022.

(5) L219-228. The differences between 2012-2015 and 2018-2021 are not clear from Fig. 7. Please revise the figures and show the significance together.

Response: Thanks. We have revised Figure 7 and discussion of this Figure (L274-287).

(6) Please check abbreviations and if they are used throughout the text or if they are not defined more than once. For example, the mixed layer is defined as ML at L33, but later it is still used (e.g., L138). PV is defined at L26 and 55. RG dataset (L89) and RG region (L113). The same abbreviation is a bit confusing.

Response: Thanks. We have checked abbreviations and used RGA dataset and RG region in the new submission (e.g., L99, L126).

(7) L136. What do the authors cite here by Oka et al. (2011)?

Response: Sorry for the incorrect reference in original manuscript. Modified (L616-617). We computed the horizontal geostrophic velocity field **u** relative to a reference level of 1000 m following the method of Oka et al. (2011).

Oka, E., Suga, T., Sukigara, C., Toyama, K., Shimada, K., and Yoshida, J.: “Eddy Resolving” Observation of the North Pacific Subtropical Mode Water, J. Phys.

Oceanogr., 41, 666–681, https://doi.org/10.1175/2011JPO4501.1, 2011.

(8) L136. Does ERA5 provide wind stress data? Do the authors calculate wind stress from the surface wind data?

Response: Yes, ERA5 provides wind stress data. No, we used the surface 10 m wind stress data provided by ERA5.

(9) Equation 6. Is M a function of not only sigma theta but also time?

Response: Yes, we have corrected the expression of $M\left(\sigma_\theta, t\right)$ instead of M (L176).

(10) Section 3.1. Please show a stable and unstable KE period together with Fig 4.

Response: Thanks, we have added the stable and unstable KE period into the Fig 4 in the new submission (L244).

(11) L169-170. What do authors mean by "Except for ... "?

Response: We are sorry for the poor expression of this sentence in the original manuscript. We mean, “In a short time period of 2006-2009 when the KE jet is unstable, the NPSTMW volume has a dramatic decrease” (L211-212).

(12) Figures 5 and 7. Winter average, not annual average?

Response: Winter average (L273, L286).

(13) L200-201. Do Suga and Hanawa (1990) pointed out these things?

Response: No, we are sorry for the incorrect reference. This reference has been removed here.

(14) L207-208. This sentence seems to be different from what the authors say at L199-200.

Response: Thanks. We have removed this incorrect sentence.

(15) L242-244. The northward shift is obvious in not only the dense isopycnal but also the light isopycnal.

Response: Thanks, we have corrected the expression of this sentence as: The surface warming due to the northward KE shift may cause the northward movement of the outcropping isopycnals in the NPSTMW density range and inhibit the deepening of the ML south of KE in the winter of 2018-2021 (L301-303).

(16) L252. What is RGA?

Response: Sorry for the incorrect abbreviation. RGA is the abbreviation of Roemmich and Gilson Argo dataset in the new submission (L99).

(17) L262. What is the ventilation region here? Is this the RG region?

Response: The ventilation region here is the whole analysis region 125°E-180°, 20°N-40°N, not the RG region (L332-334).

(18) L264-265. I am not sure if this is supported by Fig. 9.

Response: Thanks. This sentence is moved.

(19) L273. "Except for" should be "In addition to"

Response: Thanks. Changed (L390).

(20) Fig. 12. Why is the wind stress curl masked along the international dateline?

Response: Sorry for this poor expression of Fig. 12. Fig. 12 is modified in the new submission (L428-433).

(21) Fig. 12. What do the authors mean by ensembled? Do the authors use ERA5 ensemble mean data?

Response: we do not use ERA5 ensemble mean data. Sorry for this incorrect expression.

"ensembled" is removed (L429-433).

(22) L308. It is hard to see the change in the westerlies from Fig. 6. Instead of the wind stress curl, the authors may want to show the magnitude of the wind stress.

Response: Thanks. We have added the wind stress vector in Figure 15 of the new submission (L434-440).

(23) L314-315. The intensification of the surface stratification seems to be different from what we expect from the deepening of the main thermocline in Figure 11. Is the stratification indeed weakened in the depth of the thermocline after 2018?

Response: Yes, it also proved by the raw Argo in the RG region. The stratification indeed weakened in the depth of the thermocline after 2018 as shown in the Figure 20 of the new submission (L459-462).

(24) In addition, I would like to suggest the authors to ask native speakers of English to check and correct the English language usage. It is sometimes difficult to follow correctly what is mentioned.

Response: Thanks. We have check and correct the English language usage following suggestion.