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Earth System Dynamics
Discussions



# *Interactive comment on* "North Pacific subtropical sea surface temperature frontogenesis and its connection with the atmosphere above" *by* Leying Zhang et al.

**Leying Zhang et al.**

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Responses to Reviewer #1 We appreciate the reviewer's comments and suggestions on our manuscript. Our replies follow each of Reviewer's comments or suggestions.

Comments: 1. Lines 98-101: does "These data" refer to GODAS? Is atmospheric data just winds and geopotential? Please clarity.

Response: "These data" refer to Agro and GODAS data. Atmospheric data used in this study only includes winds and geopotential height. The related explorations are added in our revised manuscript.



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2. Line 104: This is not an energy equation, it is the heat equation. This needs to be corrected throughout.

Response: Corrected.

3. Line 117/118: dissipation is a subgridscale process. In general this term is not large, but the authors make no attempt to understand what process is important. It seems mostly likely to be entrainment in Fig. 4f, but some scaling estimate would be useful here. It could also be lateral eddy fluxes.

Response: As mentioned by the reviewer, the residual term, including the sub-grid scale process, is relatively large in our results, which may be due to the eddy-induced heat fluxes. Wunsch (1999) noted that eddy-induced heat fluxes are important relative to the total meridional heat fluxes in western boundary current regions of the North Atlantic and Pacific Oceans. Moreover, Qiu and Chen (2005) showed that the meridional eddy-induced heat fluxes over the subtropical North Pacific are both poleward for warm-core eddy detected in 11 Mar–3 Jun 2001 and cold-core eddy detected in 30 Dec 2001–24 Feb 2002. Accordingly, the poleward eddy-induced heat fluxes tend to transport the warm water from lower latitude to the subtropics, and benefit the warmer water there. These findings are consistent with our result that the residual term leads to the increasing SST over the NPSTF. Thus, the residual term increasing the SST over the NPSTF is very likely due to the meridional eddy fluxes. However, it is still hard to confirm this process at this stage because the spatial and temporal resolutions of observation and reanalysis data used in study are relatively coarse. Thus, further exploration is needed when finer data becomes available to us. We add this discussion in our revised manuscript.

4. Line 141: Show the region of interest on Fig.1.

Response: Fixed.

5. Line 146: define the winter and spring time period.

Response: The winter and spring time periods in this study are from December to February and from March to May, respectively, which are defined in Figure 1.

6. Line 147: I do not understand "maximum center expanding".

Response: The statement was revised to "The maximum center of ocean temperature gradients could expand from surface downward to the depth of 60 m."

7. Figure 2: The zonal velocity is surprisingly weak in the region of strongest SST gradient. Is this because salinity is density compensating?

Response: As mentioned by the reviewer, the relatively weak zonal velocity in the region of the strongest SST gradient may be due to the compensation of the salinity gradient. Figure S1 shows the latitude-depth section of the climatological mean zonal current velocity, ocean temperature (TEMP) gradient and salinity (SALT) gradient averaged from December to May. The ocean temperature gradient and salinity gradient are calculated by and , respectively, in which the zonal velocity is positively correlated with both the ocean temperature gradient and salinity gradient. Accordingly, the zonal velocity is positive and strong around 20°N where the ocean temperature gradient and salinity gradient are both positive and strong. However, the zonal velocity is positive but relatively weak over the 25°–30°N where the ocean temperature gradient is positively strong while the salinity gradient is negatively strong. Thus, the relatively weak zonal velocity over the 25°–30°N may be due to the compensation of the salinity gradient. We add this discussion in our revised manuscript.

Figure S1. Latitude-depth section of the climatological zonal current velocity (black contour; units: m s-1), superimposed with (a) ocean temperature gradient ( ; shading; units: °C (100 km)-1) and (b) ocean salinity gradient ( ; shading; units: g (kg 100 km) -1) zonally averaged over 140°E–170°W from December to May.

8. Line 151: Ecpect->Except

Response: Fixed.

9. Line 163: I do not see a significant southward shift from Sep to Feb. Similar for the "slightly migrates southward until March" comment.

Response: Qiu and Kawamura (2012) reported the NPSTF experiences the seasonally meridional shift. During the frontogenesis, the center of the NPSTF is around 28°N in December and migrates southward to 27°N in March. As mentioned by the reviewer, this 1° latitude shift from December to March may be not significant. However, the meridional scale of the NPSTF is only approximately 6° latitudes (i.e., 24°–30°N), thus we consider that this southward shift is significant relative to its meridional scale.

10. Figure 3 and line 205: Why does the residual act to halt frontogenesis? Some ideas and order of magnitude estimates would be useful here. The NCAR model could provide the residual terms explicitly.

Response: Qiu and Chen (2005) found that winter and annual-average eddy-induced heat fluxes are both poleward over the subtropical North Pacific. Accordingly, the eddy-induced heat fluxes tend to transport the warm water from the lower latitudes to the subtropics, favoring the warm water in the subtropics. Our results are consistent with theirs that the residual term benefits the increasing SST over the NPSTF during the frontogenesis. Thus, the eddy-induced heat flux may play an important role in the residual term to increase the SST and to further halt the frontogenesis. However, it is still hard to confirm this process at this stage because the spatial and temporal resolutions of observation and reanalysis data used in study are relatively coarse. Our slab model diagnoses the SST only based on surface heat flux and fails to provide the residual term. Thus, further exploration is needed when finer data becomes available to us. We add this discussion in our revised manuscript.

11. Lines 221, 224, 233: It seems that the findings up until this point are not new. Please clarify if I misunderstand.

Response: Although previous studies have demonstrated that both net heat flux and meridional temperature advection contribute to the NPSTF frontogenesis (Kazmin and

Rienecker, 1996; Dinniman and Rienecker, 1999), relative importance of these two factors in the frontogenesis is not stated clearly. We further find that the net heat flux and meridional temperature advection play different roles in the different periods of the frontogenesis. Moreover, the role of the atmosphere in the frontogenesis is also explored. The atmosphere not only benefits the meridional temperature advection but also acts to transform dominant effect of the net heat flux to the joint contributions of the meridional temperature advection and net heat flux. We clarify our conclusions in revised manuscript.

12. Figure 10 and discussion: I did not find this very surprising, but also not very useful.

Response: Figure 10 and the related discussion are no longer presented in our revised manuscript.

13. Line 329: I think of a slab ocean model as one that has no advection. However, this slab model has a horizontal advection (line 356/357) so I think the authors need to de more explicit about what the slab model is.

Response: The ocean temperature in the slab model is diagnosed from the heat flux exchange among the atmosphere, ocean and ice model, without the ocean dynamics process. The ocean temperature is also output from the ice model, together with the surface ocean currents. However, we are not sure whether the surface ocean currents are involved during the model integration so far. Thus, results from the slab ocean model are no longer analyzed in our revised manuscript.

14. Line 355: Seems like the authors have the means to provide a further explanation, why not figure this out an include it in this paper?

Response: As our response to comment #13, results from the slab ocean model are no longer presented in our revised manuscript.

Reference:

Dinniman, M. S., and Rienecker, M. M.: Frontogenesis in the North Pacific oceanic frontal zones: a numerical simulation, J. Phys. Oceanogr., 29(4), 537-559, doi: 10.1175/1520-0485(1999)029<0537:FITNPO>2.0.CO;2, 1999. Kazmin, A. S., and Rienecker, M. M.: Variability and frontogenesis in the large-scale oceanic frontal zones, J. Geophys. Res., 101(C1), 907-921, doi: 10.1029/95JC02992, 1996. Qiu, B., and Chen Q. M.: Eddy-induced heat transport in the subtropical North Pacific from Agro, TMI, and Altimetry Measurements. J. Phys. Oceanogr., 35, 458-473, doi: 10.1175/JPO2696.1, 2005. Qiu, C. H., and Kawamura, H: Study on SST front disappearance in the subtropical North Pacific using microwave SSTs. J. Oceanogr., 68, 417-426, doi: 10.1007/s10872-012-0106-z, 2012. Wunsch, C.: Where do ocean eddy heat fluxes matters? J. Geophys. Res., 104, 13235-13249, doi: 10.1029/1999JC900062, 1999.

Please also note the supplement to this comment:
https://www.earth-syst-dynam-discuss.net/esd-2018-52/esd-2018-52-AC1-supplement.pdf

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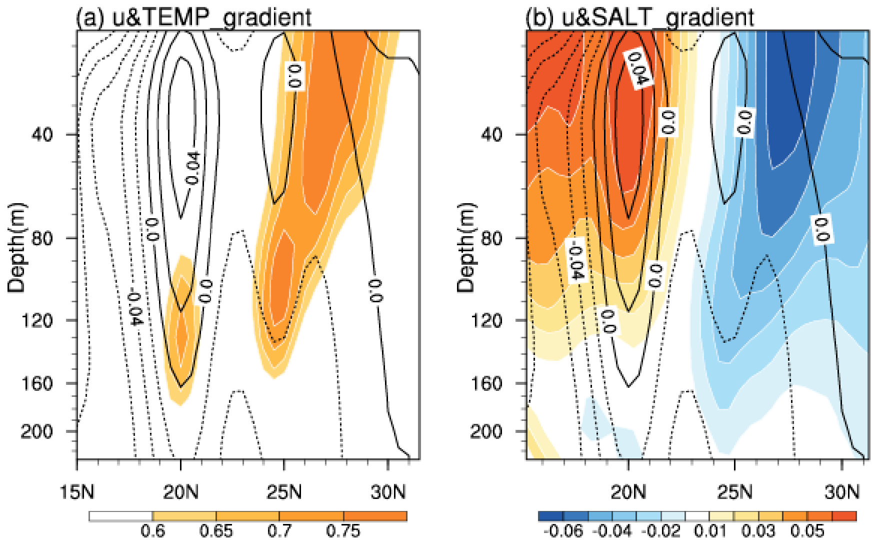


**Fig. 1.** Figure S1. Latitude-depth section of the climatological zonal current velocity (black contour), superimposed with (a) ocean temperature gradient (shading) and (b) ocean salinity gradient (shading).

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