Reply to Reviewers

We thank reviewers for their insightful comments, which really help us improve the scientific and presentation qualities of the manuscript. We substantially revised the manuscript, following their advice. Here we present a point-by-point response to the reviewers' comments and suggestions.

1. Reviewer #1

The paper presents observation of temperature structure across the East Siberian Sea with one particularly interesting profile showing the water column to be well mixed thus exposing the seabed to warmer water mixed down from the surface.

My main criticism of the paper as it stands is that the evidence used to support the claim that the water column is completely mixed is weak – ie the wavelength matches the water depth at the location of the completely mixed water column.

I would suggest to make this work more publishable additional evidence should be sort. For example, an using an energy argument, such as the calculation of the different components of potential energy anomaly (see for example the analysis in Rippeth et al, 2001, Journal of Physical Oceanography, 31(8)). In the way the relative contributions of tidal, direct wind, waves etc can be calculated to support the idea that the vertical mixing is due to waves.

Thank you for your constructive suggestions. Answering this question makes our result more solid. We calculate the maximum mixed layer depth due to wind- and wave-energy dissipations, using the parameterization scheme of wave-mixed upper ocean layer developed by Babanin (2006). The result is consistent with our previous estimations. We add the new result in Figure 1 and provide more explanation and references.

The parameterization scheme developed by Babanin (2006) is evaluated by the observations given in US. Naval Research Laboratory (Young et al. 2011; Liu et al. 2019). Based on this parameterization, we find that with the wind speed reaching 14 m/s on the western shelf on September 12, the significant wave height at station LA77-35 can increase to more than 3.5 m, and the turbulence process caused by wind and

wave breaking could deepen the mixed layer to about 42 m. This estimation is consistent with the mixed layer thickness of about 45 m observed by us, indicating that the strong wind-driven turbulence (wave breaking and wind stress) brought by the cyclone is sufficient to generate strong diapycnal mixing on the shelf and the uniform water column.

According to Rippeth et al. (2001), the rate of change of PAE due to tides is 1.4 x 10^{-4} W/m^2. Tidal mixing is also strong. However, based on Janout and Lenn (2014), the tides are enhanced under sea ice. The tidal mixing is doubled with the presence of the sea ice. Nevertheless, the bottom thermal structure can even maintain when the shelf sea is covered by sea ice. This indicates that the bottom-reached mixing we observed is not due to tidal mixing, but the enhanced wave-induced mixing.

1. Babanin, A. V. (2006), On a wave-induced turbulence and a wave-mixed upper ocean layer. Geophys. Res. Lett. 33, https://doi.org/10.1029/2006GL027308.
2. Janout, M. A., & Lenn, Y. (2014), Semidiurnal Tides on the Laptev Sea Shelf with Implications for Shear and Vertical Mixing. Journal of Physical Oceanography, 44(1), 202-219.
3. Liu, Q., Rogers, W. E., Babanin, A. V., Young, I. R., Romero, L., Zieger, S., Qiao, F., and Guan, C. (2019), Observation-Based Source Terms in the Third-Generation Wave Model WAVEWATCH III: Updates and Verification. Journal of Physical Oceanography, 49(2), 489-517.
4. Rippeth, T. P., Fisher, N. R., & Simpson, J. H. (2001), The Cycle of Turbulent Dissipation in the Presence of Tidal Straining. Journal of Physical Oceanography, 31, 2458-2471.
5. Young, I. R., Zieger, S., and Babanin, A. V. (2011), Global trends in wind speed and wave height. Science, 332(6028), 451-455.

Other points:

Line 9: Surely downward not upward?

Thanks. It is “downward”.

11: seabed – are we talking about the water temperature at the bottom of the water column, or the temperature of the seabed? Quite an important distinction.

It is the water temperature at the bottom of the water column. We clarify it in the Revision.

13: Uniform stirring, normally referred to as a well mixed water column

Yes. We rephrase the sentence as follows:

"*We attribute this notable bottom warming to enhanced wave-induced vertical mixing, which facilitates the well-mixed Arctic marginal seas and allows surface heat to reach the bottom layer.*"

14: Increased space to develop. Do you mean a longer wave fetch?

It is longer wave fetch. The word "increased" in the sentence is misleading. We correct it in the Revision, as follows:

"*As sea ice continues to retreat in the Arctic continental shelf, wind-driven waves have longer fetch to grow*"

22: Does the 50% refer to a methane flux or is it the amount of methane stored in the sea bed?

It means 50% of the methane flux for the global total coastal seas area, as given in Shakhova et al. (2007), as follows:

"This area, representing only ~13% of the global area of the coastal seas (27 × 10^6 km^2), would generate up to 50% of the 1 Tg CH_4 yr^{-1} flux given in Cynar and Yayanos (1993) for the total coastal seas area."

We add this reference in the Revision.

Shakhova, N., & I. Semiletov, Methane release and coastal environment in the East Siberian Arctic shelf, *Journal of Marine Systems*, 66, 227-243, 2007.

25: Barrier? You mean the cold water isolates the sea bed from the warmer surface layer.

Yes. We clarify it in the Revision as follows:

" This cold layer acts as a barrier to isolate the sea bed from the warmer surface layer and then reduce the methane emissions from sediments by about half "

27: Downward heat transport. Do you mean mixing down of heat? Try and be consistent.

It is the downward mixing of surface warm water. We use this description throughout the Revision.

54: I don't understand why the tides only become dominant under ice free conditions? You need to explain this.

Thank you for the careful comments on this issue. Following Janout and Lenn (2014), the tides are enhanced under sea ice. During the sea ice retreat, the tides become relatively weak. We remove "the tides" in the Revision.

This also helps us understand the relative roles between wave-induced mixing and tidal mixing. The tidal mixing is doubled with the presence of the sea ice. Nevertheless, the bottom thermal structure can even maintain. This indicates that the bottom-reached mixing we observed is not due to tidal mixing, but the enhanced wave-induced mixing.

63: "long term" is generally taken to mean over a number of years, you are only considering a season?

In Line 63 and Line 261 in previous tracked-changes version, we did use "long-term" to describe the trend over a decade.

Line 63 "We also present the long-term vertical mixing intensification during the sea ice retreat and its thermal impacts on the bottom layer in the ESS in the recent decade."

Line 261 "We further investigate the long-term trend of wind-induced mixing in the ESS during the recent decade."

We remove the word "long-term" in the Revision and rewrite sentences with the specified period for clear meaning.

63: "Intensification" do you mean the mixing is stronger?

"Intensification" means the stronger mixing. We clarify it in the Revision.

240: calculation showing the SST doesn't drop enough and so advection must be moving heat? Is this change consistent with the lateral gradients you have measured in the CTD survey?

Our CTD observations are consistent with the SST data from satellite.

284: Discussion – I would start by summarising the results before discussing the conseuqneces?

Following your suggestions, we revise the section of Conclusions and Discussion.

292: "Straightly" – do you mean mixed down? Please be consistent with language.

Thank you for pointing this out. It means "mixed down the heat". We correct it in the Revision.

We carefully check the words used in the manuscript to make it consistent and smoothly.

296: Is the 14,000 km2 the area of the sea bed? It is not clear what you mean.

The 14,000 km^2 is the sea surface area with SST cooling, derived from the SST datasets. While this number is not used for comparison, the physical meaning is not clear, we remove it in the Revision.

299: Is it increasing solar radiation, or increasing exposure to solar heating due to sea ice retreat?

It is increasing exposure to solar heating due to sea ice retreat. We make it clear in the Revision.

301: You need a reference to support your statement that there are more storms in the summer.

The following three references are added in the Revision.

Akperov, M., A. Rinke, I. I. Mokhov, and et al. (2019), Future projections of cyclone activity in the Arctic for the 21st century from regional climate models (Arctic-CORDEX), *Global and Planetary Change*, 182, 103005

Karwat, A., Franzke, C. L. E., & Blender, R. (2022), Long-term trends of Northern Hemispheric winter cyclones in the extended ERA5 reanalysis. *Journal of Geophysical Research: Atmospheres*, 127, e2022JD036952. https://doi. org/10.1029/2022JD036952

Zhang, X. D., H. Tang, J. Zhang, J. E. Walsh, E. L. Roesler, B. Hillman, T. J. Ballinger & W. Weijer, 2023, Arctic cyclones have become more intense and longer-lived over the past seven decades, *Communications Earth & Environemnt*, 4, 348, https://doi.org/10.1038/s43247-023-01003-0

2. Reviewer #2

The authors answered to all my comments, and I think it helps improving the quality of the manuscript. I don't have any more major comments, and I think that the manuscript is suited for publication.

A few typos that I noticed in the manuscript:
l.175: 108 J/m2 should be 108 J/m2
l.181: 'The net surface heat flux surface': delete surface
l.190: 'still dominants' should be 'still dominates'

Thank you very much for your insightful comments to help us improve the quality of the manuscript.

Thank you for pointing out these typos. Sorry. We corrected them in the Revision.