Response to reviewer for manuscript "Long-term eddy modulation inhibited the meridional asymmetry of halocline in the Beaufort Gyre" by Lu et al.

The author comment is presented in the following sequence: (1) itemized comments from the reviewer in black, (2) author's response in blue, (3) quotations from the revised paper in indented *blue italic*.

Anonymous reviewer #1:

This paper explores the relationship between the varying eddy field and the changes in the shape and depth of the Beaufort Gyre halocline in the past two decades. The authors used in-situ observations, altimetry, and reanalysis data, to describe the changes in the halocline structure, with an emphasis on the meridional asymmetry. They then examined eddy activities, from both individual eddies and kinetic energy perspectives, and connect them to halocline structure via available potential energy. The study found that eddies played an important role in redistributing fresh water and thus adjusted the halocline structure through analysis of eddy fluxes. Despite the paper's intriguing ideas, the writing is unclear, making it very difficult to follow. The overall flow needs improvements. Therefore, I cannot recommend this paper to be published in its current form.

Thanks to the reviewer for recognising the value of our work and constructive comments. We genuinely appreciate the time and effort you have dedicated to thoroughly reviewing our work. We agree the thorough suggestions to improve our manuscript. The overall flow has been carefully polished to clarify our scientific results. We have also made more detailed explanations in our responses and revised our manuscript.

Minor points:

Line 132: Could the authors explain how eq (3) relates to this sentence?

Thanks for pointing it out. The author apologizes for the wrong text provided. The Eq. (3) is corrected to Eq. (2).

Line 146: This is not the right place to insert citation.

Thanks for pointing it out. We corrected it.

> *(Line 149-154)*
>
> *…… ψ^* is represented as*

$$\psi^* = \frac{\overline{V'S'}}{S_Z} = -\frac{\overline{w'S'}}{S_y} \qquad (5)$$

where $\overline{V'S'}$ is the average meridional eddy salt flux and $\overline{S_Z}$ is the average vertical salt gradient (Manucharyan et al., 2016; Manucharyan and Spall, 2016; Manucharyan and Isachsen, 2019; Marshall and Radko, 2003).

Line 205-206: Mooring C ends before 2008. How can we make a conclusion about the shape in the northeast and northwest in recent years?

Sure, we are also aware of the limit of mooring observations but the results still show that the time series of halocline depth and thickness from MMP in the northwest (mooring B) and northeast (mooring C) are well overlapped before 2008. We also supplement the results from CTD (dot), which is better for better understanding the difference between northern and southern sites over the whole period. The evolutions of halocline at the southwestern (mooring A) and southeastern (mooring D) sites are similar. Likewise, The evolutions of halocline at northern sites are also similar. Compared with MMP results, the mean relative errors of CTD on halocline depth (thickness) are 2.0% (3.4%), 4.4% (7.0%), and 1.0% (3.0%) for moorings A, B, and D, respectively. Figure 2 is modified shown below.

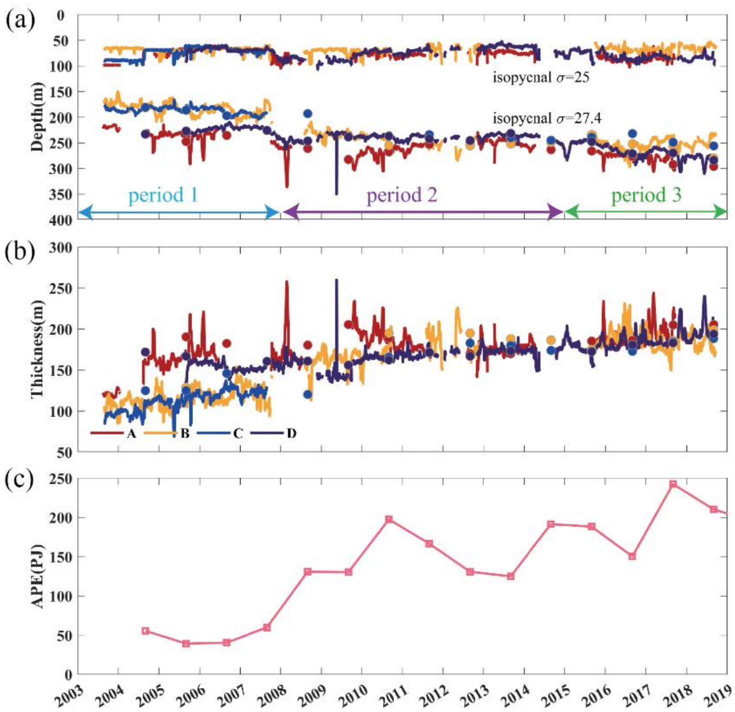


Figure 3: APE at a single point is not meaningful. It represents the slope of the halocline in a region, not a single point. The reference density in the APE equation is related to some mean density across the field. Authors should make it clear.

Thanks for the advice. The Eq. (3) is corrected to estimate the APE in the BG area. Figure 2 in our revised paper is also modified that is shown in the previous item.

(Line 147-150)

The calculation of APE here is following Eq. (3):

$$APE = PE - PE_{ref} = \iiint_{z_{ref}}^{surface} g[\rho(z) - 1027.4]zdz\,dA \quad (3)$$

where z_{ref} represent the depth of the halocline lower boundary, A is the gyre area (Armitage et al. 2020; Polyakov et al., 2018; Bertosio et al., 2022).

Figure 6: The lengths of data available are determined the days of open ocean. Will different data lengths impact the results?

The altimetry observations are available in summer and fall when there is nearly no sea ice covered in the area we interest. EKE is strongest in summer/fall and weakest in winter (Wang et al., 2020; Manucharyan and Thompson, 2022). Using altimetry, we can well reap the long-term variability of major EKE.

Figure 6: The plot is from satellite data, so I assume it indicates surface EKE. How is it related to the previous paragraphs in which subsurface EKE are discussed?

We are trying to discuss EKE at the surface and subsurface together to better clarify the EKE variability in the upper layer. The order of figures was changed in this section for better understanding. Original Figure 6 was changed to Figure 7. Figure 7 shows the evolution of EKE pattern. After 2008, EKE was strengthened along southwestern slope than before, agreeing with more active halocline eddy activity in the BG region from moored observations.

Line 306: This statement made based on observations from two points. Other factors could be responsible. For example, eddies were generated near the mooring site; or the eddies simply did not pass by the mooring.

Thanks for pointing it out. This statement was modified. There are main two factors emphasised, including the eddy distribution and eddy transportation.

Figure 10: How is the probability estimated?

The estimation of probability was added. And related expressions were added as follow:

(Line 381)

We compare the probability analysis results of EKE and geostrophic velocities averaged in the AL region based on the satellite altimetry in three periods (Fig. 10), which is estimated by statistical frequency of the area mean time series in every period.

Line 399: Eady timescale is not interpreted previously.

Meaning and calculation of Eady timescale are interpreted in section 2.2. It estimates the oceanic baroclinic instability.

Major point:

The authors described both surface and subsurface EKE. There could be asymmetry in the surface sea level and subsurface halocline. How does the surface EKE relate to the subsurface halocline shape?

Thanks for suggestions. We try to clarify the relationship between eddy activity and halocline changes which are related to Beaufort gyre variation, and we have revised the explanation in sections 4 and 5.

Based on the previous works, the surface eddy activities responding to the extra wind energy input are linked to gyre stability (Armitage et al, 2020), meanwhile the subsurface EKE from baroclinic instability and APE release are also linked to gyre stability (Manucharyan and Spall, 2016; Manucharyan et al., 2016). Since the two processes both modulate halocline variability in the BG, eddy activities at the surface and subsurface are needed to discuss together to explain their impact on oceanic stratification in the upper layer. The surface EKE can hinder the development of mean kinetic energy (MKE) and slow down the increasing rate of mean currents, which promoted the BG stabilisation (section 5.1). From this perspective, eddy activity can weaken the gradient of surface sea level to inhibit surface geostrophic currents, but it is not the main point of the study. What we are concerned about is that surface and subsurface eddy activities jointly influenced oceanic stratification by inhibiting surface mean flows and promoting APE release above the halocline layer related to BG stabilisation. When mean kinetic energy and potential energy are more stable in the final period (after 2014) than before, eddy modulation leads to freshwater redistribution in the upper layer through enhanced eddy lateral fluxes, which inhibited the meridional asymmetry of halocline changes (section 5.2). It is shown that freshwater distribution has an impact on the variability of halocline thickness and strength (Bertosio et al., 2022). Therefore, we concluded that eddy fluxes, generating low-salinity water transportations in the upper layer (Fig. 11b), resulted in a smaller difference in halocline depth between north and south of BG.

To show how the writing could be improved, I will provide some wording issues in the first 50 lines. Please note that this list is not exhaustive, but rather serves as a guide for improving the paper’s overall clarity.

Thanks for the guideline. We checked the whole manuscript again for better clarification.

Line 10: Please specify the “varying eddies”. Number, shape, velocity?

Thanks for pointing it out, we have specified.

Line 16: This long sentence is confusing. Maybe it would be clearer if breaking into several shorter sentence.

Thanks, this long sentence was divided into several segments.

> *(Line 16)*
>
> *In the meantime, eddy activities in the upper layer from the southern margin of BG to the abyssal plain have been enhanced. Moreover, eddy-induced low-salinity water transportations have been continuously increasing towards the central basin as halocline structures on either side of the basin reach a nearly identical and stable regime.*

Line 16: The second “Eddy” should not start with capital letter.

Thanks for pointing it out, it was corrected.

Line 30: This sentence is not grammatically correct.

Thanks for pointing it out. This sentence was reorganised.

> *(Line 29)*
>
> *Meanwhile, increased active ocean–atmosphere interactions and mesoscale processes in the Canada Basin (CB) due to the emergence of broader open areas have attracted increasing attention.*

Line 37: It should be “paid attention” instead of “payed attention”

Thanks for pointing it out, it was corrected.

Line 39: “The increase of isopycnal slope with depth” is a new piece of information and it should be introduced before directly describing the mechanism.

Thanks for this recommendation. “The increase of isopycnal slope with depth” explained the interior increased PWW thickness. This paragraph was reorganised.

> *(Line 43-47)*
>
> *Pacific Winter Water (PWW), which lies above the eastern Arctic origin lower halocline water, is recognized as a component of the western Arctic halocline (Shimada et al., 2005). Observations indicated that PWW layer generally deepened during 2004–2018 while isopycnal layer thickness increased (Kenigson et al., 2021). Likewise, there was an isopycnal deepening by 70 m during 2004–2011 (Zhong et al., 2018), suggesting a spin-up of the gyre. The isopycnals are increasing with depth, which can be attributed to the eddy-induced stream function, explaining the interior increased PWW thickness (Kenigson et al., 2021).*

Line 42: “Likewise” used here is confusing. The previous and this sentence do not have characteristics in common.

Thanks for pointing it out, it was corrected. These sentences are modified for more coherence.

Line 43: Should be “identified as”.

Thanks for pointing it out, it was corrected.

Line 46: high resolution eddy-resolving?

Thanks for pointing it out, it was corrected.

Line 47: “etc” should not be used.

Thanks for pointing it out, it was corrected.

Line 48: “focused on” instead of “focus”.

Thanks for pointing it out, it was corrected.

Line 48: “Moreover” is not correctly used here. The following sentence changes the topic.

Thanks for pointing it out. The following sentence is the same topic on the vertical distribution of eddy activity. This sentence was rephrased for more coherence.

Line 50: “even they may extend”?

This sentence has been rephrased.

> *(Line 52)*
> *Eddies are mainly concentrated in the subsurface (30-300 m) even though they can extend to thousands of metres in depth (Zhao et al., 2014; Zhao and Timmermans, 2015)*……

Reference:

Armitage, T., Manucharyan, G. E., Petty, A. A., Kwok, R., and Thompson, A. F.: Enhanced eddy activity in the Beaufort Gyre in response to sea ice loss. Nat. Commun., 11, 1-8. https://doi.org/10.1038/s41467-020-14449-z, 2020.

Bertosio, C., Provost, C., Athanase, M., Sennéchael, N., Garric, G., Lellouche, J. M., Bricaud, C., Kim, J. H., Cho, K. H., and Park, T.: Changes in freshwater distribution and pathways in the Arctic Ocean since 2007 in the mercator ocean global operational system. J. Geophys. Res. Oceans, 127, e2021JC017701. https://doi.org/10.1029/2021JC017701, 2022.

Manucharyan, G. E., and Spall, M. A.: Wind‐driven freshwater buildup and release in the

Beaufort Gyre constrained by mesoscale eddies. Geophys. Res. Lett., 43, 273-282. https://doi.org/10.1002/2015GL065957, 2016.Manucharyan, G. E., Spall, M. A., and Thompson, A. F.: A theory of the wind-driven Beaufort Gyre variability. J. Phys. Oceanogr., 46, 3263-3278. https://doi.org/10.1175/JPO-D-16-0091.1, 2016.

Manucharyan, G. E., and Thompson, A. F.: Heavy footprints of upper-ocean eddies on weakened Arctic sea ice in marginal ice zones. Nat. Commun., 13, 1-10. https://doi.org/10.1038/s41467-022-29663-0, 2022.

Wang, Q., Koldunov, N. V., Danilov, S., Sidorenko, D., Wekerle, C., Scholz, P., Bashmachnikov, I. L., and Jung, T.: Eddy kinetic energy in the Arctic Ocean from a global simulation with a 1 - km Arctic. Geophys. Res. Lett., 47, e2020GL088550. https://doi.org/10.1029/2020GL088550, 2020.

Anonymous reviewer #2:

Review of "Long-term eddy modulation inhibited the meridional asymmetry of halocline in the Beaufort Gyre" by Lu et al.

This paper uses a combination of satellite, in-situ and reanalysis data to investigate changes to the structure of the halocline in the Canada Basin over time. The paper begins by looking at changes in halocline depth, halocline thickness, and available potential energy from CTDs and moorings in the region to determine three periods of distinct behaviour. It then analyses both EKE and individual eddy properties at the four moorings and how they have varied over the three periods, before zooming in to a small region that experiences significant changes to EKE over the time period. The paper ends with an analysis of an eddy streamfunction for each period and relates it to salinity changes to explain the differences in the halocline between each period.

The paper has a lot of information contained within it, but I found it very hard to follow in many places. Some of the figures had long descriptions of details without reference to the relevant subpanel or feature being described, and the main take-home message of what the reader is meant to gain from the figure is often missing. This makes it difficult to understand the context. There are also a number of typos and grammatical errors which need to be corrected – I have not addressed them in the comments below but the manuscript should be checked thoroughly and rephrased in a number of places. I appreciated the instances where the authors stated the question they were addressing in the upcoming subsection, and feel it would be beneficial to do this much more often in the text to help the reader. I do not think the paper is publishable in its current form, but do think there are some interesting ideas that could be of interest to the community if they were presented in a more coherent way.

Thanks to the reviewer for your valuable feedback and suggestions. We sincerely appreciate the time and effort you have put into reviewing our work. Your comments have been incredibly helpful in improving the quality of our research. We are grateful for your illuminating insights and constructive criticism you provided, which has allowed us to address certain weaknesses and refine our findings. The overall flow has been carefully polished to clarify our scientific results. We have also made more explanations in our responses and revised our manuscript.

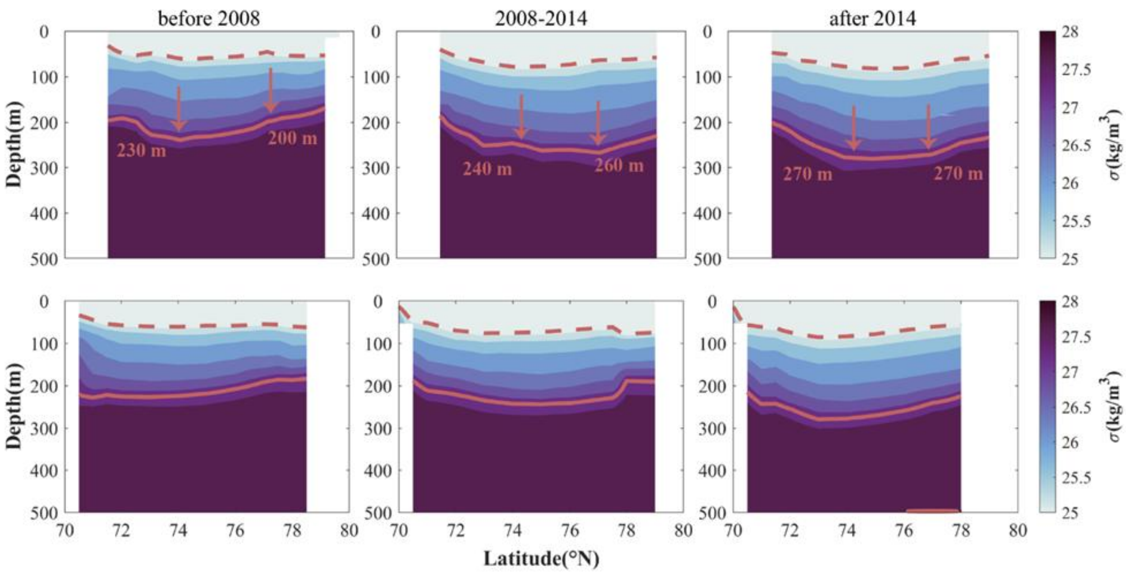
I have some points to consider based on the paper in its current form, which I feel should be addressed before the paper is resubmitted.

- The paper aims to understand why the BG has stabilised in recent years. But the asymmetry that is described is based on a) moorings in the south versus moorings in the north of the basin (which are located at around 74-75N and 78N respectively, based on Figure 1b), and b) CTD stations which head north along a transect to 79N. The paper refers to Bertosio et al (2022) and Regan et al (2019) when describing gyre asymmetry and a northward expansion, and also notes a shift in the BG found by Moore et al. (2018). Given this acknowledgement that the gyre is not always in the same place or has the same size/strength, it is surprising that there is no discussion of how choosing a static section or static moorings that are limited in their northward extent could affect the perceived loss of asymmetry of the gyre. The gyre has deepened in the portion of the basin captured by the observations, but the deepest part of the section has also moved further north – so the sloping isopycnals are likely now further north than the section shows. It is not known from this data whether they are steeper or flatter than before, but I feel this should be acknowledged in the paper (does the SODA data show this if you look further north?)

We thank the reviewer's suggestions. We agreed that BG area and size, depending on dynamic ocean topography, significantly changed with seasonal and long-term variabilities (Regan et al., 2019). In our study, the main point is the long-term variability of the halocline relating to the main BG area. Thus, we need to determine a referential BG region. The observations are limited in the area we interest, resulting in directly tracking the gyre area for analysis considerably challenging. The fundamental BG area is located in the Canada Basin even if the whole size is changing for each year. Therefore, we choose the static section and moorings in our study to reap the long-term variability in the fundamental BG area.

We replaced the WOA18 in the previous version with the newest WOA23 including 1990-2020 climatology hydrography, for discerning the fundamental BG area to analyse halocline variability. We supplemented a map illustrating the climatology halocline depth (Fig. 1a). Additionally, a BG box (referred to as the pink box), along with the climatology BG center based on Regan et al. (2020), has been marked. This BG box is defined as the region between 70.5-80.5°N and 170-130°W, bounded by the 300 m bathymetry. The centre of the mean gyre from 1990 to 2014 is situated at 74.74°N and 150.62°W. Despite the variations in BG area over the past years, the chosen BG box effectively captures the primary pattern of halocline characteristics that relates to core BG region, encompassing the deepest region in the western Arctic. The definition of fundamental BG area is widely adopted by many studies on BG (e.g., Doddridge et al. 2019; Manucharyan and Spall, 2016; Regan et al., 2019; Timmermans and Toole, 2023).

The placement of the four moorings at the corners of the BG box allows for a better understanding of the overall BG halocline variability, which is used by former research for analysing BG stratification (e.g., Kenigson et al., 2021; Manucharyan and Stewart, 2022; Zhong et al. 2019). We specifically selected the static section along 150°W for further analysis. To supplement the discussion, we also analysed the section along 140°W and made a comparison (**Fig. 4, shown below**), as both sections traverse the deepest part of the BG halocline. Timmermans and Toole (2023) found that theses two sections through BG have similar hydrographic structures. Our results also demonstrate similar shifts along these two sections. However, we think the section along 150°W offers a more representative perspective since the BG centre is positioned between 150°W and 140°W for most years, with closer proximity to 150°W (Regan et al., 2019). the change is more significant and the halocline layer is much thicker along 150ºW than along 140ºW because the gyre centre is closer to the 150ºW longitude. Thus, we choose the 150°W transect for better discerning variability of the halocline layer.



We discussed halocline slope in the BG through supplementary APE evolution in the BG box that can represent the slope of the halocline in a region. The halocline slope in BG region was increasing before 2010. However, in the final term, halocline was flatter than before with APE decreasing after 2010 and remained at a relatively stable level after 2014, which represented the flattening of halocline .

- The discussion around EKE and individual eddies is unclear. In particular, surface and subsurface (from 50m down) EKE seem to be shown on the same plot, and surface-generated EKE from wind input is linked to gyre stability (e.g. lines 347-349) even though the eddies associated with baroclinic instability are generated in the halocline. Care should be taken when associating these.

Thanks for the reviewer's suggestion. In the revised manuscript, the discussion in section 4 is checked carefully to better clarify our main points.

We are talking about the spatiotemporal variability of eddy activity using limited observations. On the one hand, from moored observations we focus on the variability of individual eddies at the subsurface due to a lack of surface observations. The number and kinetic energy of individual eddies here are used for estimating eddy activeness and number. On the other hand, we put more attention to analyse EKE variability from multiple datasets to comprehend thoroughly eddy strength evolution in the upper layer for insufficient moored observations.

The surface eddy activity from extra wind energy input is linked to gyre stability (Armitage et al, 2020), and subsurface EKE from baroclinic instability and APE release is also linked to gyre stability (Manucharyan and Spall, 2016; Manucharyan et al., 2016). We think the long-term cumulative effects from transient eddies can influence the mean states of halocline structure. And it is necessary to explore the spatiotemporal variability in the eddy field before discussing its effects on the halocline structure. Thus, we put them on the same plot to discuss their similar variability at the surface and subsurface together. The surface and subsurface EKE peaked in 2009 and experienced a low ebb in 2010-2014. With APE in the BG decreasing continuously over the years 2010-2014, after 2015 EKE increased again and remained at a stronger level than before. In section 5, we discuss eddy modulation detailedly. The surface EKE can hinder the development of mean kinetic energy and slow down the increasing rate of currents, which promoted the BG stabilisation (section 5.1). What's more, surface and subsurface eddy activities jointly influenced the freshwater redistribution through eddy lateral flux (section 5.2), which inhibited the meridional asymmetry of halocline.

- In terms of structure, the flow is broken after Figure 5 (Mooring-based EKE and eddy counts) to Figure 6 (maps of EKE from other datasets), then back to eddies from moorings in Figure 7, then back to the maps to identify a key region to zoom in on for Figure 8. Is there a reason that we jump between datasets and region size? It might flow better if all of the information from moorings was put together. I found the jumps from Figure 6 to 7, then 7 to 8, quite confusing, so maybe that would help to make it clearer

Thanks for this suggestion. We reorganised section 4 and modified the order of figures based on the suggestion. In section 4.1, we just discuss mooring-based eddy counts and EKE profiles. In section 4.2, we analyse EKE variability from multiple datasets, especially on the long-term variability, including surface EKE from altimetry and SODA, and subsurface EKE (averaged over 250 m) from MMP. The order of figures in section 4 is changed accordingly.

- Introduction: there is a lot of information that has not been fully synthesised. In particular, the second paragraph is very long and detailed with a lot of different threads. I would suggest splitting into multiple paragraphs, perhaps one describing the vertical structure and one based on eddies. In general, there is a large amount of information on eddies in the introduction paragraphs – perhaps it can be streamlined, or reordered to group similar themes together.

Thanks for this suggestion. This paragraph has been synthesised in the revised version. This paragraph was divided into three parts, including vertical distribution, horizontal distribution and long-term evolution of eddy number and EKE.

Line 42: The Pacific Winter Water layer is mentioned without describing how it fits into the vertical structure. It should be introduced first

Thanks for pointing it out, we supplement the description of Pacific Winter Water layer.

(Line 42)

Pacific Winter Water (PWW), which lies above the eastern Arctic origin lower halocline water, is recognised as a component of the western Arctic halocline (Shimada et al., 2005).

Line 50: What depth range is meant by "subsurface"?

Eddies are found concentrated in the halocline (Zhao et al., 2014; Zhao and Timmermans, 2015). "Subsurface" means the halocline depth range about 30-300 m.

(Line 53)

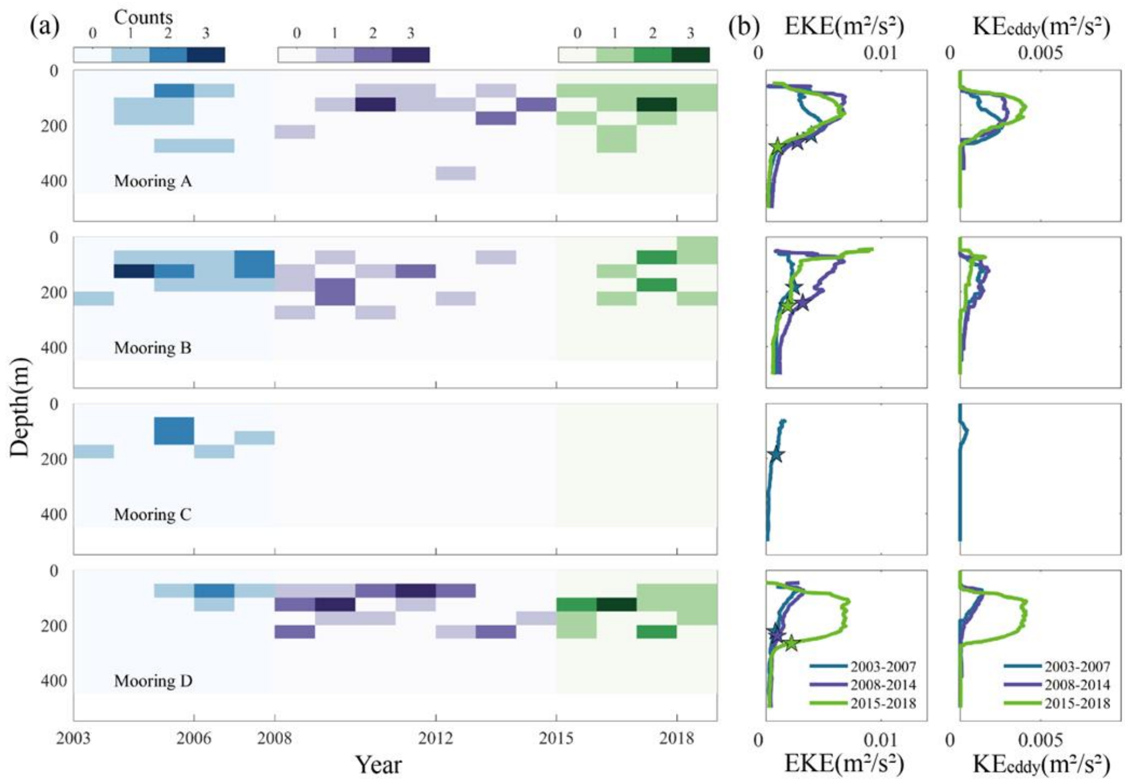
Eddies are mainly concentrated in the subsurface (30-300 m) even though they can extend to thousands of metres in depth (Zhao et al., 2014; Zhao and Timmermans, 2015)……

Line 132: is (3) the correct equation reference here? It hasn't yet been introduced

Thanks for pointing it out. Sorry, it is a clerical error. The author apologizes for the wrong text provided. The Eq. (3) is corrected to Eq. (2).

Line 155: Simth, 2007 should be Smith, 2007. Eddies are only a part of the EKE which also includes deviations from a mean current. How much EKE is not attributable to eddies? I.e. how much is not due to eddy genesis? That might affect the assumption that it is correlated with baroclinic growth rate. How much EKE do you miss by only having SODA at ½ degree resolution?

Thanks for pointing it out . To discern how much EKE is not due to eddy genesis, we make a comparison between EKE and kinetic energy from eddies (KE_{eddy}) in modified Fig. 6 (shown below). Approximately 50% of EKE is due to eddy genesis.



South of the CB is populated with a large number of cold core, anticyclonic halocline eddies. Eddy genesis in area we interest is more correlated with baroclinic instability rather than barotropic instability. Baroclinic conversion term associated with eddy flux is dominant. Integrated barotropic energy conversion over the Beaufort slope sea section is about an order of magnitude less than the integrated baroclinic conversion term (Spall et al., 2008). Hence, in our study, Eady growth rate correlated with baroclinic instability is applicative.

EKE is just the estimation of eddy strength. It is unrealistic for us to provide how much EKE precisely from SODA reanalysis. We compare the climatology EKE in the Beaufort slope sea region from altimetry (¼ degree resolution) and SODA (½ degree resolution). The magnitude of EKE is comparable within the two datasets. EKE range is approximately 4-6×10^{-3} m^2/s^2 in the southeast of Beaufort slope (Fig. 9). The correlation coefficient of EKE long-term time series between altimetry and SODA during overlapping years is 0.48 (confidence level 95%). Because altimetry observations are just at the surface, three-dimensional SODA is necessary to be used in section 5 for analysing eddy fluxes.

Lines 160-161: Section 3 talks about the asymmetry of the halocline being the focus of the article, but this was only mentioned briefly amongst all of the text about eddies. I understand that EKE is being investigated to explain the asymmetry, but feel the asymmetry needs to be introduced more thoroughly first – why do we care that it's asymmetric or not?

Thanks for this recommendation. The introduction to the asymmetry of the halocline is accentuated in section 4 first.

(Line 249-254)

With BG spin-up and regional sea ice retreat, mesoscale eddies are responding to dissipate extra energy input and influence the energy redistribution (Armitage et al, 2020). It is speculated that the eddy genesis is related to APE accumulation and release in the BG region, which can influence the vertical structure of the internal halocline (Manucharyan and Spall, 2016; Manucharyan et al., 2016). In the final period, the developments of meridional asymmetry in the halocline layer and APE within the BG box have been inhibited. Under this background, the spatiotemporal variability in eddy activity, needed for a comprehensive understanding, is discussed in this section.

Line 169: I think by “void measurements” you mean “lack of measurements”?

Thanks for pointing it out, we changed it.

Line 174: what do you mean by “30m company”?

Thanks for pointing it out, this sentence was rephrased.

(Line 184)

The thickness of the halocline in the southern part of the basin (moorings A and D) increased by approximately 30 m with the halocline base deepening by approximately 40 m.

Line 182: Does “in final” mean “in the final period”? Or “finally”, as in the final point being made? I am not sure what is meant by “homogeneously distributed”, or what differences are being described as reduced compared to what.

Thanks for pointing it out. It means “in the final period”. “homogeneously distributed” means values for different sites are at a similar level. This sentence is rephrased.

(Line 193)

The halocline thickness and depth between every site tend to be at a similar level in the final period and those differences are smaller than in the first period.

Line 191: “improving” is not correct here. “Increasing”?

Thanks, it was corrected.

Lines 194-195: what are partial variables?

“Partial variables” mean “halocline variables”. And it was modified.

Table 1, and related text: what is the significance of these trends? Some are very small, and there is clear variability in the time series. For example, lines 177-179 state “A negative trend of halocline depth is clearly during 2008– 2014 in the southern sites of the basin (moorings A and D)" but in the table Mooring D only deepens by 0.35 m/yr – is it statistically significant? Is the short-lived deepening in early 2009 having an effect on this trend?

These trends are all statistically significant and all pass significance tests. The confidence levels of these trends are all exceeding 99%. The significance is added to our revised manuscript. The negative trend means halocline depth is lifting during that period, which is not comparable with the deepening trend, because the deepening trend is dominant over the whole period. The short-lived deepening is in later 2008 belonging to period 1, which does not have an effect on the trend of period 2.

Lines 205-206: "According to section 3.1, we find the main differences of evolution only between northern and southern basin are obvious, which is not completely identical with previous findings." What specifically is different from previous studies?

Previous observations have revealed that isopycnals have deepened at different rates in the northwestern and southeastern parts of the basin during 2002–2016 (Zhong et al., 2019). Here we find halocline depth in south and north has been deepening at different rates. The meridional difference between north and south is more obvious. As shown in Fig. 2 and Table 1, the evolution of northwestern (mooring A) and northeastern (mooring D) halocline depth time series are similar.

> *(Line 212)*
>
> *According to section 3.1, we find that the major differences in evolution only between the north and south of the basin are obvious, which is not completely identical to previous findings. Previous observations have revealed that isopycnals have deepened at different rates in the northwestern and southeastern parts of the basin during 2002–2016 (Zhong et al., 2019). Here, we find the meridional difference between north and south is more obvious.*

Figure 3: Are these the average values?

The figure has been modified. The values are averaged in every period.

Lines 220-235, Figure 4: See one of the major points - this analysis does not consider that the gyre centre moves and area it covers expands/contracts over time. Given that the northern limit is only 79N, perhaps the stationary section is seeing a different part of the gyre/not capturing all of the northern extent in later years? You might see the same "equilibrium" if you took just the 73-76N range of "before 2008" plot, for example.

Thanks for this suggestion. We explained it and showed the modified figures above. Results in Fig. 4 are interpolated, so some observations at the northern and southern edges are missing. In period 1, the deepest point is only in the south (~74°N). However, there are similar deep points in the south (~74°N) and north (~77°N). We consider that the northern gyre edge can reach 80°N. We rather focus on the part including the gyre centre and edge than just see the 73-76N range only near the gyre centre.

Line 256: "The cold-core anticyclones are popular in the BG region due to oceanic stratification and large-scale dominated circulation.". Why is this? Also, the word "popular" should not be used here – maybe "common"?

Thanks for pointing it out. We added the explanation.

> *(Line 264)*
>
> *The cold-core anticyclones are common in the BG region due to large-scale dominant anticyclonic circulation coupled with oceanic stratification, where cold and fresh Pacific water overlies warm and salty Atlantic water.*

Figure 5, section 4.1: There are some interesting features here. However, it would be nice to have a paragraph relating the individual eddy counts with the EKE profiles. For example, why does Mooring D have a similar profile of EKE in 2003-2007 and 2008-2014, but more eddies identified in 2008-2014 than 2003-2007? Does this mean that the deviation of velocities from the mean is contributing a lot to the EKE profile in 2008-2014?

Thanks for this suggestion, we added a paragraph relating eddy counts with the EKE profile.

> *(Line 293-300)*
>
> *At the southwestern corner (mooring A) of the basin, only 9 eddies were detected in the first period. EKE increased in the second period when there were 15 eddies and remained stable in the third period where were 13 eddies. Northwestern (mooring B) EKE was stronger with 14 eddies in the second period than before, despite 17 eddies detected in 2003–2007. And EKE was weaker in the third period due to less valid observations. Southeastern (mooring D) EKE did not occur apparent growth until the third period due to much stronger eddies detected. There were only 14 eddies in 2014–2018 and 24 eddies detected in 2008–2014. In short, there were either stronger eddies or much more eddies after 2008 than before.*

Lines 326, Figure 8: you have spent much of the paper describing the differences between the moorings (halocline properties and EKE). So you need to justify more why you are choosing to combine the mooring data here.

The explanation was added.

> *(Line 335)*
>
> *As shown in the eddy detection from MMP, eddies are common in the halocline layer. Results from MMP can well represent the variability in halocline eddies in the BG region, which are also consistent with former research. Results from every mooring*

are thought equal to characterize the main features of eddy strength in the BG region, so EKE above the halocline base for different moorings are vertically averaged with depth to obtain the whole evolution over the years between 2003 and 2018.

Lines 333-335: A fluctuation of both datasets doesn't seem to be the case between 2010 and 2015?

This paragraph was modified.

(Line 341)

EKE from altimetry has increased gradually since the 1990s and peaked in 2009, and then, it decreased in 2009–2010, resulting in relatively weak and stable EKE in 2010–2015. Although the EKE from reanalysis is the highest estimate among them, it has also increased since the 1990s and remained at a stable level after 2010.

Lines 339-341: Which datasets are you talking about here? MMP data seems to be higher since 2014. "Recently" should be specified, since oscillations occur at different times in each dataset.

This is talking about all EKE time series. This sentence was modified.

(Line 349)

After experiencing a low ebb, especially from altimetry and MMP, since 2014/2015, EKE has presented some enhancement and oscillated around constant levels between the central BG and its marginal continental slope.

Lines 334-335: which halocline variables? Do you mean depth and thickness from the first few figures in the paper? If so, refer to that here. The "plateauing" is only relevant for SODA and altimetry – MMP seems to decrease over this time period.

It means halocline depth and thickness. We corrected it.

(Line 346)

Between 2010 and 2015, EKE was relatively weak and even decreased in the two regions, lagging behind the plateauing of halocline depth and thickness.

Lines 357-358: it would help to guide the reader to the relevant part of the figure here (where the Alaska box is) as this is a new way of looking at the information.

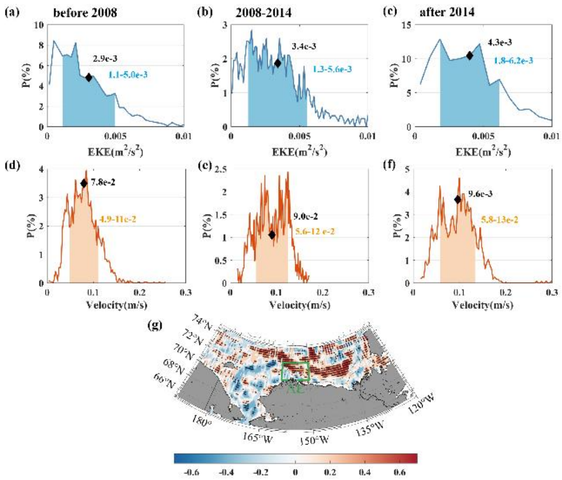
We specified the location of the Alaska coast. And the Alaska box is marked in Figure 10.

Lines 359-362: This is the second time MKE is referred to. Since it is not shown, it should not be described as though it is referring to a figure unless it is of relevance to the discussion. What is the main point of talking about MKE here?

Thanks for pointing it out. The description of mean kinetic energy (MKE) was added. We are relating MKE and EKE here in this discussion. MKE is much smaller along Alaska region. EKE is dominant in kinetic energy.

Figure 10: I would recommend putting the Alaska box on this map to help the reader.

The Alaska box was added.



Lines 390-391: see major point about asymmetry along the section

We explained it above.

lines 397-413: I found this paragraph hard to follow. It might help if figure was referred to more. Perhaps remind the reader what a positive value in A means, as you described in the methods. Why can't the salinity anomaly can be related to changes in freshwater rather than eddy transport?

Thanks for this recommendation. This paragraph was modified according to your suggestion.

(Line 418)

In the first period, when the Eady timescale was relatively larger over the long term (Fig. 11c), meaning stronger stability, the salinity anomalies in the mixed layer and the halocline layer were both positive, more than 0.5 (Fig. 11b). Combined with the distribution pattern of the eddy stream function, the eddy thickness fluxes were generally positive at the surface, about 0.1 m^2/s^2, and represented the southwards (northwards) propagation of low-salinity (high-salinity) water. ……

Line 450: The proposed relationship between changes in the mixed layer and the tilt of the halocline should be explained much more clearly here.

Several instances:

- "abnormal" or "anormal" salinity should be clarified
- "mean time" is used a lot – is it meant to mean "average state"? Or "same time"?

This paragraph was modified according to your suggestion. The expression about salinity anomaly was unified. We checked the usage of "mean time" and distinguished two meanings. "mean time" is changed to"same time" or "average state" in the revised version. And some expressions are also modified in this discussion.

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